RADIO FREQUENCY COMPATIBILITY (RFC)

ACCESSORY EQUIPMENT SET (U)

by

JOSEPH R. WALSH

⌐and others⌐

Contract No. DA 36-039 AMC-02223(E)

Department of the Army Project:

1G620501D4490111

Project A-693

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia
1963 - 64

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GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

15 May 1963

A-693

Electromagnetic Environment Division
Interference Evaluation Branch
U. S. Army Electronics Research and
Development Laboratory
Fort Monmouth, New Jersey

Attention: Mr. Sidney Weitz

Subject: Monthly Letter Report No. 1, 15 May 1963, Contract No. DA 36-039 AMC-02223(E), "Radio Frequency Compatibility (RFC) Accessory Equipment Set."

Gentlemen:

There are essentially three areas of investigation that will be pursued on this contract. The major area of investigation will be the design plan for the radio frequency compatibility accessory equipment. This includes evaluation, and possibly extension, of the state-of-the-art components and techniques. The second area of investigation will be the audio susceptibility tester, consisting of a coupling transformer and amplifier. The third area of investigation will be the development of a receiver input coupler.

The following progress was made during the period 15 April - 15 May:

(1) Senior personnel were assigned and technical assistants were selected. J. R. Walsh, Jr., a full-time research engineer, is project director. H. W. Denny, research assistant, is working full time on the contract. W. B. Warren, Jr., research engineer, and E. W. Wood, assistant research engineer, will contribute to the technical effort. The technical assistants will begin work about 1 June 1963.

(2) Detailed analysis of the various tests required by military specification MIL-I-11748 was started. Each test is being studied to determine the accessory equipment required.

(3) Cataloguing was started to determine what commercially available devices are presently available for the radio frequency compatibility accessory set.

(4) An ASTIA Field of Interest Register was submitted so that other military work of interest to the contract can be utilized.

The work planned for the period 15 May - 15 June includes:

(1) Continuation of the cataloguing of commercially available items needed in the accessory set.

(2) Continuation of analysis of the tests required by MIL-I-11748. This information will be reviewed with the objective of combining the various individual test set-ups into a single package, if feasible.

(3) Initiation of effort on the audio susceptibility tester.

Respectfully submitted:

Joseph R. Walsh, Jr.
Project Director

Approved:

for D. W. Robertson, Head
Communications Branch

JUN 21 1963

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

17 June 1963

Electromagnetic Environment Division
Interference Evaluation Branch
U. S. Army Electronics Research and
Development Laboratory
Fort Monmouth, New Jersey

Attention: Mr. Sidney Weitz, SELRA/GFE

Subject: Monthly Letter Report No. 2, 15 June 1963, Project A-693, Contract No. DA 36-039 AMC-02223(E), "Radio Frequency Compatibility (RFC) Accessory Equipment Set."

Gentlemen:

The following progress was made on the contract during the period 15 May to 15 June.

(1) Study of the tests which need to be performed and of the accessory equipment required in the performance of these tests was continued.

(2) Cataloguing of the accessory items that will be needed is progressing. A large volume of technical data on accessory items has been collected.

(3) Design work was started on the audio susceptibility tester, with emphasis on the coupling transformer.

(4) Construction of a high frequency voltage-controlled oscillator for the deviation detector was started.

(5) Study of thin film techniques for their possible application to dummy loads was begun.

(6) Mrs. E. N. Bone, technical assistant, joined the project 1 June 1963.

(7) D. W. Robertson and J. R. Walsh, Jr. visited USAELRDL, Fort Monmouth, New Jersey on 22 May 1963, to discuss technical details of the contract.

(8) J. R. Walsh, Jr. attended the Fifth National Symposium on Radio Frequency Interference held in Philadelphia, Pennsylvania, 4-5 June 1963.

(9) The ASTIA Field of Interest Register has been approved.

The work planned for the period 15 June to 15 July includes:

(1) Continuation of analysis of tests required and accessory equipment needed.

(2) Continuation of the cataloguing of commercially available items needed in the accessory set. Effort in this area will be limited to those items for which tabulated lists are not commercially available.

(3) Continuation of work on the audio susceptibility tester and frequency deviation monitor.

(4) Continuation of investigation into thin films for possible application in loads.

Respectfully submitted:

Joseph R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

16 August 1963

Electromagnetic Environment Division
Interference Evaluation Branch
U. S. Army Electronics Research and
Development Laboratory
Fort Monmouth, New Jersey

Attention: Mr. Sidney Weitz, SELRA/GFE

Subject: Monthly Letter Report No. 3, 15 August 1963, Project A-693, Contract No. DA 36-039 AMC-02223(E), "Radio Frequency Compatibility (RFC) Accessory Equipment Set."

Gentlemen:

The following progress was made on the contract during the period 15 July to 15 August.

(1) Work on the first quarterly report was completed and the approval copies of the report were forwarded.

(2) Refinements were made on the audio susceptibility tester amplifier.

(3) Substrate material and configurations for a thin film load were investigated. Discussions were held concerning the details of depositing a thin film in various configurations.

(4) Line stabilization networks were studied and several coils tested for the purpose of producing a single network to cover the frequency range of interest. At present, the solution to this problem seems to be the use of two networks to cover the range.

(5) Literature searching and study of the problem of the measurement of spurious and harmonic emissions in waveguide systems progressed.

(6) Work on the deviation detector progressed and system tests were started.

(7) Discussions of project technical and contractual details were held at Georgia Tech, 16-18 July 1963, with Mr. Sidney Weitz and Mr. R. L. McKenzie of USAELRDL.

(8) A visit was made 30 July 1963 by Mr. Warren Kesselman of USAELRDL and Mr. I. N. Mindel, Mr. J. T. Ludwig, and Mr. Martin Sherman of IITRI to Georgia Tech and a discussion of nonlinear effects in dummy loads was held.

The work planned for the period 15 August to 15 September includes the following:

(1) Work on the deviation detector and audio susceptibility amplifier will continue. Transformer details for the audio susceptibility tester will be considered.

(2) Study of the various techniques presented in the literature for the measurement of spurious and harmonic emissions in waveguide systems will continue.

(3) Details of the Design Plan involving interconnection of the equipment required by the RFC Accessory Set will be considered.

(4) Construction of a thin film load involving the selection of a configuration for such a load and the depositing of a suitable film on a selected substrate will be started.

Respectfully submitted:

Joseph R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

16 September 1963

Electromagnetic Environment Division
Interference Evaluation Branch
U. S. Army Electronics Research and
Development Laboratory
Fort Monmouth, New Jersey

Attention: Mr. Sidney Weitz, SELRA/GFE

Subject: Monthly Letter Report No. 4, 15 September 1963, Project A-693, Contract No. DA 36-039 AMC-02223(E), "Radio Frequency Compatibility (RFC) Accessory Equipment Set."

Gentlemen:

The following progress was made on the contract during the period 15 August to 15 September:

(1) Additional circuits for the audio susceptibility tester amplifier were investigated. The circuit which at present looks most promising is that consisting of a bridge arrangement of transistors to drive the coupling transformer.

(2) Substrate material has been procured and a taper section for a coaxial thin film load is presently being machined. Several methods of deposition of the thin film are being investigated.

(3) Detailed analysis of the interconnection of equipment required for the Design Plan was continued.

(4) A survey of the various methods presented in the literature for the measurement of spurious and harmonic emission power under the conditions of multimode propagation is in progress.

(5) A 50 to 300 ohm matching pad with application to the receiver input coupler was constructed and tested. This pad seemed to be adequate for use to 400 mc using molded carbon resistors. An additional pad is presently being constructed so that insertion loss measurements can be made.

(6) Work on the deviation detector involved preliminary system tests.

(7) An Electromechanics rejection filter Model MF was ordered for evaluation purposes. Delivery of this filter is expected in late September.

(8) Polarad signal generators have been purchased that at present extend our capabilities in this area to 30 gc.

The work planned for the period 15 September to 15 October includes the following:

(1) Work on the deviation detector and audio susceptibility amplifier and transformer will continue.

(2) Detailed evaluation of the Design Plan involving interconnection of the equipment required by the RFC Accessory Set will continue.

(3) A first model of a thin film load should be completed and evaluation started.

(4) Design and testing of the receiver input coupler will continue.

(5) Evaluation of the Electromechanics rejection filter will begin on receipt of the filter.

Respectfully submitted:

Joseph R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

1-693

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

18 November 1963

Electromagnetic Environment Division
Interference Evaluation Branch
U. S. Army Electronics Research and
Development Laboratory
Fort Monmouth, New Jersey

Attention: Mr. Sidney Weitz, SELRA/GFE

Subject: Monthly Letter Report No. 5, 15 November 1963, Project A-693, Contract No. DA 36-039 AMC-02223(E), "Radio Frequency Compatibility (RFC) Accessory Equipment Set."

Gentlemen:

The following progress was made on the contract during the period 15 October to 15 November.

(1) Work on Quarterly Report No. 2 was completed and the approval copies were forwarded.

(2) An amplifier for the audio susceptibility tester was constructed and performance tests are underway. A design for the coupling transformer was completed and materials have been ordered for the construction of the unit.

(3) Several resistive elements for the thin film dummy load were deposited on alumina rods and their temperature coefficient of resistance investigated. A combination of platinum and gold shows a much better characteristic than a film using platinum alone. Power dissipation characteristics are also being studied.

(4) Evaluation tests of the Electro-Mechanics rejection filter were started.

(5) Improvement in the configuration of the receiver input coupler has resulted in a better insertion loss versus frequency characteristic. A new housing which should give a better transition in impedance levels is presently being constructed.

(6) Study of the equipment needed in the RFC Accessory Set continued.

(7) Extension of the VSWR prediction criterion was made to include cases where all reflections are not assumed to have the same magnitude.

(8) J. R. Walsh, Jr. attended the Ninth TRI-SERVICE Conference on Electromagnetic Compatibility held in Chicago on 15-17 October 1963.

The work planned for the period 15 November to 15 December includes the following:

(1) Work on the audio susceptibility tester will continue.

(2) Detailed evaluation of the Design Plan involving interconnection of equipment required by the RFC Accessory Set will continue.

(3) Work on the deposition of a thin film resistive element for the dummy load will continue.

(4) The new configuration of the receiver input coupler will be tested.

(5) Evaluation tests of the Electro-Mechanics rejection filter will continue.

Respectfully submitted:

Joseph R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

17 December 1963

Electromagnetic Environment Division
Interference Evaluation Branch
U. S. Army Electronics Research and
Development Laboratory
Fort Monmouth, New Jersey

Attention: Mr. Sidney Weitz, SELRA/GFE

Subject: Monthly Letter Report No. 6, 15 December 1963, Project A-693, Contract No. DA 36-039 AMC-02223(E), "Radio Frequency Compatibility (RFC) Accessory Equipment Set."

Gentlemen:

The following progress was made on the contract during the period 15 November to 15 December.

(1) Study of the equipment needed in the RFC Accessory Set and the interconnection details of this equipment continued. Equipment needs in several areas have been clarified.

(2) Work is continuing on the audio susceptibility tester. Some of the materials for the construction of the transformer have been received. Amplifier circuits are still under investigation and protection techniques for these circuits are being evaluated.

(3) Investigation of different metals to produce a thin film resistive element for a high power dummy load continued. Rhenium and palladium are being investigated as possible metals to alloy with platinum to form a resistive element with a low temperature coefficient of resistance.

(4) Construction of a new configuration of the receiver input coupler has been completed. An improvement in insertion loss characteristics was obtained.

(5) Insertion loss and operational characteristics of the Electro-Mechanics rejection filter are being investigated.

(6) H. W. Denny, W. R. Free, and J. R. Walsh, Jr., attended a technical conference at USAELRDL on 26 November 1963 to discuss accessory equipment components which could be specified at that time. Areas in which development work is needed were also discussed.

The work planned for the period 15 December 1963 to 15 January 1964 includes the following:

(1) Major effort will be directed toward the consideration of the details associated with the Design Plan for the RFC Accessory Set.

(2) Evaluation tests of the Electro-Mechanics rejection filter will continue.

(3) Work on the audio susceptibility tester will continue.

(4) Techniques for the deposition of a resistive element for a high power dummy load will continue.

Respectfully submitted:

Joseph R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

19 February 1964

Electromagnetic Environment Division
Interference Evaluation Branch
U. S. Army Electronics Research and
Development Laboratory
Fort Monmouth, New Jersey

Attention: Mr. R. L. McKenzie

Subject: Monthly Letter Report No. 7, 15 February 1964, Project A-693, Contract No. DA 36-039 AMC-02223(E), "Radio Frequency Compatibility (RFC) Accessory Set."

Gentlemen:

The following progress was made on the contract during the period 15 January to 15 February.

(1) Work on Quarterly Report No. 3 was completed and approval copies were forwarded.

(2) Formal preparation of the Design Plan for the Accessory Equipment Set was started during this period. The equipment setups presented in the block diagrams of Quarterly Reports Nos. 1 and 2 were analyzed and combined into a unified test setup which will provide for the performance of tests required by MIL-I-11748. Tentative equipment arrangements have been made utilizing standard 19 inch racks. Extensive use of switches, both manual and electrical, is planned for the system.

(3) Consideration of a mobile test system resulted in a tentative floor plan for a 28 foot shielded van.

(4) Preliminary calculations of expected signal losses due to transmission line attenuation were made for the primary signal paths of the accessory set. Prediction of signal losses will be extended to include mismatch losses.

(5) An amplifier and transformer for the audio susceptibility tester were constructed. Tests on the transformer indicate that the parameters of the transformer are very close to those expected from the design calculations. An amplifier has been constructed and operated at a 50 watt power level. Studies of the effects of ac line power feedback into the amplifier and line transients on the amplifier are underway.

The work planned for the period 15 February to 15 March includes the following:

(1) The major effort will be directed toward the completion of the Design Plan for the RFC Accessory Set.

(2) Work on the audio susceptibility tester will continue.

(3) Techniques for the deposition of a resistive element for a high power dummy load will continue to be studied.

Respectfully Submitted:

J. R. Walsh, Jr.
Project Director

Approved:

for D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

18 March 1964

Electromagnetic Environment Division
Interference Evaluation Branch
U. S. Army Electronics Research and
Development Laboratory
Fort Monmouth, New Jersey

Attention: Mr. R. L. McKenzie, SELRA/GFE

Subject: Monthly Letter Report No. 8, 15 March 1964, Project A-693, Contract No. DA 36-039 AMC-02223(E), "Radio Frequency Compatibility (RFC) Accessory Set."

Gentlemen:

The following progress was made on the contract during the period 15 February to 15 March:

(1) Preparation of the Design Plan for the Accessory Equipment Set was continued. Consideration was given to such problems as attenuation as a function of frequency and voltage standing wave ratio in the various coaxial cable and waveguide transmission systems. The placement of items of equipment resulting from these considerations was investigated. Block diagrams of proposed systems and discussions of items of interest were prepared.

(2) An exploratory investigation was undertaken into the use of electron beam techniques for the deposition of thin film resistive elements for a high power dummy load.

(3) Tests made on the audio susceptibility tester indicate that the frequency response of the amplifier is adequate and that the AC power feedback from the power line does not cause any apparent degradation of the audio signal. Another transformer will be constructed which will provide higher open circuit inductance thereby reducing the reactive current which must be supplied by the amplifier at the lower frequencies. A further reduction in the output impedance of the amplifier is being studied.

The work planned for the period 15 March to 15 April includes the following:

(1) The major effort will again be directed toward the completion of the Design Plan for the RFC Accessory Set.

(2) Work will continue on the audio susceptibility tester with the purpose of improving the design of the transformer and amplifier. Protection methods for the amplifier will receive further attention.

(3) Techniques for the deposition of a resistive element for a high power dummy load will continue to be studied. It is planned that several films will be deposited and evaluated during this period.

Respectfully Submitted:

J. R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

21 April 1964

Electromagnetic Environment Division
Interference Evaluation Branch
U. S. Army Electronics Research and
Development Laboratory
Fort Monmouth, New Jersey

Attention: Mr. R. L. McKenzie, SELRA/GFE

Subject: Monthly Letter Report No. 9, 15 April 1964, Project A-693, Contract No. DA 36-039 AMC-02223(E), "Radio Frequency Compatibility (RFC) Accessory Set."

Gentlemen:

The following progress was made on the contract during the period 15 March to 15 April:

(1) Preparation of the Design Plan for the Accessory Equipment Set was continued. Block diagrams of proposed systems and discussions of items of interest were prepared.

(2) Investigation of techniques required to deposite a resistive element for a dummy load on a fused quartz substrate continued. Electron beam techniques were utilized. A substrate heater, which was found to be essential for the deposition of a uniform film, was fabricated and is in use. Techniques for the production of coatings of silicon monoxide were investigated.

(3) The possible application of lossy filter techniques for line impedance stabilization networks was considered.

(4) Construction of a transistorized audio susceptibility amplifier continued. Preliminary testing has been completed. Protective circuits have been designed and will be incorporated into the amplifier upon procurement of required components. A new version of the susceptibility transformer was constructed to lower the reactive volt-amperes which the amplifier must supply at low frequencies.

The work planned for the period 15 April to 15 May includes the following:

(1) The major effort will again be directed toward the completion of the Design Plan for the RFC Accessory Set.

(2) Work will continue on the audio susceptibility tester. Protection circuits will be incorporated into the amplifier.

(3) Techniques for the deposition of a thin film resistive element for a dummy load will continue to be studied.

(4) Various methods of production of lossy filter elements with possible application to line stabilization networks will be investigated.

Respectfully Submitted:

J. R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

A-693

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

19 May 1964

Electromagnetic Environment Division
Interference Evaluation Branch
U. S. Army Electronics Research and
Development Laboratory
Fort Monmouth, New Jersey

Attention: Mr. R. L. McKenzie, SELRA/GFE

Subject: Monthly Letter Report No. 10, 15 May 1964, Project A-693, Contract No. DA 36-039 AMC-02223(E), "Radio Frequency Compatibility (RFC) Accessory Set"

Gentlemen:

The following progress was made on the contract during the period 15 April to 15 May:

(1) Preparation of the Design Plan for the Accessory Equipment Set was continued. Block diagrams of proposed systems were reviewed and technical specifications of items of equipment were investigated.

(2) Tests performed on the audio susceptibility tester transformer indicate that the open circuit and leakage inductances are as expected from design calculations. A circuit providing protection for the amplifier against short circuits at the amplifier output was designed and successfully operated. Modifications to improve the operation of this circuit are presently underway.

(3) Elements for a lossy filter with possible application to line impedance stabilization networks have been produced using a 10:1 and 20:1 mixtures of carbonyl iron powder. These elements are presently being tested.

The work planned for the period 15 May to 15 June includes the following:

(1) The major effort will again be directed toward the completion of the Design Plan for the RFC Accessory Set.

(2) Work will continue on the audio susceptibility tester. Test of the amplifier and transformer will continue and design refinements will be made as needed.

(3) Techniques for the deposition of a thin film resistive element for a dummy load will continue to be studied.

(4) Various methods of production of lossy filter elements will continue to be studied.

J. R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

QUARTERLY REPORT NO. 1

PROJECT A-693

RADIO FREQUENCY COMPATIBILITY (RFC) ACCESSORY EQUIPMENT SET (U)

H. W. DENNY AND J. R. WALSH, JR.

CONTRACT NO. DA 36-039 AMC-02223(E)
DEPARTMENT OF THE ARMY PROJECT: 1G620501D4490111

Placed by the
U. S. Army Electronics Research
and Development Laboratories
Fort Monmouth, New Jersey

15 April 1963 to 15 July 1963

1963

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 1

PROJECT NO. A-693

RADIO FREQUENCY COMPATIBILITY (RFC) ACCESSORY EQUIPMENT SET (U)

By

H. W. DENNY and J. R. WALSH, JR.

CONTRACT NO. DA 36-039 AMC-02223(E)
DEPARTMENT OF THE ARMY PROJECT: 1G620501D4490111

SIGNAL CORPS TECHNICAL REQUIREMENT
SCL-7687, dtd. 28 SEPT. 1962

The object of this research is to prepare a Design Plan for a Radio Frequency Compatibility Accessory Set.

15 APRIL 1963 to 15 JULY 1963

PLACED BY THE U. S. ARMY
ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORIES
FORT MONMOUTH, NEW JERSEY

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I. PURPOSE

The purpose of this project is to conduct a study leading to a Design Plan for accessory equipment to be used with Radio Interference Measuring Sets and signal generators. The accessory equipment includes the complementary devices necessary to determine radio frequency interference characteristics of U. S. Army electrical and electronic equipment in accordance with military specification MIL-I-11748. The frequency range of interest is 0.014 to 40,000 Mc. It is also the purpose of the project to investigate two items of equipment. These are a receiver input coupler and an audio susceptibility tester.

The areas of investigation on this project are divided into three tasks as follows:

I. Evaluation of state-of-the-art items and techniques from the viewpoint of modifying or extending them to fill the Design Plan requirements.

II. Investigation of new techniques and materials when the Design Plan requirements cannot be met by state-of-the-art items or techniques.

III. Verification of findings and conclusions by experimental work when necessary.

II. ABSTRACT

Tests and test setups for performing the various measurements specified in military specification MIL-I-11748 are discussed and outlined in block diagram form. Emphasis has been placed on the accessory items required for the Design Plan for the Radio Frequency Compatibility Accessory Set.

Various types of dummy loads are discussed. A cross section of commercially available medium and high power dummy loads is presented as a result of correspondence with many manufacturers of these devices. Preliminary research on the application of thin films to high power loads is presented.

Other accessory items such as signal sampling networks, filters, etc are discussed.

Work on the audio susceptibility tester, receiver input coupler, and deviation detector is reviewed.

III. PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

On May 22, 1963, Mr. D. W. Robertson, and Mr. J. R. Walsh, Jr., visited USAELRDL, Fort Monmouth, New Jersey, to discuss technical matters concerning the project.

Mr. J. R. Walsh, Jr. attended the Fifth National Symposium on Radio Frequency Interference held June 4-5, 1963, in Philadelphia, Pennsylvania.

IV. FACTUAL DATA

A. Design plan discussion

1. Introduction

Military specification MIL-I-11748B is cited as the Standard for measurements to be performed using available signal generators, Radio Interference Measuring Sets (RIMS), and accessory equipment which is to be specified by this Design Plan. The "C" version of MIL-I-11748 is to be released sometime in the near future.[1]

Some of the tests that need to be performed on class I equipment are:

(1) Power line conducted emissions

(2) Power line and nonsignal line conducted susceptibility

(3) Nonsignal line audio susceptibility

(4) Antenna and signal line conducted susceptibility--Receiver

(a) narrow band

(b) broad band

(5) Antenna conducted emissions--Transmitter

(a) stand-by

(b) operating

(6) Antenna conducted emissions--Receiver

(7) Intermodulation

(8) Case and cable radiation

(a) narrow band

(b) broad band

(9) Radiated susceptibility

(a) CW only

(b) CW modulated

(10) Antenna radiated extraneous outputs, integral systems

Many of the test procedures for the above tests are specified in MIL-STD-449A, "Measurement of Military Standard Radio Frequency Spectrum Characteristics," 24 October 1961. A Georgia Tech publication[2] which closely parallels MIL-STD-449A has been used as a guide to determine the equipment requirements and setups for the above tests.

A threefold approach is being made in the development of the Design Plan for the accessory items for the RFC Accessory Set. The first step, which is reported in this first quarterly report, was the investigation of each of the tests required to determine the necessary equipment and the equipment setups required. The second step, which was started this quarter, is the investigation of the various accessory items required in order to determine how they may be utilized to meet the power and frequency requirements. The third step will be the combination of the accessory items into an efficient and compatible arrangement to produce the final Design Plan for the Accessory Set.

2. Test setups and equipment requirements

a. Power line conducted emissions.

(1) Receiver. Any large signal voltages that exist in a radio receiver, such as signals generated by local oscillators, calibration oscillators, beat frequency oscillators, and mixers, may couple into adjacent communications equipment through the power line and cause interference. Though

the primary emphasis of this test is on interfering signals that are conducted via the power lines, other paths such as interconnecting cables between equipments should also be tested.

The items of accessory equipment required are line stabilization networks, receiver input couplers, filters, and the necessary switches. Since the impedance of the power source varies appreciably from installation to installation, a line stabilization network is introduced into the power line to provide a reference impedance for measurement purposes. Only recently have line stabilization networks been developed that are useful above 100 Mc. Designs are now available that are useful to 150 Mc.[3,4] A low frequency line stabilization network has also been developed that makes possible measurements between 15 and 150 kc.[5] One study group[6] concluded that conducted interference tests were meaningless above 300 Mc and recommended studies of the radiated fields only.

<u>(1.1) Test setup.</u> Figure 1 is the block diagram of the test setup. This diagram shows only the power line conducted interference setup. The signal generator supplies a signal to the receiver to simulate actual operating conditions for the generation of intermediate frequencies and any other frequencies that are affected by the received signal. The low-pass filter serves to keep harmonics of the signal generator from affecting the test. Appropriate modifications must be made for measuring interference signals in other leads. Current probes* are available that may have application in this regard.

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*Stoddart Aircraft Radio Company, Inc., 6644 Santa Monica Boulevard, Hollywood 38, California, or Empire Devices, Amsterdam, New York.

(1.2) Equipment required.

(1.2.1) Signal generator with provisions for modulation compatible with the equipment under test

(1.2.2) Radio Interference Measuring Set

(1.2.3) Line stabilization network

(1.2.4) Low-pass filters

(1.2.5) Receiver input coupler

(1.2.6) DPDT rf switch

(1.2.7) Frequency meter

(1.2.8) Signal generator with calibrated output attenuator

(2) Transmitter. Since large audio and rf voltages exist in a transmitter, some or all of these signals could appear on nonsignal conducting leads. This test is designed to measure the frequencies and amplitudes of all signals which emanate from the transmitter and appear on these lines. This test is not necessarily limited to power leads but other nonsignal leads should be tested also. Again a current probe may be useful.

(2.1) Test setup. Figure 2 shows the block diagram of the equipment setup for this test.

(2.2) Equipment required.

(2.2.1) Dummy load capable of handling the transmitter output

(2.2.2) Line stabilization network

(2.2.3) Output monitor such as a deviation detector

(2.2.4) Radio Interference Measuring Set

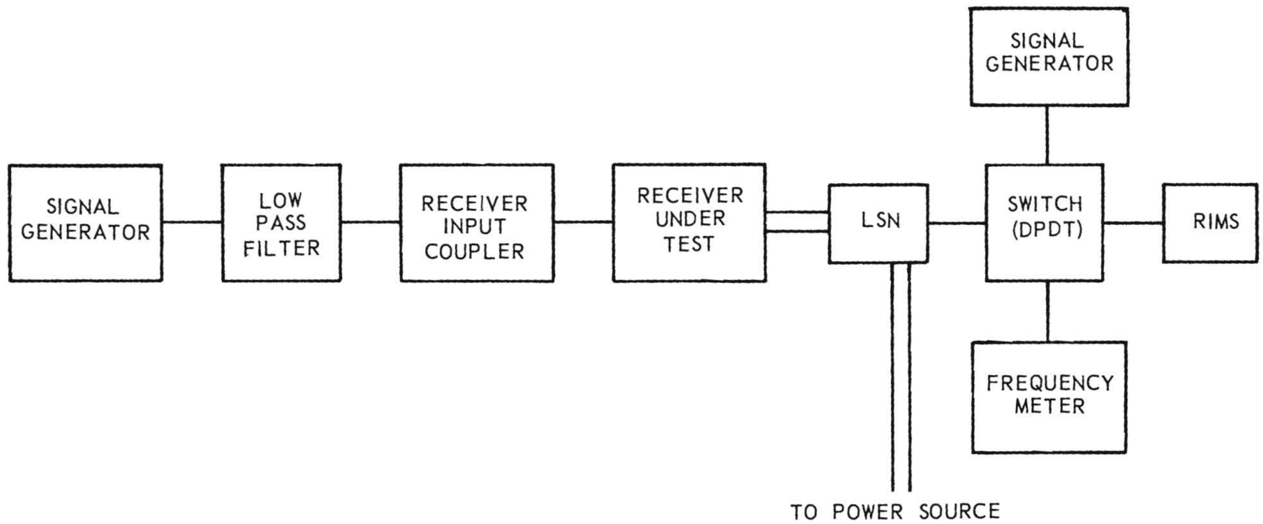


Figure 1. Block diagram of power line conducted emissions test setup for receivers.

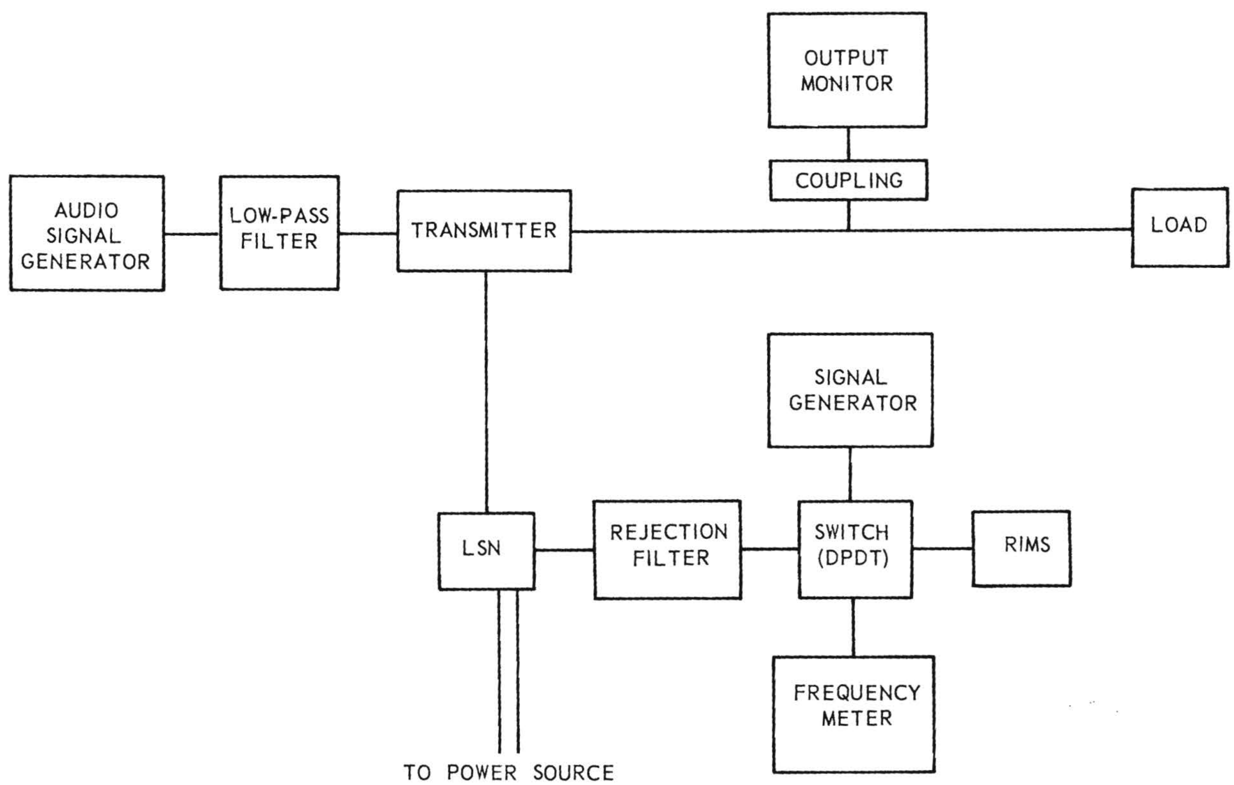


Figure 2. Block diagram of power line conducted emissions test setup for transmitters.

(2.2.5) Signal generators

(2.2.6) Low-pass filter

(2.2.7) Rejection filter

(2.2.8) DPDT rf switch

(2.2.9) Frequency meter

This test will be performed on noncommunication type equipment also such as test equipment, tools, generators, and other specified interference producing equipment. The test setups will be similiar to those shown with appropriate modifications for the type equipment being tested.

b. Power line and nonsignal line conducted susceptibility.

(1) Receiver. Interference to a radio receiver by other electronic equipment in the same location may be caused by coupling into the receiver by the power leads or other nonsignal leads.

In the evaluation of this leakage, the stabilization network is needed to stabilize the impedance presented to a receiver by the nonsignal lead and to provide a point for attaching a signal generator or other measuring equipment.

(1.1) Test setup. Figure 3 shows the setup necessary to conduct this test.

(1.2) Equipment required.

(1.2.1) RF signal generator with provisions for modulation or impulse generator

(1.2.2) Output monitor such as distortion analyzer

(1.2.3) Line stabilization network

(1.2.4) Low-pass filter

(1.2.5) SPDT rf switch

(1.2.6) Frequency meter for narrow band test

(2) Transmitter. A transmitter may respond to interfering signals which are coupled into the transmitter through the power leads and into the low level rf stages and modulator stages. The test to evaluate this type of interference is performed with modulated rf interfering signals on the power line.

(2.1) Test setup. Figure 4 is the block diagram of the transmitter portion of this test setup.

(2.2) Equipment required.

(2.2.1) Dummy load for the transmitter

(2.2.2) Modulation monitor

(2.2.3) Line stabilization network

(2.2.4) Signal generator or impulse generator

(2.2.5) Low-pass filters

(2.2.6) SPDT rf switch

(2.2.7) Frequency meter

c. Nonsignal line audio susceptibility.

The audio susceptibility test is a procedure wherein an audio signal voltage is inserted in series with a nonsignal line of a piece of equipment to determine whether or not these signals so inserted will degrade the

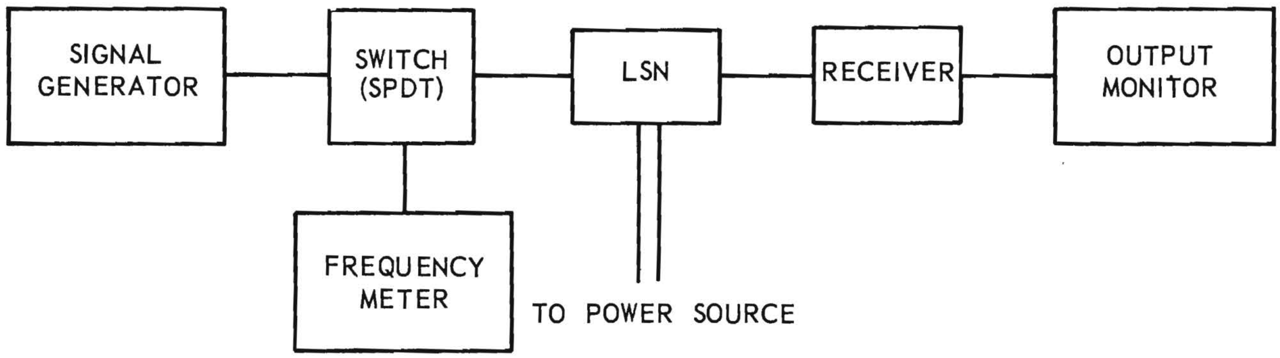


Figure 3. Block diagram of power line and nonsignal line conducted susceptibility test setup for receivers.

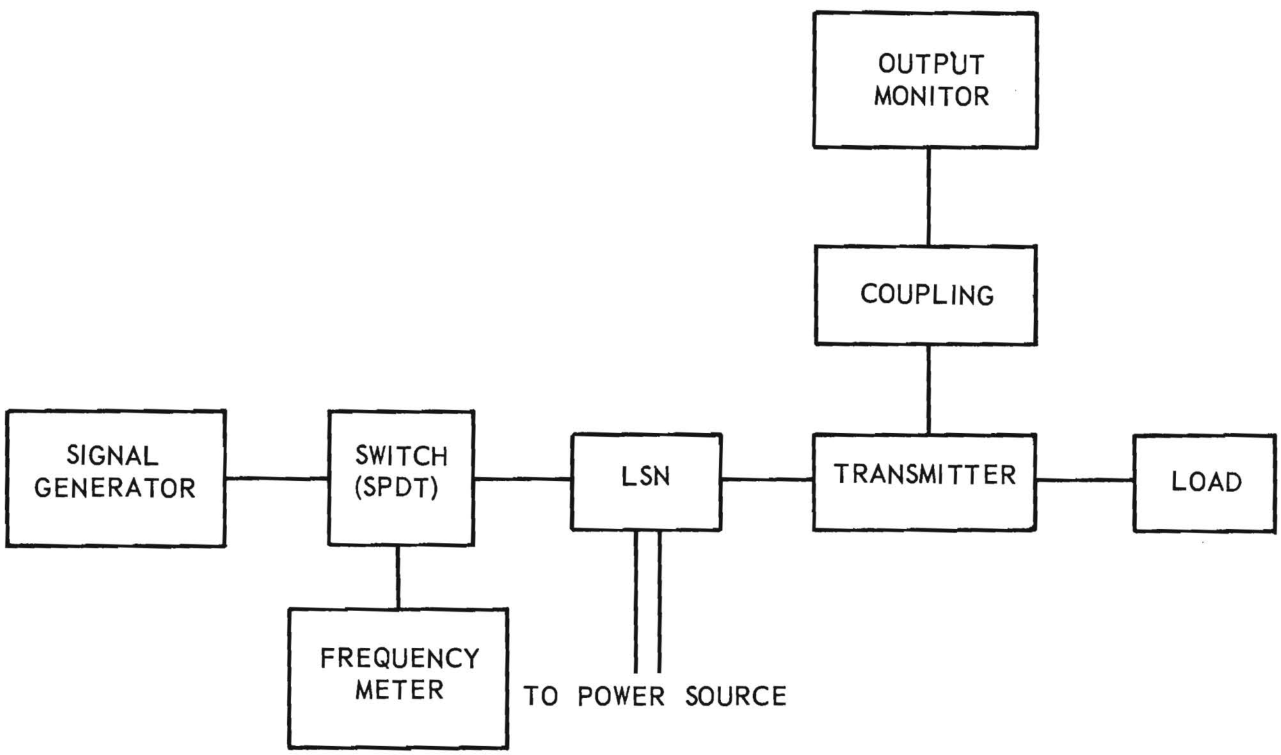


Figure 4. Block diagram of power line and nonsignal line conducted susceptibility test setup for transmitters.

performance of the equipment under test. The voltage inserted is an audio voltage of 3 volts rms open circuit in the frequency range of 50 to 15,000 cps. Insertion of this voltage in the nonsignal line is usually accomplished by means of an isolation transformer.

(1) Receiver.

(1.1) Test setup. Figure 5 shows the test setup for this test.

(1.2) Equipment required.

(1.2.1) Isolation transformer

(1.2.2) Audio amplifier

(1.2.3) Audio oscillator

(1.2.4) Output monitoring device such as modulation monitor or distortion analyzer

(1.2.5) Frequency meter

(2) Transmitter. The transmitter portion of this test is similiar to the receiver portion.

d. Antenna and signal line conducted susceptibility.

(1) Receiver. Spurious responses in a receiver can be a major source of interference. They are not distinct from the selectivity characteristics because the susceptibility to spurious responses is increased at points of poor rejection. The magnitude of the spurious response is in part a function of the rf amplifier filter circuits and in part due to the characteristics of the mixer. Unusually large responses may be caused by poor tracking in the rf

amplifier tuned circuitry or by improper operation of the mixer or rf stages. Other unusually large responses, especially at frequencies much higher than the receiver-tuned frequency, are due to leakage around the tuned circuits and to spurious resonances.

(1.1) Test setup. The test setup is as shown in figure 6.

(1.2) Equipment required.

(1.2.1) Signal generator with provision for modulation

(1.2.2) Low-pass filter

(1.2.3) Output monitoring device such as a distortion analyzer

(1.2.4) Frequency meter

(1.2.5) SPDT rf switch

(2) Transmitter. This test is not applicable to transmitters.

e. Antenna conducted emissions.

(1) Receiver. Any signal generated in a superheterodyne receiver, such as signals generated by local oscillators, calibration oscillators, beat frequency oscillators, and mixers, may radiate sufficient power to cause interference in adjacent communications equipment. Interference from these sources is usually caused by coupling to the adjacent equipment through the antenna terminals, receiver case, and power leads.

(1.1) Test setup. Figure 7 shows the block diagram of the test setup.

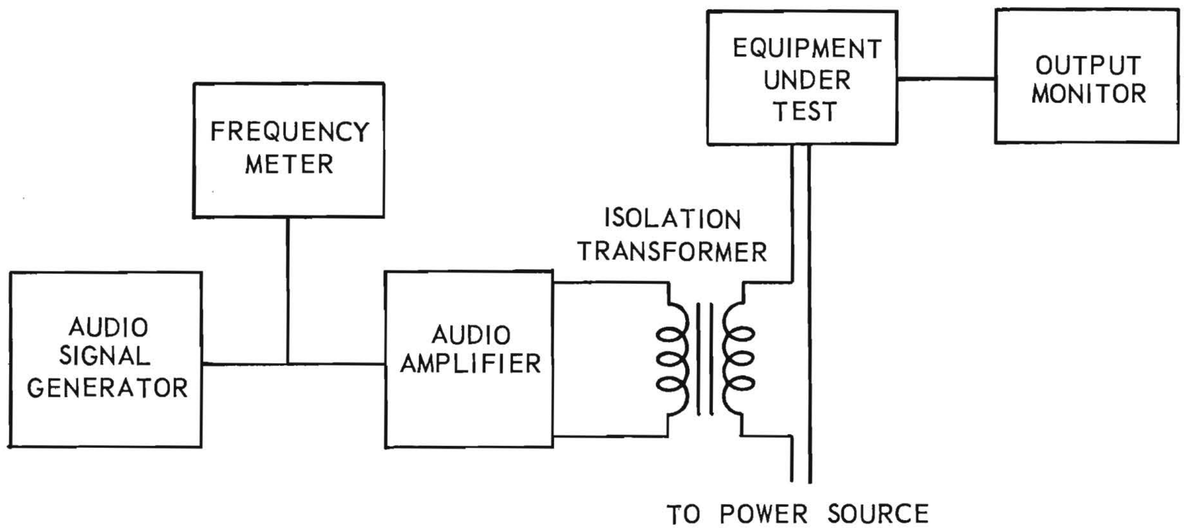


Figure 5. Block diagram of nonsignal line audio susceptibility test setup.

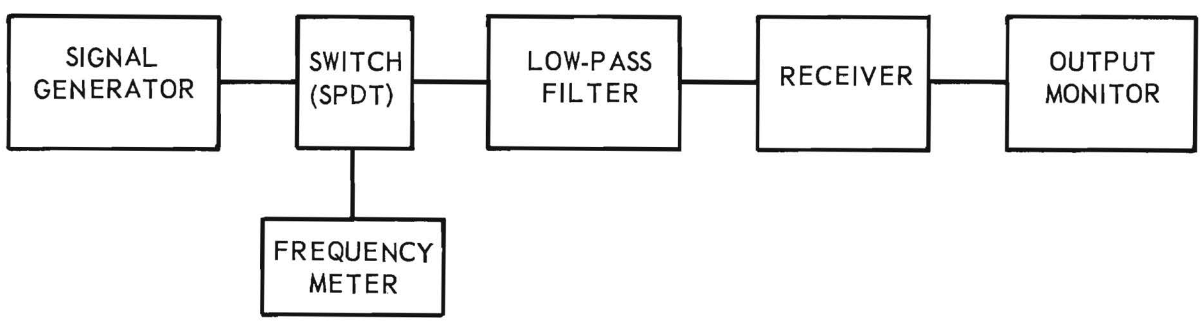


Figure 6. Block diagram of antenna and signal line conducted susceptibility test setup.

(1.2) Equipment required.

(1.2.1) Receiver input coupler

(1.2.2) Radio Interference Measuring Set

(1.2.3) Signal generators

(1.2.4) Frequency meter

(1.2.5) DPDT switch

(2) Transmitter. This test is essentially the same as the Spurious and Harmonic Emissions Test as specified in MIL-STD-449A.

The purpose of the test is to scan the spectrum from 0.014 Mc to 40 Gc and detect and measure any spurious and harmonic outputs of the transmitter under test. The majority of these outputs are related to the fundamental and harmonics of the master oscillator, multipliers, driver, and power amplifier frequencies. Other frequencies which are not harmonically related to the master oscillator may be present due to the mixing of the various frequencies present in a transmitter. These intermodulation products are usually harmonically related to oscillators used in control systems and auxiliary circuits. Also, in some transmitters containing both the above emissions, sums and differences of some of these frequencies are present.

This test is performed with the transmitter terminated in a matched resistive load. Although communications type transmitters are not used with the same antenna at all times, the test provides a basis for the comparison of different transmitter types.

If the fundamental output signal is not attenuated, spurious responses of the Radio Interference Measuring Set will give erroneous data. A wide selection of low-pass, high-pass, band-pass, and band-reject filters are necessary for this test.

(2.1) Test setup. The test setup is shown in figure 8.

(2.2) Equipment required.

(2.2.1) Dummy load

(2.2.2) Coupling device (such as a directional coupler)

(2.2.3) Filters

(2.2.4) DPDT rf switch

(2.2.5) Signal generators

(2.2.6) Radio Interference Measuring Set

(2.2.7) Frequency meter

f. Intermodulation.

(1) Receiver. Intermodulation in a receiver is caused by two signals (rf) mixing at the input of the receiver to produce a product frequency that falls near the tuned frequency.

The farther away from the tuned frequency that the two signals are, the less likely they will generate intermodulation products. Whether or not the two signals will produce intermodulation products depends greatly upon the front-end rejection.

In this test, signal generator intermodulation products can produce erroneous results unless precautions are taken to prevent their occurrence. This is best accomplished with filters or a hybrid coupler. If a hybrid coupler is not available or not adequate, filters may be utilized in the following manner:

i. Insert band-pass filters in the paths of f_1 and f_2 tuned to the respective frequencies.

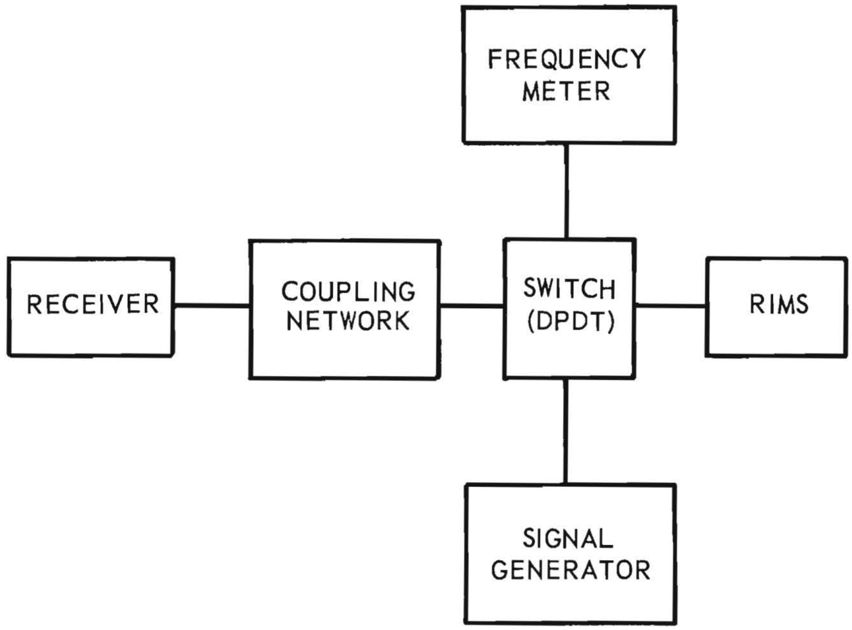


Figure 7. Block diagram of antenna conducted emissions test setup for receivers.

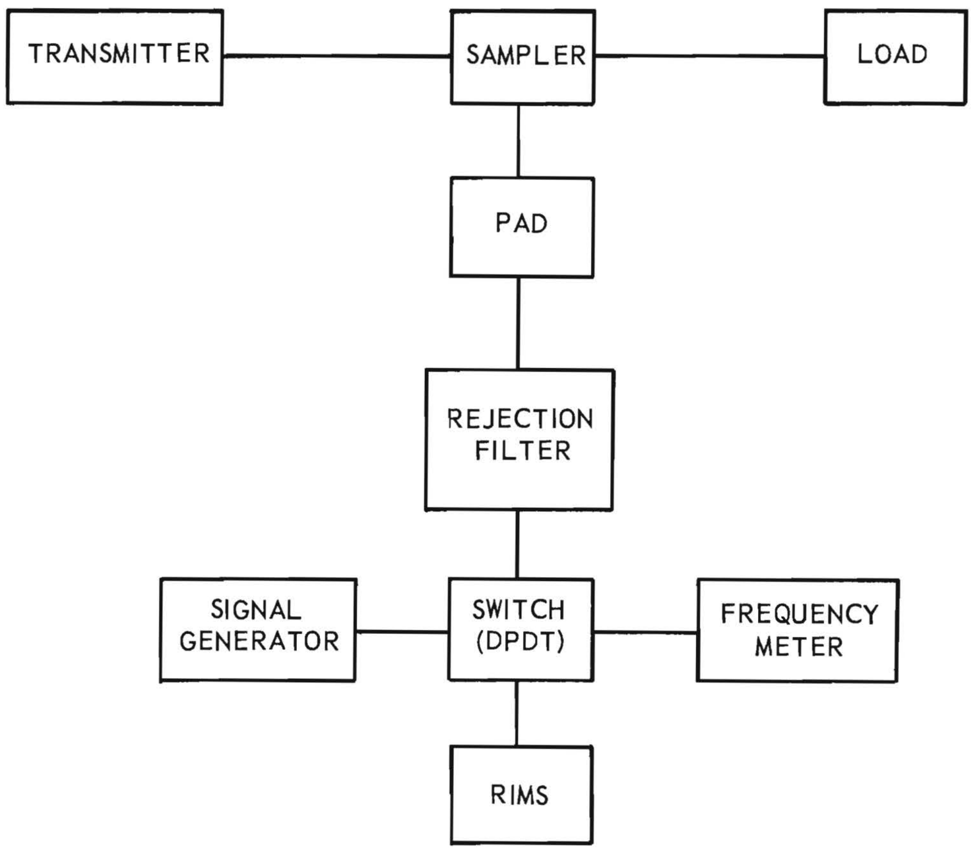


Figure 8. Block diagram of antenna conducted emissions test setup for transmitters.

ii. Insert a band-reject filter in the path of f_1 tuned to f_2 and another band-reject filter in the path of f_2 tuned to f_1.

iii. If low-pass and high-pass filters are available with cutoff frequencies between f_1 and f_2, the low-pass filter may be placed in the path of the lower of the two frequencies and the high-pass filter may be placed in the path of the higher of the two.

(1.1) Test setup. Figure 9 shows two possible test setups for this test using different signal generator coupling schemes.

(1.2) Equipment required.

(1.2.1) Signal generators

(1.2.2) Hybrid coupler or appropriate filters

(1.2.3) Output monitoring device such as a distortion analyzer

(1.2.4) SPDT rf switch

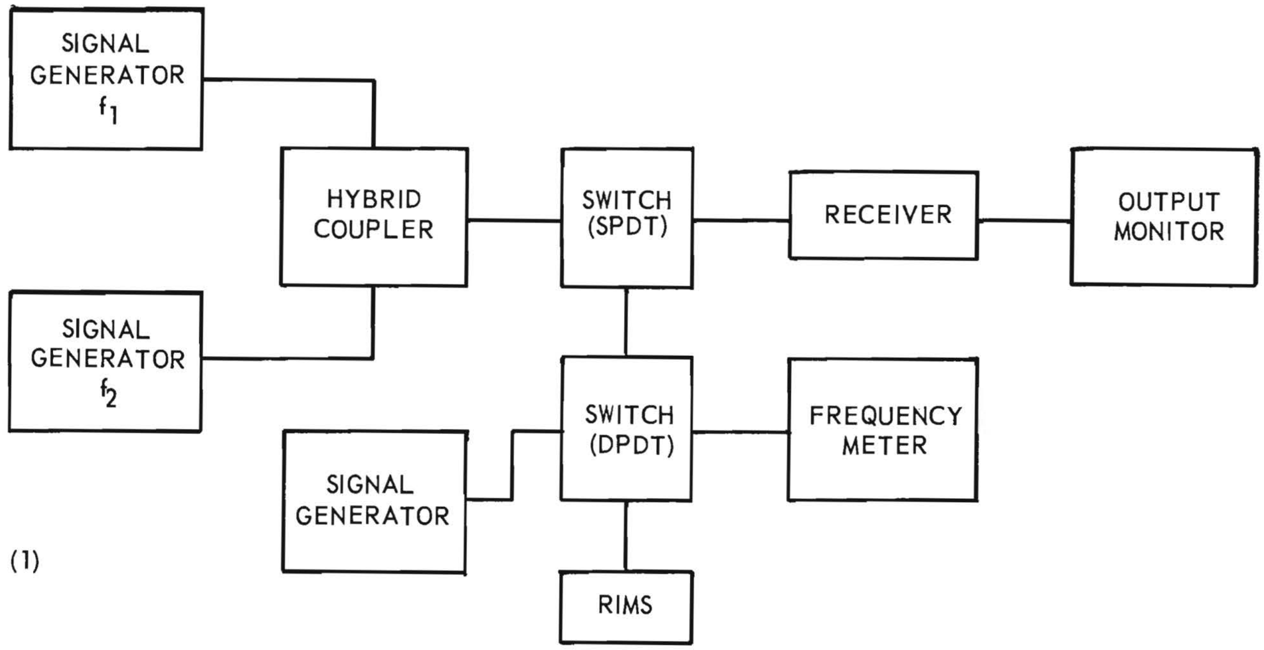
(1.2.5) DPDT rf switch

(1.2.6) Frequency meter

(1.2.7) Radio Interference Measuring Set

(2) Transmitter. The level of intermodulation products obtained when an external signal is coupled into a transmitter output circuit depends on the selectivity of the coupling circuits, the level of the interfering signal, and the nonlinearity of the output stage.

The spurious frequencies generated, which are relatively near the fundamental output frequency, will be radiated at much higher levels due to the selectivity of the output circuit.



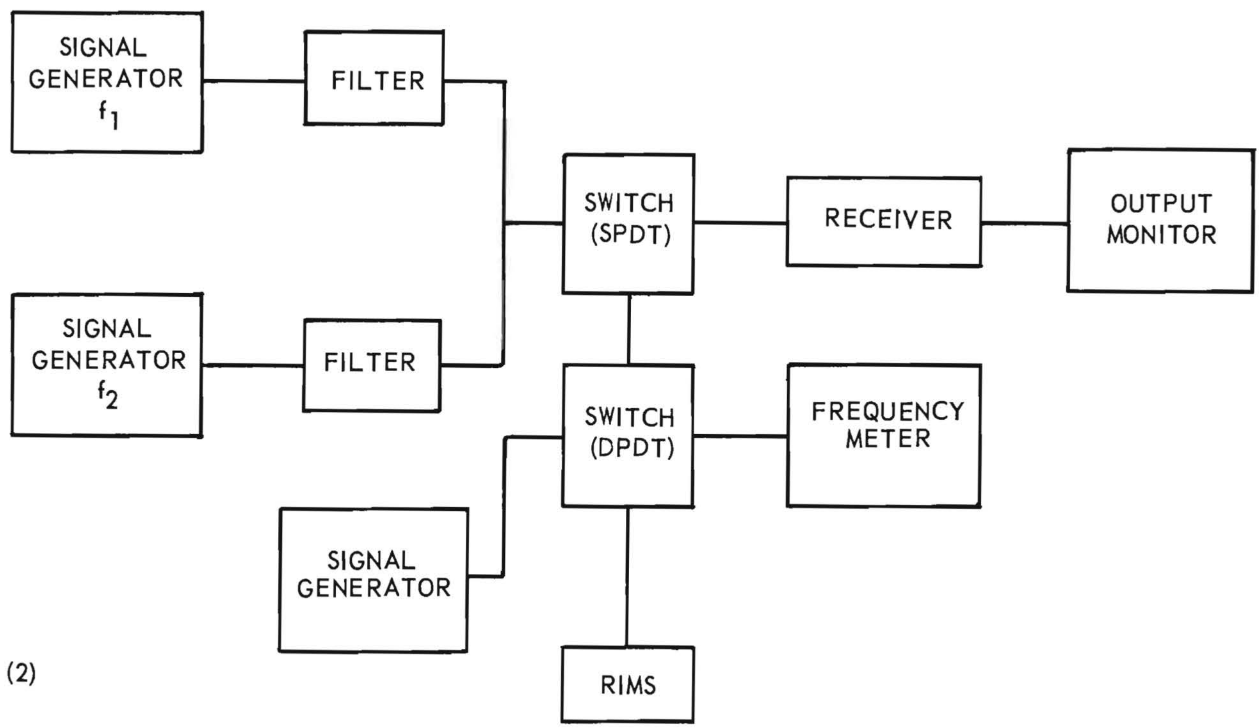


Figure 9. Block diagrams of intermodulation test setup for receivers.

A principal source of trouble in this test is intermodulation products generated in the measuring set. This can be minimized by the judicious use of filters.

(2.1) Test setup. The test setup is shown in figure 10.

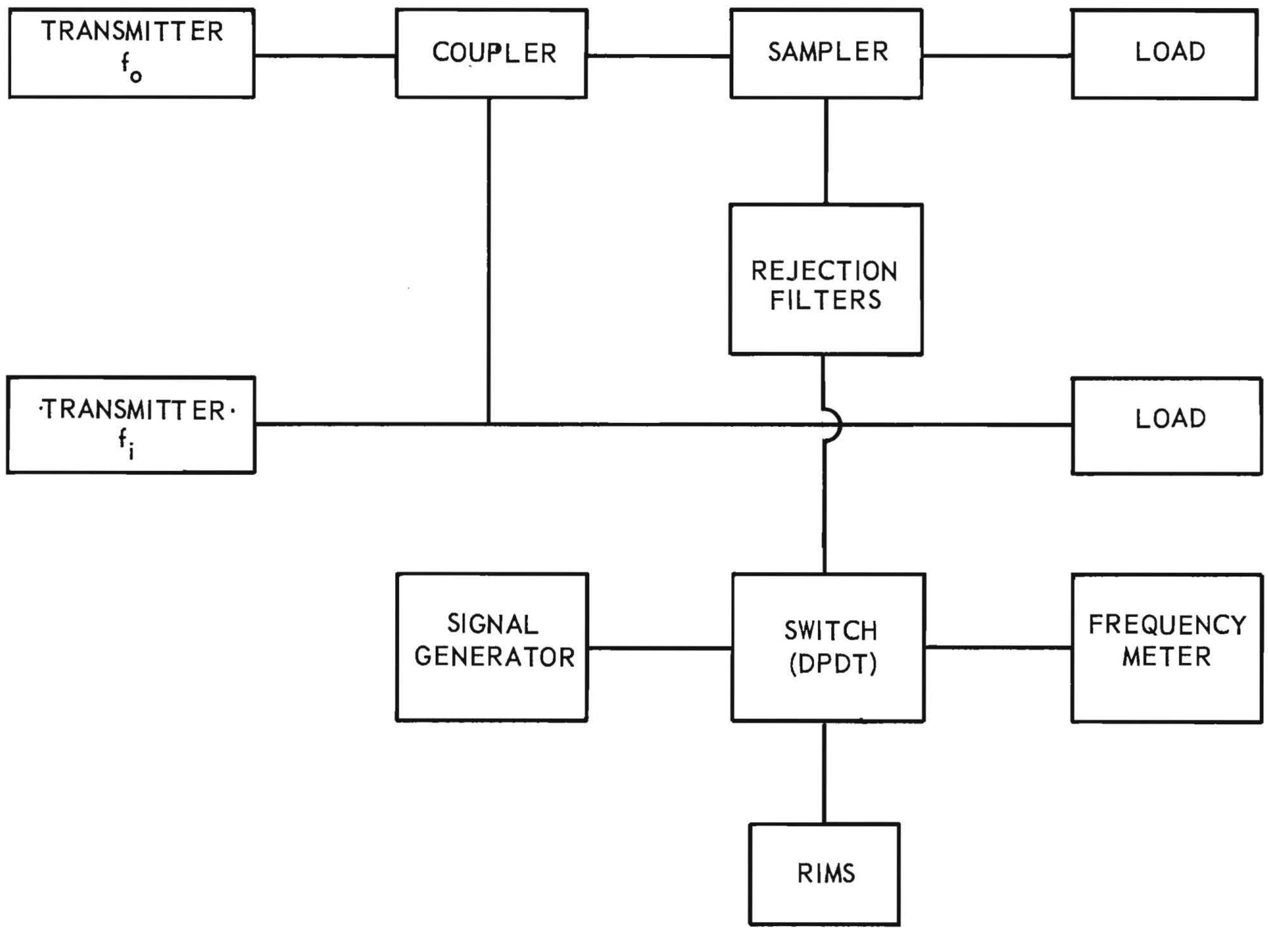


Figure 10. Block Diagram of Intermodulation Test Setup for Transmitters

(2.2) Equipment required.

(2.2.1) Dummy loads for both transmitters

(2.2.2) Two coupling networks

(2.2.3) Radio Interference Measuring Set

(2.2.4) DPDT rf switch

(2.2.5) Signal generator

(2.2.6) Filters

(2.2.7) Frequency meter

g. Case and cable radiation.

The object of the Case Radiation Test is to determine the frequency, source, and field strength of radiation from the equipment case and any associated cables.

There are two types of tests used in the overall test. The first of these is the Probing Test which discovers the source and frequency of each signal radiated. The Field Intensity Test measures the field strength at a fixed distance from the equipment case.

(1) Test setup. The test setup is shown in figure 11.

(2) Equipment required.

(2.1) Radio Interference Measuring Set with associated antenna

(2.2) Test probe (loop probe antenna)

(2.3) Termination for the equipment under test if necessary

(2.4) Signal generator

(2.5) Frequency meter

(2.6) DPDT rf switch

h. Radiated susceptibility.

The object of this test is to determine the susceptibility of the equipment under test to radiated signals that penetrate the case or are picked up by the cables.

(1) Test setup. The test setup is shown in figure 12.

(2) Equipment required.

(2.1) Signal source capable of generating the required field

(2.2) Radiating antenna

(2.3) Termination for equipment if required

(2.4) Output monitor

(2.5) SPDT switch

(2.6) Frequency meter

i. Antenna radiated extraneous outputs, integral systems.

Where it is not practical to detach the antenna from a system and operate into a dummy load, all tests must be performed on a radiated basis. The equipment requirements and test setups are essentially no different than presented in the foregoing tests.

B. Accessory items

1. Introduction

During this report period, efforts have been directed toward the accumulation of information on various accessory items that will be needed to

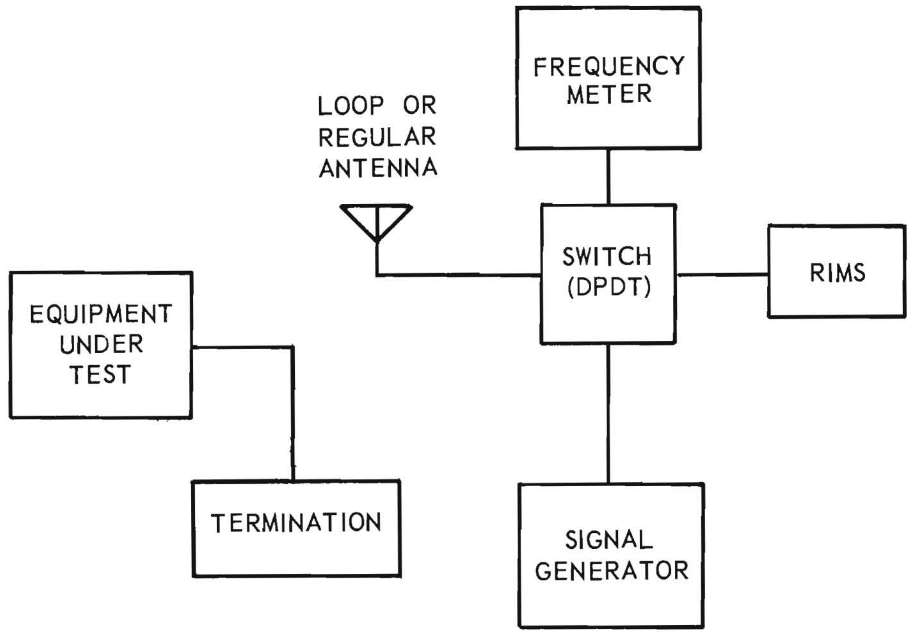


Figure 11. Block diagram of case and cable radiation test setup.

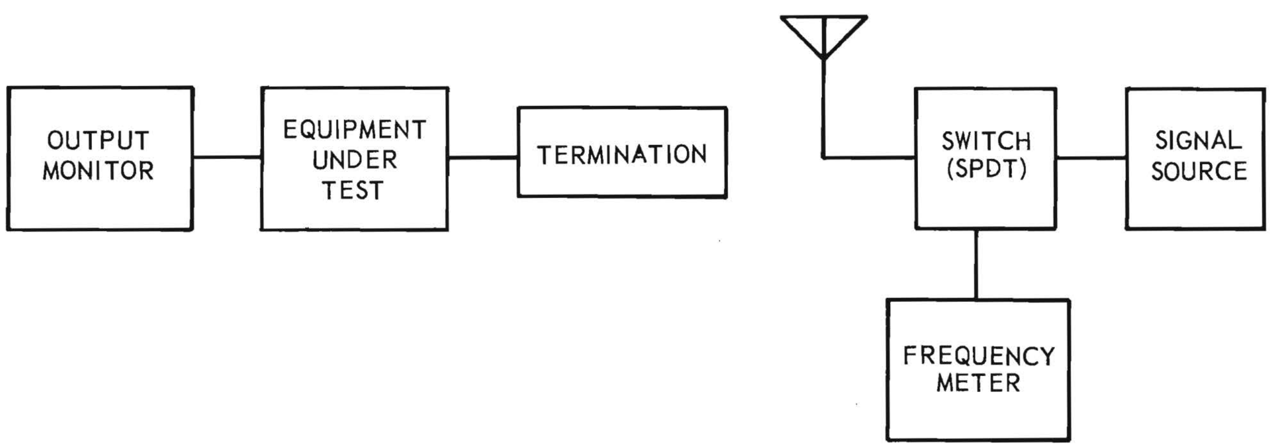


Figure 12. Block diagram of radiated susceptibility test setup.

perform the tests that are required. As a result, a good cross section of information on currently available test apparatus for both coaxial and waveguide systems has been obtained. This information is currently being catalogued and cross-referenced for more rapid and complete evaluation. That information for which an immediate need is present will be presented in tabular form. Some of this information may be duplicated by commercial tabulation services.

In searching the literature and manufacturers' catalogues, particular emphasis has been placed on power handling capabilities and frequency coverage. Coaxial components are generally wideband in nature. For this reason, coaxial components would probably be preferred up to about 12 kMc. This range can be covered with a minimum number of components. The power handling capability of coaxial components is less than waveguides. The large coaxial systems have increased power handling capabilities, but have the possibility of other modes of propagation being present.

The problem of handling the power requirements imposed upon this test set has been analyzed in view of commercially available components and recent developments in the state-of-the-art and in view of the test setups required to perform each of the required tests. A survey of all the test setups revealed that the high powered components could be limited to transmissions lines, dummy loads, sampling networks, and possibly a special type of filter.

The theoretical power rating of a waveguide size can be obtained from standard waveguide data. This power rating is usually computed on the basis of the voltage breakdown of air, and must be reduced for such factors as SWR, imperfections in the waveguide systems, etc. There are many factors that can affect the breakdown power:[7]

(1) The nature and pressure of the gases present in the component

(2) The extent of ionization by ultraviolet light or by other ionizing radiations

(3) Surface conditions

(4) The frequency

(5) The pulse width

(6) The pulse repetition rate

(7) The electric field configuration inside the component

(8) The size of the component

The results of studies of some of these factors can be summarized as follows:

Factors Influencing Breakdown	Effect on the Power Handling Capacity
increase in gas pressure	increases
increase in pulse width	decreases
increase in pulse repetition rate	decreases
use of ionizing source	decreases
presence of metal filings and surface points (rough surface)	decreases
humidity	practically no effect on air; may affect surface breakdown at a dielectric-air interface

As the average power being handled by a waveguide goes up, heating of the waveguide takes place. The heating of the waveguide imposes a limitation on the CW power handling capacity. King[8] has shown the relationship between waveguide heating and the limitation imposed on the power rating. His paper presents a comparison between the power limitation imposed due to voltage breakdown and the limitation due to temperature rise. He concludes "...the

CW power handling limitation is a function of the temperature rise, rather than the limitation imposed by voltage breakdown." In the same paper, King discusses an additional limitation that is imposed by a VSWR.

2. Dummy loads

Many of the tests of equipment require that they be properly terminated in an appropriate load. As the operating frequency and output power levels of transmitters increase, the problems of heat dissipation and matching become more severe than at the low frequencies.

Two primary problems are associated with loading. First, the loading material must be a good absorber of the incident wave. Its electrical properties must be such that there is little reflection. The reflection of the incident wave is affected by both the composition of the absorber and its configuration.

The other major problem with loads is the difficulty of dissipating the heat that is absorbed by the load. The three states of matter--solids, liquids, and gases--have been suggested and successfully used as energy absorbers. Solids are most frequently used as loads, particularly at the low and medium power levels. Their frequency range extends to 40 Gc and beyond, with their loading capabilities decreasing with increasing frequency. Recent developments with high temperature materials give promise of increasing the power dissipating capabilities of solid loads. Liquids, usually water, may be used as the rf load directly, or as the coolant for solid loads. Loads in which the water directly absorbs the rf energy are presently available. The water load is often equiped with temperature-measuring devices and flow regulators and the device used as a calorimetric wattmeter. Water loads generally are capable of handling high power levels but their disadvantage is the size and complexity of the associated flow system. Gases, such as ammonia,[7] have been used to absorb rf energy. The energy heats the gas. The resultant pressure increase may be calibrated and used as a wattmeter. Ammonia is effective up to 40 Gc. The heat capacity of this method is not known due to incomplete information.

Two approaches are being taken to provide a load which provides proper termination for transmitters in the frequency range and power output levels required of the RFC Accessory Set. First, presently available loads are being examined for the possibility of meeting as much of the requirement as possible. Second, the state-of-the-art in load dissipation devices and techniques is being investigated with the idea of possible extension into the power levels and frequency ranges required. A cross section of commercially available loads is presented in table I. These data are restricted to medium and high power loads.

From a preliminary investigation of the catalogues of several commercial producers of dummy loads it has been observed that loads are available to dissipate 10 kw average in the VHF, UHF, and low microwave frequency ranges. The typical power handling capability at 40 Gc is in the neighborhood of 100 watts.

For convenience, dummy load techniques are divided into five classes: (1) lossy dielectric, (2) water, (3) bonded metal powder, (4) gases, and (5) thin films of metals. There is some overlapping among these classes since the lossy dielectric may be a thin film or even a metal powder. Also the water may be used as a coolant for classes 1, 3, or 5.

a. Lossy dielectric. The lossy dielectric may be carbon or other material having high loss properties. The lossy element is constructed to produce minimum reflections and to minimize the production of "hot spots" in the element.

A limitation to this type of load is the relatively low power handling capability. This is primarily due to the problem of heat removal. Increasing the radiating surface of the load by the addition of fins helps somewhat. Forced air, water, and oil baths also aid in the removal of heat. As the size of the load becomes smaller, as required if used as a waveguide load at the higher microwave frequencies, the power handling capability decreases due to inability to dissipate the heat.

b. Water load. Water loads have been used to dissipate large amounts of rf power. Thus far, such use has been limited to less than 10 Gc in commercially available loads. Water has good loss characteristics in the microwave spectrum as well as desirable thermal characteristics. By providing a continuous flow of water through the loads, large amounts of power in the form of heat can be removed. An accurate wattmeter can be constructed using a water load by providing a known constant water flow and monitoring the temperature change in the water as it passes through the load.

c. Gas load. Ammonia has been used as an rf load[7] with fairly good results in the 10 to 30 Gc range, where the power absorption of ammonia gas is relatively high.

d. Bonded metal powder load. Metal powder bonded by an epoxy material can be used to dissipate large power levels and can be constructed to produce low reflections in the line. One manufacturer* uses this technique to

*Narda Microwave Corporation, Plainview, L. I., New York.

produce loads capable of handling 4500 watts average power at L-band. Hinckelmann et al[9] report the construction of a multimode load capable of dissipating 10 kw average power. The load was constructed of a mixture of powdered iron and epoxy cast in the shape of a 36 inch hollow pyramid. The maximum dominant mode standing-wave-ratio over the 2.7 to 4.0 Gc range was 1.008. At 9.75 Gc, the reflected power was equivalent to a 1.02 standing-wave-ratio.

e. Thin film loads. Studies of thin films of various metals for high temperature resistors have been conducted at the Engineering Experiment Station of Georgia Tech in the past.[10,11] The study by Belser and Hicklin reports data taken on 162 thin films of various metals. This study revealed four metals that had sufficiently low temperature coefficients of resistance to be considered as possible high temperature devices. These four were molybdenum, tantalum, zirconium, and titanium. The resistance versus temperature behavior of titanium is shown in figure 13.

The authors report the results of electrical power dissipation studies and these results are given in the appendix, table II. They further report,

> "The ability of thin film resistors to dissipate electrical power is determined by the melting temperature of the metal used for the resistor element because the agglomeration temperature of the film is related to the melting temperature of the metal. For the metals gold, silver, and platinum it is less than 0.5 K_m (melting point °K). For a given metal, the ambient temperature conditions during the test determine the maximum electrical power dissipation obtainable."

Belser and Robertson[12] followed up the above study with a specific study of high temperature resistors. They also reported four metals with satisfactory TCR's to be considered as high temperature resistors. The four metals fell in the classification of Refractory Metals and included molybdenum, tantalum, rhenium and tungsten. The characteristics of these four are:

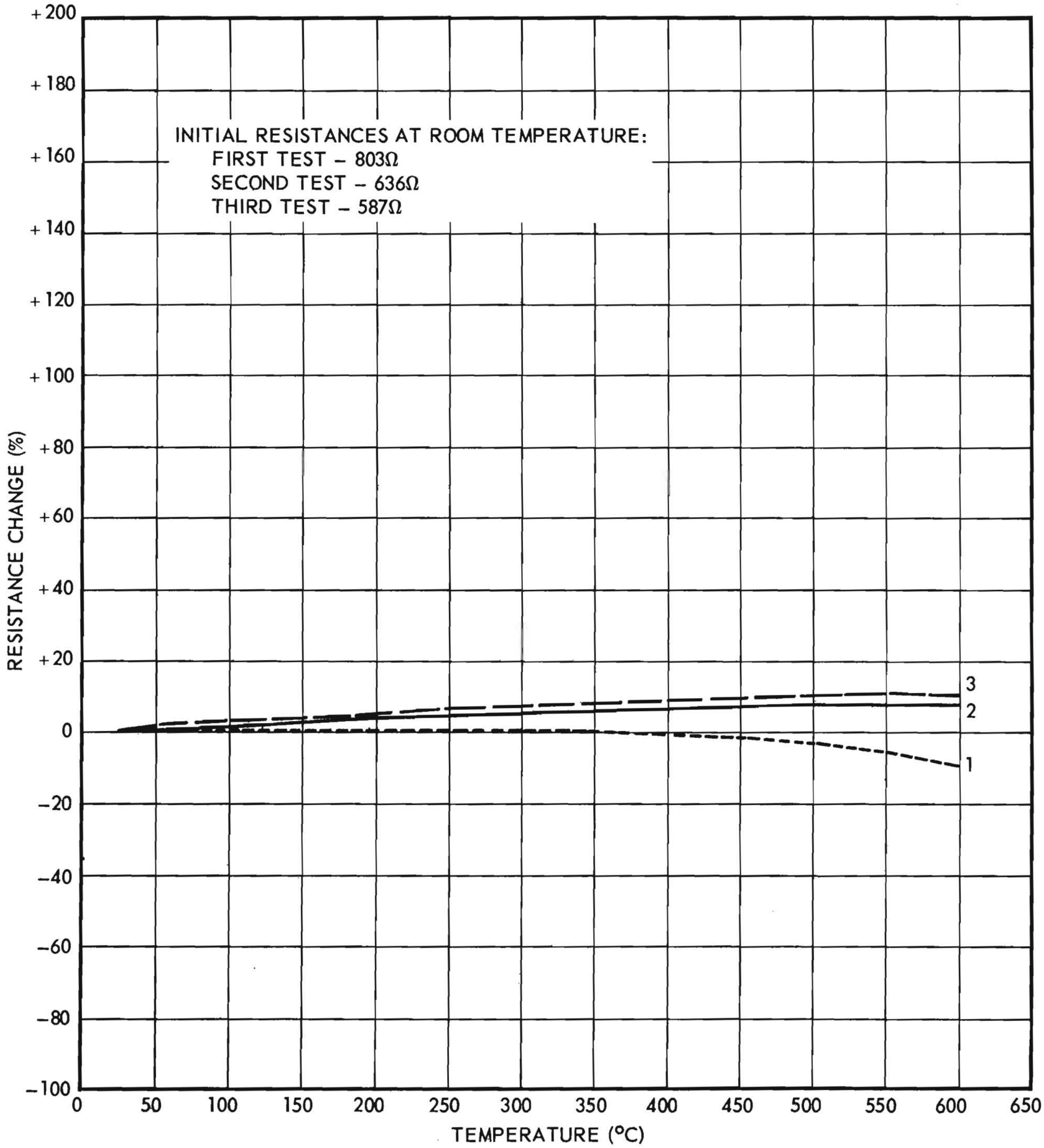


Figure 13. Resistance versus temperature characteristics of titanium film tested in air after coating it with silicon monoxide.[10]

1. Molybdenum melts at 2620 °C and is one of the most common, workable, and economic of the refractory metals. It has one major fault: it forms a highly volatile oxide when heated in air above about 300 °C. TCR values were observed from -0.000010 to +0.000610.

2. Tantalum melts at 3005 °C. It is both ductile and corrosion resistant. The low TCR value of this film, 0.000087, is typical of sputtered films of this metal. Typical behavior of films of this metal is shown in figure 14.

3. Rhenium exhibited TCR values from -0.000160 to +0.000330. When cycled in air, oxidation appeared to occur at a temperature of 300 to 350 °C but several units protected by silicon monoxide overcoats were successfully cycled to 600 °C in air without suffering major damage. Figure 15 shows a typical behavior pattern for this metal.

4. Tungsten exhibited TCR values from +0.000380 to -0.000360. Figure 16 shows a pattern of behavior of tungsten film temperature cycled to 600 °C.

About the power dissipating possibilities of thin films, the authors concluded:

> "Although the amount of data obtained was not large, it is apparent that thin film resistors of sputtered tungsten and rhenium overcoated with evaporated silicon monoxide, are capable of withstanding rather high power dissipations in relationship to their small physical mass.
>
> 'The metals molybdenum, tantalum, rhenium, and tungsten exhibited TCR values largely in the range 0 to 200 ppm/°C with some values less than 10 ppm/°C in either a positive or negative direction. Furthermore, these materials exhibited high stability and high power dissipation abilities up to about 800 °C when properly protected from oxidation."

Feldman and Culver[12] report that they were able to dissipate up to 10.26 watts in a film resistor of about 0.1 in^2 area. Their films were stable up

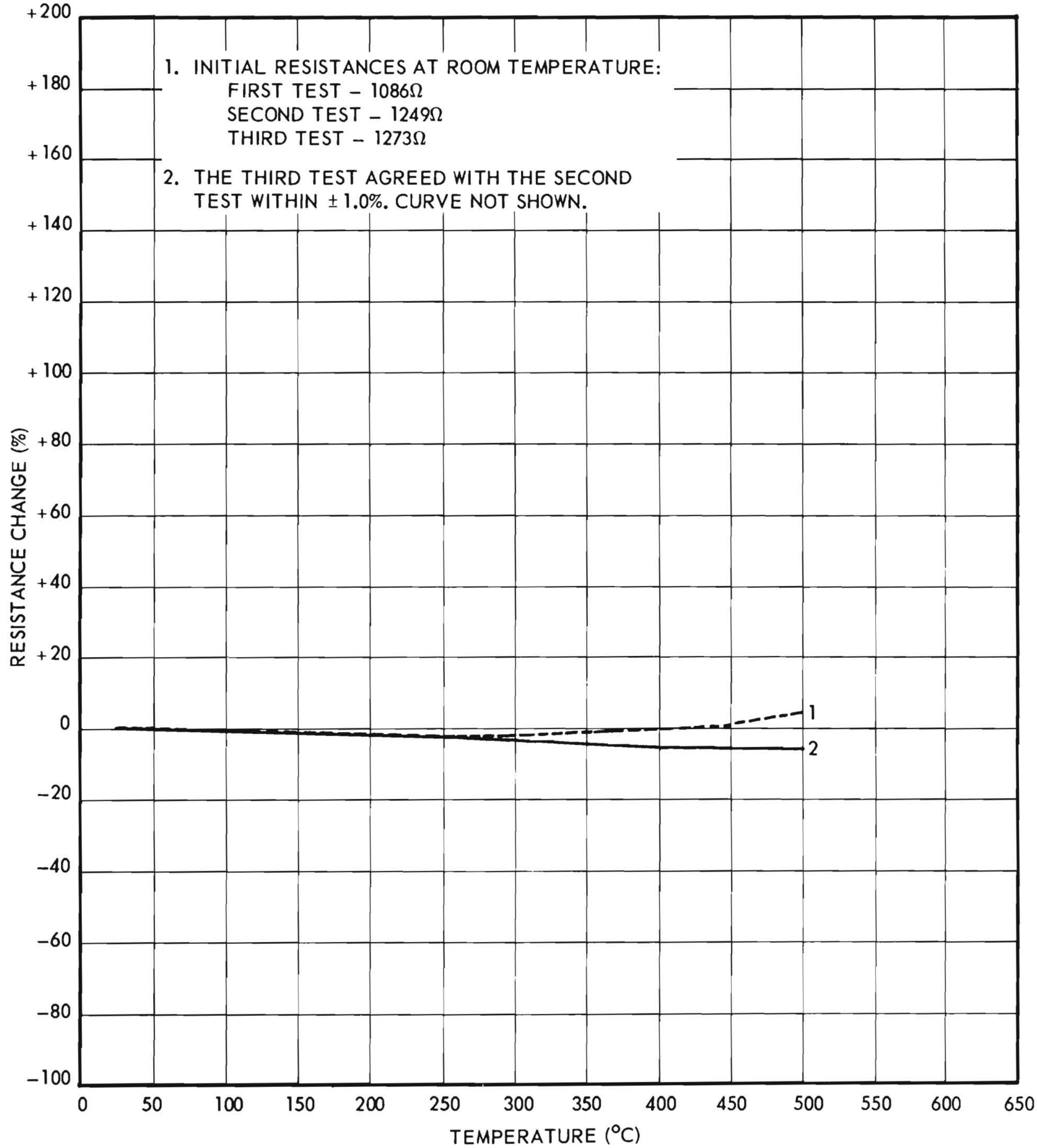


Figure 14. Resistance versus temperature data for a film of sputtered tantalum deposited on a hot (400° C) substrate.[11]

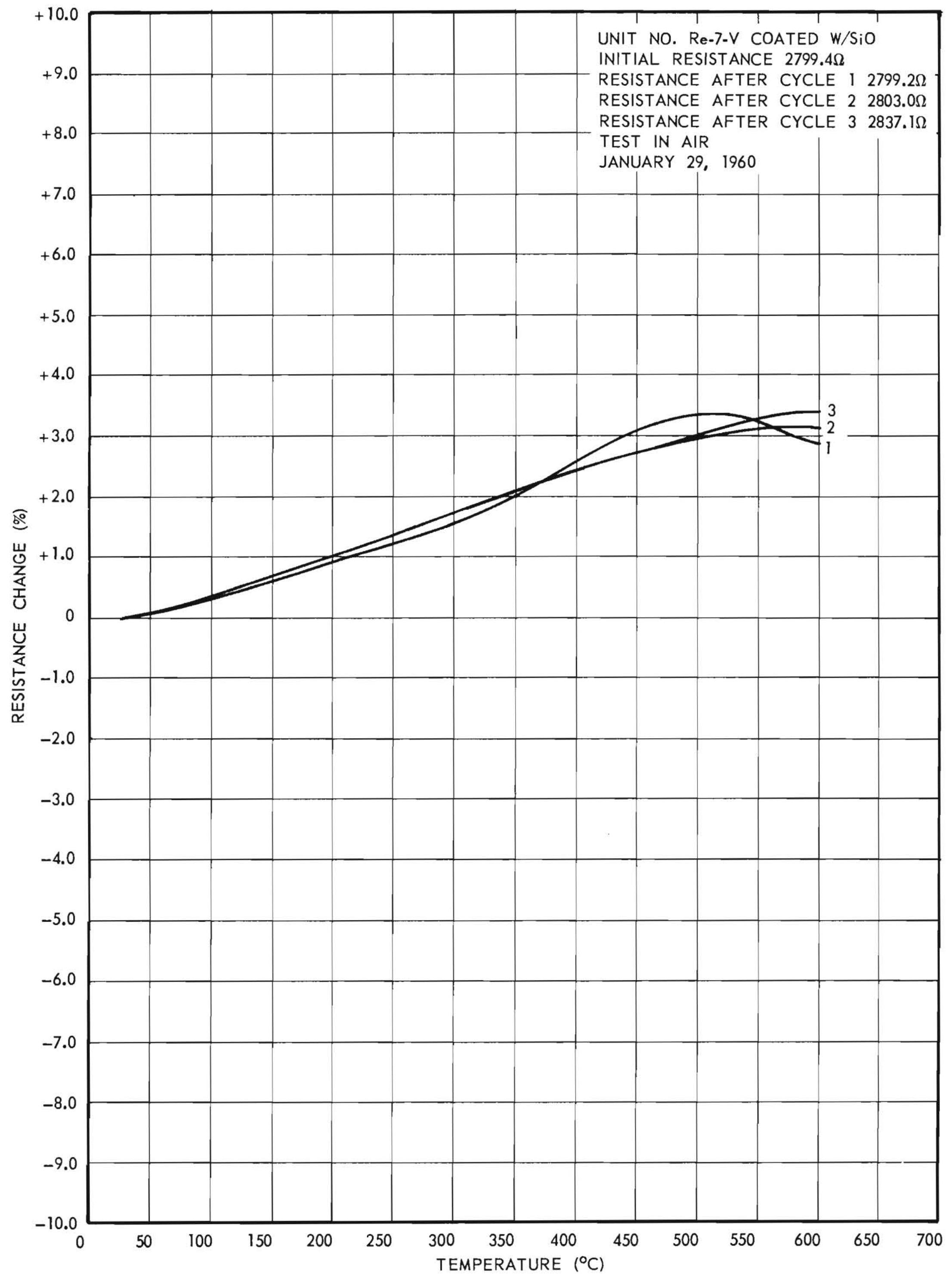


Figure 15. Resistance versus temperature data for a film of sputtered rhenium deposited on a substrate heated initially to 500°C, coated with silicon monoxide and temperature cycled in air.[11]

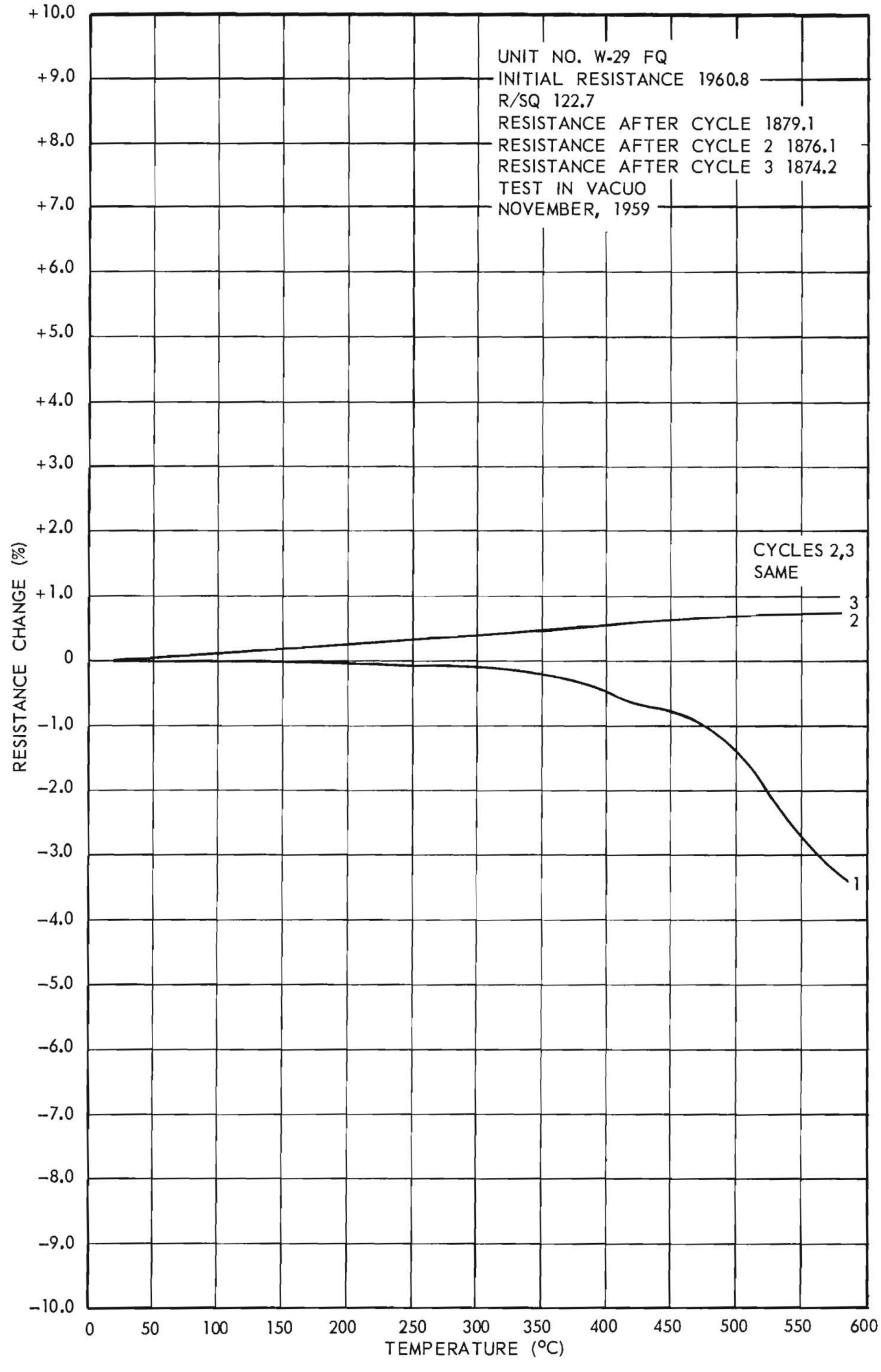


Figure 16. Resistance versus temperature data for a film of sputtered tungsten deposited on a substrate heated initially to 400°C and temperature cycled *in vacuo*.[11]

to 500 °C in a vacuum. They concluded: "The stability outside a vacuum and the power dissipation depend on the type of surface protection."

Either fused quartz or a high temperature glass is normally used as a substrate for the deposited thin films. Neither of these materials are very good conductors of heat. Bohrer et al[13] reported an evaluation of alumina as a substrate and concluded that it had superior heat dissipating capabilities to glass or glass bonded mica.

Most of the power dissipation tests that have been reported have been for films of small areas. The power gradients per area appear encouraging. It is not likely that such gradients would be maintained for larger areas of metal. Additional means for removing heat other than radiation and normal air convection may have to be supplied. The high temperature operating capabilities of the films hold promise of high power loads in a reasonable sized package. Further investigation and possible experimentation will be necessary to develop construction techniques that will minimize reflections and maximize heat dissipation of thin film loads.

3. Sampling networks

Sampling networks are used to provide a representative sample of the signal under test. This representative sample should have the same characteristics as the primary signal. This requirement imposes limitations as to the disturbance that the sampling network may introduce into the primary signal's path. Various types of signal sampling devices are currently available commercially that do produce a representative sample of the primary signal without introducing unnecessary disturbances into its path. The purpose of using a sampling device in testing is to obtain a sample of the signals in the transmitter output and to reduce the power level of the test signal to avoid having excessive power requirements on all the test equipment. A sampling method worthy of consideration is the use of high power attenuators directly in the signal path to reduce the signal to a useable level. Generally, Radio Interference Measuring Sets operate at low levels to enable the detection of as many signals as possible. Therefore, to avoid damage to the instrument and to eliminate the possibility of spurious responses, it is generally necessary to attenuate the fundamental signal.

For the purpose of this Test Set, there are five devices or techniques of sampling the output signal. These are directional couplers, capacitance couplers, magnetic or electric field probes, resistive-type samplers, and high power attenuators.

a. Directional couplers. Directional couplers are generally available commercially to cover the frequency range required of this Test Set above 300 Mc. A few models are available below 300 Mc. They are available in both coaxial and waveguide configurations and can be designed for high power applications. Considerable design work has been done on high powered branch guide directional couplers by Stanford Research Institute.[15]

In addition to not being available at low frequencies, the directional coupler generally is limited in bandwidth. They are available to cover a normal waveguide band. In coaxial configuration, they are generally limited to an octave of frequency coverage. As is true with many other components, this requires the availability of several couplers to cover the required frequency range and requires care in their use to make sure they are not used in an improper frequency range. A group of directional couplers has been used to cover the frequency range of 300 to 10,000 Mc, the higher frequency couplers being left in the signal line with no detrimental effect when measurements were made using other couplers.[6]

Various degrees of coupling can be designed into a directional coupler. The standard values are 3, 6, 10, 20, 40, and 60 db of coupling.

b. Capacitance couplers. A capacity coupler uses capacitance coupling to the main transmission line. Such a device may be fabricated by modifying a coaxial "tee" connector. The insertion loss or coupling is a straight line function of log frequency if the capacitive reactance of the coupling capacitor is large with respect to the terminating impedance. The devices are useful at low frequencies, but have the disadvantage of not having a constant coupling versus frequency.

c. Probes. There are two types of field probes in both coaxial and waveguide configurations. The magnetic or loop probe couples to the magnetic field. The electric or single post probe couples to the electric field. The construction of the probe element must be such that minimum disturbance of the field configuration is caused by the probe.

Probe samplers suffer from two disadvantages: (1) similar to the directional couplers, they are not usable at the low frequencies; (2) their degree of coupling is inversely proportional to frequency. For a relatively wide range of operation a calibration curve is required or the coupling must be measured at the frequency of interest. Probes are commercially available that are adjustable with the maximum coupling being dependent upon the frequency.

d. Resistive-type samplers. Since the directional coupler and field probes are not useful at vhf and lower frequencies and the capacitance coupler has a coupling that is a function of frequency, some type of coupler that has a coupling loss which is not a function of frequency is desirable. An approach to this problem is the design of a resistive-type coupler[6] which is good up to about 300 Mc. The power rating of the resistors used is not excessive. With proper techniques the coupler should be adaptable to the power capability required for this Test Set. The desired degree of coupling can be adjusted by the selection of the resistors used.

General considerations of the maximum power requirements and of the estimated system sensitivity required result in 40 db of coupling being the nominal value that would be most useful. If it is assumed that transmitters normally range from +30 dbm to +70 dbm (1 watt to 10 kw), 40 db of coupling would reduce the maximum power level down to less than +30 dbm. Most components such as attenuators, switches, filters and the like are rated at least at 1 watt power level. Such items would not have to have high power ratings. By being able to use components that have the normal power ratings, the selection of items for the Test Set is simplified. The minimum signal level required to be measured by MIL-I-11748(B) is -64 dbm. This is measured with the transmitter in the stand-by condition, which means the high-powered fundamental does not present any problem. The lowest signal level to be measured with the transmitter operating is -50 dbm or 60 db below the fundamental. These considerations show that the 1 watt maximum operating level after sampling is a reasonable level. The minimum sensitivity of radio interference measuring sets should be at least -70 to -80 dbm. The addition of other required components for filtering, matching, or other purposes should still retain the required system sensitivity.

4. Filters

There are many occasions in interference testing where selective passage or rejection of frequencies is desired. Every test that requires a signal generator to be used has an occasion to use a low-pass filter to filter out the harmonics that the generator produces. The spurious emissions test and the intermodulation test require filters to prevent erroneous responses from occurring. Filters fall into four general classes: low-pass, high-pass, band-pass, and band-reject.

a. Low-pass filters. Low-pass filters are readily available commercially for coaxial applications. They may be obtained with various cutoff frequencies and various degrees of sharpness at cutoff. A characteristic of a typical short line type low-pass filter is that the insertion loss is subject, depending on the filter design, to decreases at frequencies above approximately 6 f_c. The fact that low-pass filters do not necessarily maintain a high insertion loss at frequencies higher than their cutoff frequency must be considered in their application.

b. High-pass filters. High-pass filters are readily available commercially for coaxial applications. Waveguide is inherently a high-pass filter. High-pass filters generally are not as sharp in their cutoff characteristic as are low-pass filters. Coaxial types are characterized by degeneration of the pass-band at about 2 to 3 f_c.

c. Band-pass filters. Fixed-tuned band-pass filters for various frequencies and for varying bandwidths are readily obtainable. For testing purposes, fixed-tuned band-pass filters are not very appropriate. Searching of product catalogues revealed one source* of tunable band-pass filters. These filters are tunable over an octave range. Nine filters are required to cover the range from 500 Mc to 40 Gc. Tunable YIG filters are becoming available in the region above 1 Gc.

d. Band-reject filters. In some of the tests to be performed by this Test Set, it is particularly desirable to attenuate a specific frequency or a band of frequencies. By attenuating a specific frequency, the effective sensitivity of the system is increased to measure other interference-producing signals that are nearby. A set of coaxial tunable rejection filters have been designed and built[14] to cover the range from 14 kc to 1 kMc. Seventeen of these filters are required since each one covers approximately an octave range. A few tunable rejection filters above 1,000 Mc have been found available commercially. Voltage tunable YIG filters offer attractive characteristics in the microwave region.

So-called "waffle-iron" filters have been designed[15] that can cover varying bandwidths. In this same reference, a rejection filter that covered a band from 2 to 10 Gc was described. The "waffle-iron" filter is capable of high powered applications and can be used to attenuate transmitter harmonics and other spurious outputs above the fundamental.

5. Switches

Additional items are needed to complete the selection of test accessories. To facilitate rapid measurements, switches are necessary to minimize

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*Frequency Engineering Laboratories, Asbury Park, New Jersey.

the time spent in connecting and disconnecting cables and test equipment. Switches will be needed if an integrated combination of accessories are assembled in a relatively fixed setup. Current literature from manufacturers indicates that there should be no problem in obtaining adequate switches to perform any required function. Coaxial switches are available that cover from direct current to about 12 kMc. Waveguide switches normally cover the waveguide band. Mechanical, electrical, and electro-mechanical switching is available.

6. Attenuators

A very important item that has not been relegated to secondary importance is attenuators. Various types of attenuators are available encompassing fixed and variable operation. At least two attenuators are needed to cover the range from direct current to 12 kMc in coaxial attenuators. In waveguide configurations, both fixed and variable attenuators are available. These attenuators normally cover a waveguide bandwidth in frequency. Most attenuators are relatively low powered.

7. Receiver input coupler

The requirements for the receiver input coupler which specify that the input VSWR be less than 1.3:1 when the output VSWR is not greater than 3:1 can be met by the insertion of a 6 db pad in the transmission line at the input of the receiver. Many commercially available attenuators are available for 50 ohms or waveguide systems which will meet this requirement. To date, no 300 ohm commercial attenuators have been located. A 300 ohm attenuator and matching pads to a 50 ohm system for test purposes was constructed using small values of regular carbon resistors with the expected result that it was not suitable for operation to 400 Mc. Inquires are being made as to the availability of more suitable resistors for this application. The mechanical configuration of the attenuator is under consideration.

8. Audio susceptibility tester and amplifier

An audio susceptibility tester and audio amplifier are being investigated. The audio susceptibility tester is required to deliver 3 volts rms open circuit voltage into the power line of the equipment under test. It must handle line currents up to 50 amperes and have no more than 5 per cent of the supply voltage drop across the line winding of the transformer. Response shall be 50 to 15,000 cps with no more than 5 per cent distortion.

Investigation is underway on both the audio amplifier and coupling transformer. Although it is only required that the tester deliver an open circuit voltage of 3 volts rms, it seems desirable that this voltage should be developed across some impedance which might approximate the actual load seen by the transformer during operation. An approximate load impedance can be arrived at by assuming that the line impedance is zero and that the minimum impedance of the equipment under test is that which applies for the lowest voltage system at the highest operating current. For this situation with a supply voltage of 24 volts and a load current of 50 amperes, the minimum load impedance will be approximately 1/2 ohm. To deliver 3 volts rms across a resistive 1/2 ohm load, the tester must deliver a minimum of 18 watts. Any line impedance greater than zero will reduce the power required to deliver the voltage. Investigation of line impedance characteristics is being pursued to determine the possibilities of resonance effects between equipment and line impedances which could result in high voltages in the circuit.

A transistorized audio amplifier with an extremely low output impedance is being experimentally evaluated. It is hoped that its output impedance will be only a fraction of an ohm so that the turns ratio in the coupling transformer will be low. From another consideration, if the amplifier can be made to drive a transformer with a secondary self-inductance low enough, the amplifier output impedance will not be depended on for the low line impedance. The design details of an isolation transformer with similar characteristics are being studied.[16]

9. Microwave frequency deviation detector

In the development of a Design Plan for the RFC Accessory Test Set, all accessory devices must be considered. Signal generators and Radio Interference Measuring Sets are specifically excluded from the Accessory Set. Devices for monitoring the output of the equipment under test should be considered. Distortion analyzers which can be used to monitor the output of a receiver are generally available on the commercial market. Frequency modulation monitors are available for monitoring transmitter output up through the vhf regions, but at microwave frequencies this type modulation monitor is not readily available. These monitors are required because many of the tests required by MIL-I-11748B specify that the output of a transmitter be monitored to detect any disturbances in its operation due to interfering signals. In addition other tests require that the output of a transmitter be deviated a specified amount and be monitored.

Above the region where modulation monitors are available, the principal method has been the "zero-count" using a spectrum analyzer. This method becomes inaccurate because of the resolution capabilities of most spectrum analyzers, and it is time consuming in that new computations must be made for each value of modulation produced or required and for each different modulating frequency.

In an effort to improve the technique of measurement of frequency deviation and improve the accuracy of frequency deviation detection, a system has been designed and construction of some of the components has been completed. Evaluation of the components has begun.

The system uses the principle of frequency compression demodulation. Ruthroff and Bodtmann[17] applied the principle in the very high frequency range.

The block diagram of the detector is shown in figure 17. This system is designed with RFI testing in mind and assumes that signal generators near the frequency of the transmitter are available for use.

The oscillator is designed to operate at a convenient frequency near 100 Mc. The band-pass amplifier is centered at 60 Mc. The difference frequency from the first mixer with the oscillator output signal produces the 60 Mc intermediate frequency in the second mixer. The output of the discriminator is amplified by the low-pass amplifier and changes the oscillator frequency to produce a minimum output at the discriminator. The meter reads rectified output of the low-pass amplifier. The amplitude of this signal is proportional to the deviation of the transmitter output signal. The bandwidths required by the 60 Mc intermediate frequency and the low-pass amplifiers are determined by the modulating frequency of the transmitter.

The Hartley oscillator shown in figure 18 was constructed with part of the tank capacitance provided by a voltage variable silicon capacitor. The oscillator demonstrated a region of fairly linear operation between 4 and 7 volts of control voltage. The free running stability of the oscillator was better than $1:10^4$.

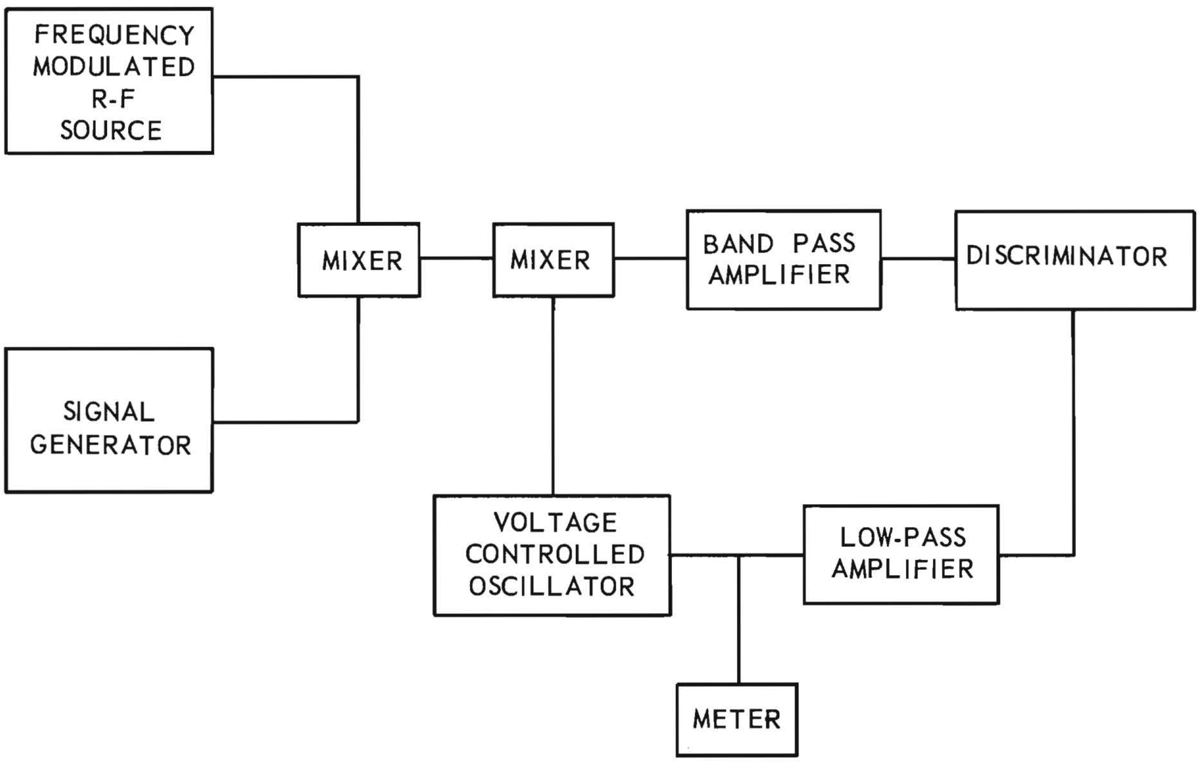
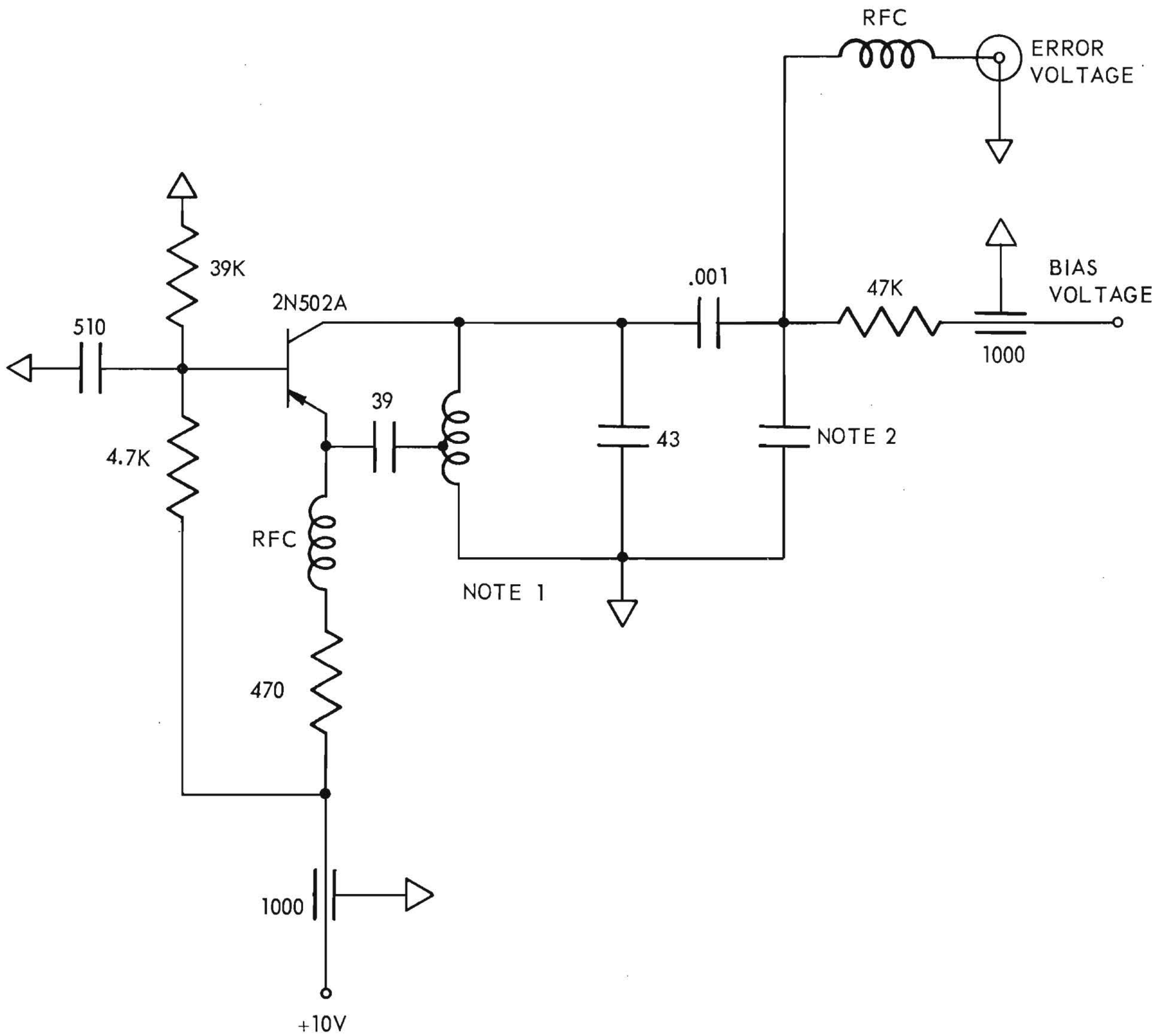


Figure 17. Block diagram of frequency deviation detector.



NOTE 1: Tank Coil Dimensions. Two turns, No 20 AWG. 1/4" ID, 1/4" Long. Tapped 1:1 turns Ratio.

NOTE 2. Pacific Semiconductors V12 Standard Varicap.

NOTE 3. All capacitance values in picofarads and all resistance values in ohms.

Figure 18. Schematic diagram of voltage-controlled oscillator.

Future plans include the construction of the discriminator and testing of the system using available amplifiers and mixers.

10. Collection of data on accessory equipment

A large volume of data has been collected on commercially available accessory equipment such as filters, directional couplers, dummy loads, attenuators, waveguide components, etc. In addition to the direct communication by letter with manufacturers of such equipment, the applicable sections of the Directory of Technical Specifications published by the Technical Information Corporation* have been obtained.

*Technical Information Corporation, 260 Glen Head Road, Glen Head, L. I., New York.

V. CONCLUSIONS

Investigation of the measurements required by military specification MIL-I-11748 was started and test setups indicating the basic accessory equipment were outlined. It will be necessary to continue this investigation and to make refinements as progress is made.

Accessory equipment availability has been studied so that a knowledge of items of accessory equipment available commercially will be at hand. Reference will be made to this information when equipment is needed. This study shows that many of the accessory items are available commercially.

Further research is required on materials and construction techniques to produce a small size thin film dummy load. Certain refractory metals show promise as high temperature materials which could be used as a thin film load.

Further investigation of tunable rejection filters will be required to meet the needs of the Design Plan. Low frequency rejection filters will be studied and evaluated. YIG filters offer attractive characteristics at the higher frequencies.

The audio susceptibility tester amplifier shows promise of providing a low output impedance and should, therefore, provide a low series impedance in the line so that line voltage drop can be kept a minimum.

VI. PROGRAM FOR NEXT INTERVAL

During the next quarter work on the outline of tests required will continue. Methods of combining the various test setups into an integral system will begin.

Work on the audio susceptibility amplifier and transformer will continue, as will work on the receiver input coupler and frequency deviation detector.

Consideration of the problem of the measurement of spurious and harmonic emissions in waveguide systems will begin. Review will be made of the various techniques for making these measurement found in the literature.

Possible improvement of line stabilization networks will be studied.

VII. IDENTIFICATION OF KEY TECHNICAL PERSONNEL

Name	Title	Approximate Hours
Hugh W. Denny	Research Assistant	391
Neil T. Huddleston	Graduate Research Assistant	160
D. W. Robertson	Head, Communications Branch	82
Joseph R. Walsh, Jr.	Project Director	364
W. Bruce Warren	Research Engineer	48
E. Wendell Wood	Assistant Research Engineer	65

The background and qualifications of these men are presented in the following paragraphs.

Mr. Denny joined the project shortly after it was initiated in April 1963. He received a B.E.E. degree from Tennessee Polytechnic Institute in 1960 and is presently working toward an M.S. degree in the same field at the Georgia Institute of Technology. His previous experience includes work in design, construction, and testing of transistorized, crystal controlled, vhf oscillators. As an Army Officer, he served as a Wire Communications Officer with a combat area Signal Batallion in Texas and Germany. While at Florida Power and Light Company, he worked in the System Control Division in the planning of load control systems and in the Relay Division.

Mr. Huddleston joined the project on June 24, 1963. He received his B.E.E. degree from Tennessee Polytechnic Institute in 1963 and is presently working toward an M.S. degree in the same field at Georgia Tech.

Mr. Robertson is Head of the Communications Branch. He has been associated with the Georgia Institute of Technology since 1947. He received a B.S. degree in E.E. in 1950 and a M.S. degree in the same field in 1957. From 1941 to 1947, he was employed by Civil Service where his work included maintenance and installation of airborne radio and radar equipments. At Georgia Tech, he has been a staff member and director of various projects.

Mr. Walsh assumed duties as Project Director when the project began in April 1963. He received a B.E.E. from the Georgia Institute of Technology in 1949 and an M.S. in the same field in 1961. His previous experience includes work with Westinghouse Electric Corporation in electronic design and with the Civil Aeronautics Administration where he installed and tested VOR and ILS navigation systems. At Georgia Tech, he was an assistant director of a project to design and construct a radar system for studying characteristics of ground clutter and target return, and was concerned with applications of these results in an experimental radar system. He has been associated with the design and development of electronic circuitry of a radar system for study of the polarization and statistical properties of sea return, and with field operation of this equipment. He has been connected with several projects concerned with radio frequency interference.

Mr. Warren received a B.E.E. degree from the Georgia Institute of Technology in 1953, and an M.S. degree in the same field in 1955. He was first associated with Georgia Tech from 1953 to 1957 doing electronic design work in the fields of radar and communications. He was later associated with Bell Telephone Laboratories working on missile guidance systems. After his return to Georgia Tech, he has been associated with communication systems and radio frequency interference. He is the holder of several patents in the electronics field.

Mr. Wood received a B.E.E. degree from the Georgia Institute of Technology in 1960 and a M.S.E.E. degree in June 1963. His previous experience includes

3 years with the Federal Communications Commission at the Atlanta Field Office where he worked with radio interference cases; 15 months as a Test Assistant for the Georgia Power Company; 2 years as a Radio Engineer with an Atlanta broadcasting company; and 2 years as a radio and TV technician in Thomas County, Georgia.

Respectfully submitted:

J. R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

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IX. APPENDIX

TABLE I

SOME COMMERCIALLY AVAILABLE MEDIUM AND HIGH POWER DUMMY LOADS

Frequency (mc)	Power Avg (kw)	Power Peak (Mw)	Impedance (ohms)	Type*	VSWR	Absorber	Cooling method	Source
0-30	10	----	60	c	1.1	Deposited carbon resistor	Forced air	Rohde & Schwarz Type RBN 10/60
0-220	25	----	50	3-1/8" c	1.1	Cylindrical film resistor	Water	Bird Model 5025
0-220	50	----	50	6-1/8" c	1.1	Cylindrical film resistor	Water	Bird Model 8903
0-1000	10	----	51.5	3-1/8" c	1.2	Oil filled resistor	Forced air	Electro-Impulse Type CPTA 10,000
0-1000	10	----	51.5	3-1/8" c	1.2	Oil filled resistor	Water	Electro-Impulse Type CPTL 10 K
0-1000	16	----	50	c	1.05 (up to 800 mc)	----	----	Rohde & Schwarz Type RD 10/50
0-5000	0.5	0.5	50	c	1.3	----	Fins	WacLine Model DS-58
400-450	4	2.0	----	3-1/8" c	1.1	----	500 ft^3/min air flow	Diamond Model HPL1-1
470-1200	15	2	50	3-1/8" c	1.15	Water	Water	Varian V-4042
470-2300	10	----	50	c	1.05	----	----	Rohde & Schwarz RC 10/50
1000-10,000	0.35	----	----	c	1.2	Molded dielectric	Fins	Douglas Model 189 B

(Continued)

*c--coaxial
w--waveguide

TABLE I (Continued)

SOME COMMERCIALLY AVAILABLE MEDIUM AND HIGH POWER DUMMY LOADS

Frequency (mc)	Power Avg (kw)	Power Peak (Mw)	Impedance (ohms)	Type*	VSWR	Absorber	Cooling method	Source
1,120-1,700	0.75	----	----	7/8" c	1.15	Molded dielectric	Fins	Douglas Model 193 L
1,120-1,700	0.75	0.75	----	1-5/8" c	1.2	Molded dielectric	Fins	Douglas Model 194 L
1,120-1,700	2	----	----	w	1.15	High-low material used for waveguide walls	Fins	Electro-Impulse
1,120-1,700	6	----	----	w	1.1	Molded dielectric	Fins	Douglas Model 202L-HP
1,120-1,700	8	2.2	----	w	1.15	Silicon carbide	Can be modified for liquid cooling	Airtron Model 890374
1,150-1,750	1.5	----	----	w	1.15	Double walled, fiber glass probe filled with coolant	Glycol solution	WacLine Model DS-59
1,700-2,600	1.5	----	----	w	1.15	High-loss material used for waveguide walls	Fins	Electro-Impulse
1,700-2,600	3	----	----	w	1.1	Molded dielectric	Fins	Douglas Model 202M-HP

(Continued)

*c--coaxial
w--waveguide

TABLE I (Continued)

SOME COMMERCIALLY AVAILABLE MEDIUM AND HIGH POWER DUMMY LOADS

Frequency (mc)	Power Avg (kw)	Power Peak (Mw)	Impedance (ohms)	Type*	VSWR	Absorber	Cooling method	Source
1,700-2,600	12	----	----	w	1.15	Water	Water	Varian V-4041
1,700-2,600	20	2.0	----	w	1.1	Water	Water	Sierra Model 187B-SL
2,600-3,100	0.45	----	----	7/8" c	1.15	Molded dielectric	Fins	Douglas Model 193 S
2,600-3,950	1.5	2.2	----	w	1.15	Molded dielectric	Fins	WacLine Model D-18
2,600-3,950	2	----	----	w	1.1	Molded dielectric	Fins	Douglas Model 202S-HP
2,600-3,950	2.5	----	----	w	1.15	High-loss material used for waveguide walls	Fins	Electro-Impulse
2,600-3,950	4.5	3.2	----	w	1.15	Silicon carbide	Can be modified for liquid cooling	Airtron Model 890375
2,600-3,950	5	2.0	----	w	1.08	Silicon carbide	Fins	DeMornay-Bonardi Model DBL-461
2,600-3,950	20	3.0	----	w	1.08	Silicon carbide	Water	DeMornay-Bonardi Model DBL-462
2,600-4,000	10	1.0	----	w	1.1	Water	Water	Sierra Model 187B-S

(Continued)

*c--coaxial
w--waveguide

TABLE I (Continued)

Frequency (mc)	Power Avg (kw)	Power Peak (Mw)	Impedance (ohms)	Type*	VSWR	Absorber	Cooling method	Source
2,800-4,800	30	3	----	w	1.15	Water	Water	Varian V-4045
3,950-5,850	0.8	----	----	w	1.15	High-loss material used for waveguide walls	Fins	Electro-Impulse
3,950-5,850	1	1.4	----	w	1.15	Molded dielectric	Fins	WacLine Model D-19
3,950-5,850	1.5	----	----	w	1.1	Molded dielectric	Fins	Douglas Model 202C-HP
3,950-5,850	2	2.0	----	w	1.15	Silicon carbide	Can be modified for liquid cooling	Airtron Model 890376
3,950-5,850	3	1.2	----	w	1.08	Silicon carbide	Fins	DeMornay-Bonardi Model DBK-461
3,950-5,850	14	2.0	----	w	1.08	Silicon carbide	Water	DeMornay-Bonardi Model DBK-462
4,000-5,800	5	0.75	----	w	1.1	Water	Water	Sierra Model 187
4,000-6,000	8	2	----	w	1.5	Water	Water	Varian V-4023B
4,800-7,500	8	2	----	w	1.5	Water	Water	Varian V-4023A

(Continued)

*c--coaxial
w--waveguide

TABLE I (Continued)

SOME COMMERCIALLY AVAILABLE MEDIUM AND HIGH POWER DUMMY LOADS

Frequency (mc)	Power Avg (kw)	Power Peak (Mw)	Impedance (ohms)	Type*	VSWR	Absorber	Cooling method	Source
5,850-8,200	0.3	----	----	w	1.15	High-loss material used for waveguide walls	Fins	Electro-Impulse
5,850-8,200	0.42	0.56	----	w	1.15	Molded dielectric	Fins	WacLine Model D-20
5,850-8,200	0.85	----	----	w	1.1	Molded dielectric	Fins	Douglas Model 202A-HP
5,850-8,200	1	0.71	----	w	1.15	Silicon carbide	Can be modified for liquid cooling	Airtron Model 890377
5,850-8,200	2	0.6	----	w	1.08	Silicon carbide	Fins	DeMornay-Bonardi Model DBJ-461
5,800-8,200	5	0.50	----	w	1.1	Water	Water	Sierra Model 187B-C
5,850-8,200	5.6	1.0	----	w	1.08	Silicon carbide	Water	DeMornay-Bonardi Model DBJ-462
7,000-10,000	0.45	----	----	w	1.15	High-loss material used for waveguide walls	Fins	Electro-Impulse
7,000-10,000	3	0.25	----	w	1.1	Water	Water	Sierra Model 187B-XB

(Continued)

*c--coaxial
w--waveguide

TABLE I (Continued)

SOME COMMERCIALLY AVAILABLE MEDIUM AND HIGH POWER DUMMY LOADS

Frequency (mc)	Power Avg (kw)	Power Peak (Mw)	Impedance (ohms)	Type*	VSWR	Absorber	Cooling method	Source
7,000-10,200	30	0.5	----	w	1.10	Water	Water	Varian V-4045D
7,050-10,000	0.3	0.35	----	w	1.15	Molded dielectric	Fins	WacLine Model D-21
7,050-10,000	0.6	0.46	----	w	1.15	Silicon carbide	Can be modified for liquid cooling	Airtron Model 890378
7,050-10,000	0.75	0.4	----	w	1.08	Silicon carbide	Fins	DeMornay-Bonardi Model DBH-461
7,050-10,000	0.75	----	----	w	1.1	Molded dielectric	Fins	Douglas Model 202B-HP
7,050-10,000	3.5	0.5	----	w	1.08	Silicon carbide	Water	DeMornay-Bonardi Model DBH-462
7,100-10,200	5	0.5	----	w	1.15	Water	Water	Varian V-4022B
7,100-12,400	5	0.3	----	w	1.15	Water	Water	Varian V-4022C
8,200-12,000	0.25	----	----	w	1.15	High-loss material used for waveguide walls	Fins	Electro-Impulse
8,200-12,400	0.175	0.20	----	w	1.15	Molded dielectric	Fins	WacLine Model D-22

(Continued)

*c--coaxial
w--waveguide

TABLE I (Continued)

SOME COMMERCIALLY AVAILABLE MEDIUM AND HIGH POWER DUMMY LOADS

Frequency (mc)	Power Avg (kw)	Power Peak (Mw)	Impedance (ohms)	Type*	VSWR	Absorber	Cooling method	Source
8,200-12,400	0.5	0.29	----	w	1.15	Silicon carbide	Can be modified for liquid cooling	Airtron Model 890379
8,200-12,400	0.6	0.3	----	w	1.08	Silicon carbide	Fins	DeMornay-Bonardi Model DBG-461
8,200-12,400	0.6	----	----	w	1.1	Molded dielectric	Fins	Douglas Model 202X-HP
8,200-12,400	2	0.15	----	w	1.1	Water	Water	Sierra Model 187B-X
8,200-12,400	2	0.3	----	w	1.08	Silicon carbide	Water	DeMornay-Bonardi Model DBG-462
10,000-15,000	0.3	0.15	----	w	1.08	Silicon carbide	Fins	DeMornay-Bonardi Model DBFA-461
12,400-18,000	0.125	0.12	----	w	1.15	Molded dielectric	Fins	WacLine Model D-23
12,400-18,000	0.25	0.16	----	w	1.15	Silicon carbide	Can be modified for liquid cooling	Airtron Model 890380
12,400-18,000	0.275	0.2	----	w	1.08	Silicon carbide	Fins	DeMornay-Bonardi Model DBF-461
12,400-18,000	0.4	----	----	w	1.1	Molded dielectric	Fins	Douglas Model 202G-HP

(Continued)

*c--coaxial
w--waveguide

TABLE I (Concluded)

SOME COMMERCIALLY AVAILABLE MEDIUM AND HIGH POWER DUMMY LOADS

Frequency (mc)	Power		Impedance (ohms)	Type*	VSWR	Absorber	Cooling method	Source
	Avg (kw)	Peak (Mw)						
18,000-26,500	0.05	0.043	----	w	1.15	Molded dielectric	Fins	WacLine Model D-24
18,000-26,500	0.15	0.125	----	w	1.15	Silicon carbide	Can be modified for liquid cooling	Airtron Model 890381
18,000-26,500	0.15	0.1	----	w	1.08	Silicon carbide	Fins	DeMornay-Bonardi Model DBE-461
18,000-26,500	0.25	----	----	w	1.1	Molded dielectric	Fins	Douglas Model 202K-HP
26,500-39,500	0.035	0.022	----	w	1.15	Molded dielectric	Fins	WacLine Model D-25
26,500-40,000	0.075	0.05	----	w	1.08	Silicon carbide	Fins	DeMornay-Bonardi Model DBD-461
26,500-40,000	0.075	0.1	----	w	1.15	Silicon carbide	Can be modified for liquid cooling	Airtron Model 890382
26,500-40,000	0.1	----	----	w	1.1	Molded dielectric	Fins	Douglas Model 202T-HP

*c--coaxial
w--waveguide

TABLE II

COMPARISON OF POWER DISSIPATED BY FILMS OF VARIOUS METALS*[10]

Metal Film	Melting Temperature of Metal (°C)	Resistance of Film (Ω/SQ)	Power Dissipation (watts)	Atmosphere	Ambient Temperature (°C)	Remarks
Au	1063	3.5	0.20	Air	600	Film failed
Au-Pt	----	57.8	0.26	Air	600	Film failed
Au-Pt	----	15.3	2.9	Air	600	Film failed
Cr	1550	30.5	2.6	Air	600	Film failed
Zr	1830	156.0	2.4	Air	450	Film failed (SiO coated)
Zr	1830	94.2	5.4	Air	450	Film failed (SiO coated)
Rh	1966	11.9	4.03	Vacuum	100	End bonds failed
Pt-Ir	----	41.8	11.2	Air	25	Film failed
Ir	2454	24.4	7.5	Air	25	End bonds failed
Mo	2622	99.0	10.0	Argon	600	Resistance decreased 66 per cent
Mo	2622	38.8	9.2	Argon	600	Resistance decreased 41.7 per cent
Mo	2622	20.4	17.25	Argon	600	Film failed

*All elements were of similar areas but differed in thicknesses. The thickness of a specific metal film may be roughly estimated from resistance per square values.

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QUARTERLY REPORT NO. 2

PROJECT A-693

RADIO FREQUENCY COMPATIBILITY (RFC) ACCESSORY EQUIPMENT SET (U)

H. W. DENNY AND J. R. WALSH, JR.

CONTRACT NO. DA 36-039 AMC-02223(E)
DEPARTMENT OF THE ARMY PROJECT: 1G620501D449

Placed by the
U. S. Army Electronics Research
and Development Laboratories
Fort Monmouth, New Jersey

15 July 1963 to 15 October 1963

1963

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

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DEPARTMENT OF THE ARMY PROJECT: 1G620501D449

SIGNAL CORPS TECHNICAL REQUIREMENT
SCL-7687, dtd. 28 Sept. 1962

The object of this research is to prepare a Design Plan for a Radio Frequency Compatibility Accessory Set.

15 JULY 1963 to 15 OCTOBER 1963

PLACED BY THE U. S. ARMY
ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORIES
FORT MONMOUTH, NEW JERSEY

FOREWORD

This report was prepared at the Georgia Tech Engineering Experiment Station on Contract No. DA 36-039 AMC-02223(E). The report covers the activity and results of the second quarter's effort on a study project leading to the establishment of a Design Plan for accessory equipments to be used with Radio Interference Measuring Sets.

Respectfully Submitted:

W. R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

TABLE OF CONTENTS

This report contains 38 pages.

LIST OF FIGURES

LIST OF TABLES

I. PURPOSE

The purpose of this project is to conduct a study leading to a Design Plan for accessory equipment to be used with Radio Interference Measuring Sets and signal generators. The accessory equipment includes the complementary devices necessary to determine radio frequency interference characteristics of U. S. Army electrical and electronic equipment in accordance with military specification MIL-I-11748. The frequency range of interest is 0.014 to 40,000 Mc. It is also the purpose of the project to investigate two items of equipment. These are a receiver input coupler and an audio susceptibility tester.

The areas of investigation on this project are divided into three tasks as follows:

I. Evaluation of state-of-the-art items and techniques from the viewpoint of modifying or extending them to fill the Design Plan requirements.

II. Investigation of new techniques and materials when the Design Plan requirements cannot be met by state-of-the-art items or techniques.

III. Verification of findings and conclusions by experimental work when necessary.

II. ABSTRACT

Consolidation of as many of the various test setups for performing the various measurements specified in military specification MIL-I-11748B into as few basic setups as possible is considered. Some differences applying to waveguide systems are noted.

Work on a thin film dummy load in a coaxial configuration was started. A taper section for this load was electroformed.

Work on the audio susceptibility tester continued with consideration given to both the amplifier and transformer. A receiver input coupler was constructed and preliminary results are shown.

A discussion of the various techniques presented in the literature for the measurement of spurious and harmonic emissions in waveguide systems is presented.

A method for determining the maximum VSWR that can be expected from the connection of a group of components with given VSWR's is described.

III. PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

Discussions of project technical and contractual details were held at Georgia Tech, 16-18 July 1963, with Mr. Sidney Weitz and Mr. R. L. McKenzie of USAELRDL.

A visit was made 30 July 1963 by Mr. Warren Kesselman of USAELRDL and Mr. I. N. Mindel, Mr. J. T. Ludwig, and Mr. Martin Sherman of IIT Research Institute to Georgia Tech and a discussion of nonlinear effects in dummy loads was held.

IV. FACTUAL DATA

A. Design plan

During the first quarter, work on the Design Plan was limited to an examination of the various test setups and a survey of accessory items necessary to implement the test setups. During the second quarter effort was devoted to consolidating as many of the tests into as few basic setups as possible in order to reduce the number of equipment changes to a minimum when going from one test to another.

The test equipment setups as presented in Quarterly Report No. 1 apply primarily to coaxial systems. Minor differences appear in the waveguide setups.

An analysis of the test setups revealed that they could be conveniently classified as follows:

1. Power line tests
    a. Line conducted emissions
    b. Line conducted susceptibility
2. Susceptibility tests
    a. Antenna conducted susceptibility
    b. Radiated susceptibility
    c. Receiver intermodulation
3. Emissions tests
    a. Antenna conducted emissions
    b. Transmitter intermodulation
    c. Case and cable radiation

Figure 1 shows a possible test setup that would enable both power line conducted emissions and power line conducted susceptibility tests to be run

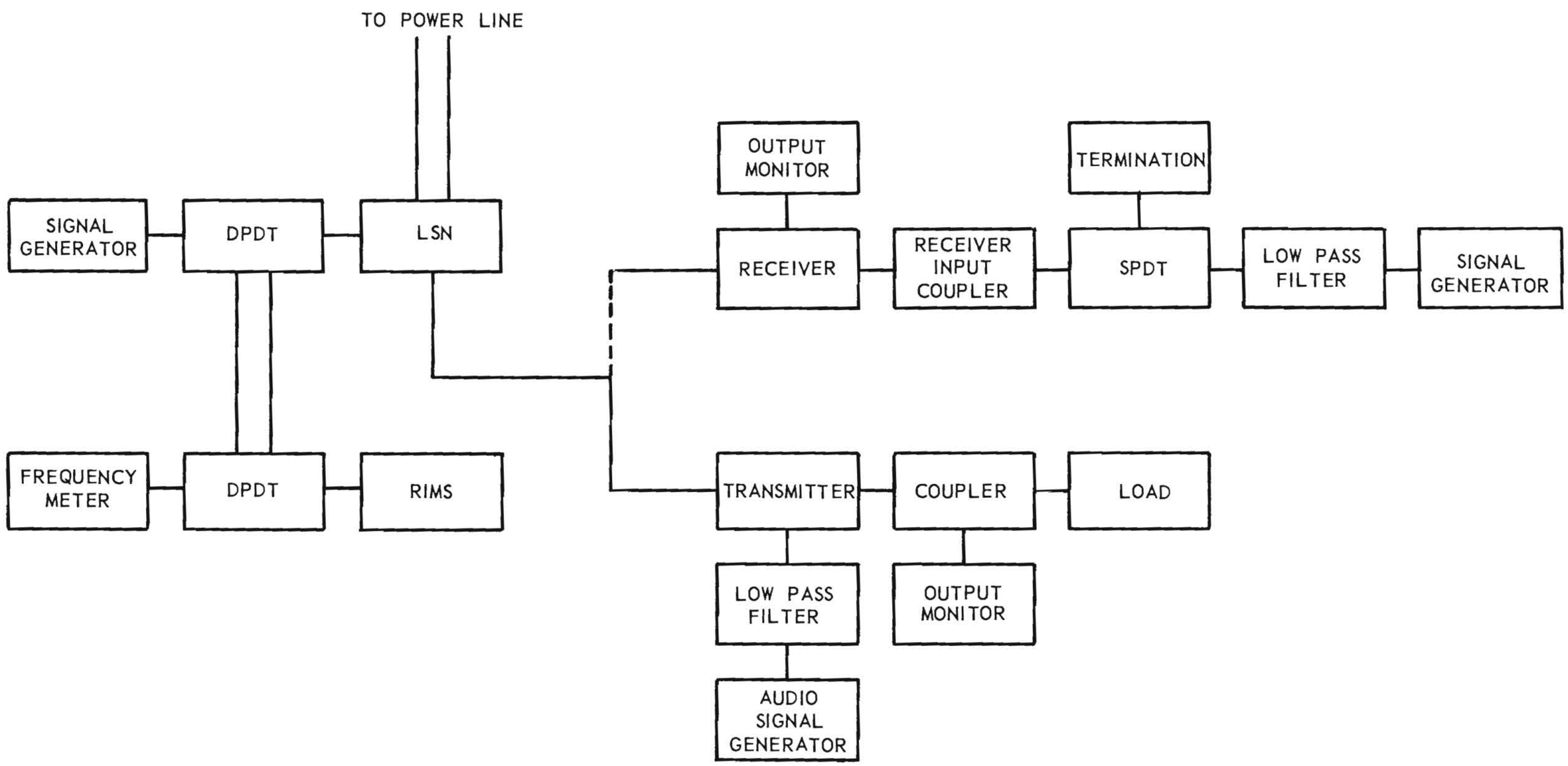

Figure 1. Block diagram of power line tests.

on transmitters and receivers with a minimum of equipment changes. The line conducted interference tests are limited to a maximum frequency of 100 Mc; therefore the test setup is applicable to waveguide as well as coaxial systems.

Figures 2 and 3 show possible setup configurations for the susceptibility tests. Signal generators necessary to cover the range up to 12 Gc are combined through a single-pole, multiple-throw switch to facilitate rapid coverage of the range. The diagram in figure 2 shows a setup which could be modified to accommodate the generators available. The antenna is indicated for the radiated test. The receiver intermodulation test is awkward to incorporate into a general setup; therefore it is indicated as requiring some different connections.

Figures 4 and 5 show possible setups for the emissions tests. The transmitter intermodulation test is indicated as a closed system test for low-powered transmitters. From a review of available components and a survey of usual techniques of performing high-power tests, radiated tests seem to be the answer to the problems encountered in coupling one high-powered transmitter into another. The low-power configuration shown would be modified to load the transmitters with antennas and couple f_i into f_o by proper orientation of the antennas. Here low power is intended to mean 100 watts or less.

As mentioned, these setups are possible configurations. Further analysis may reveal that more consolidation is feasible.

Several of the elements shown in the blocks of the diagrams were investigated to varying degrees. Those which warranted a more thorough examination are reported in sections B and C of this report.

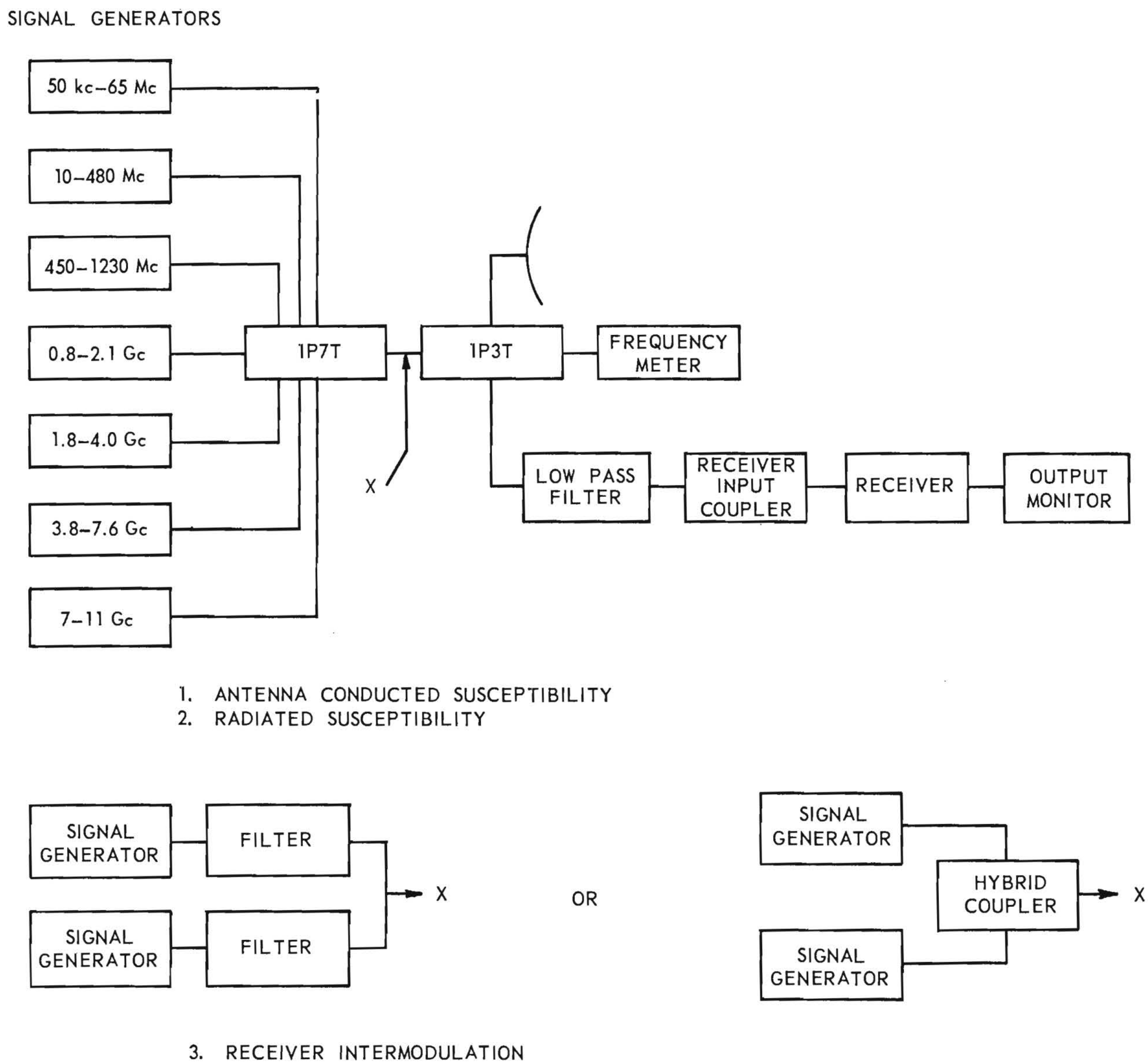

Figure 2. Block diagram of susceptibility tests for coaxial systems.

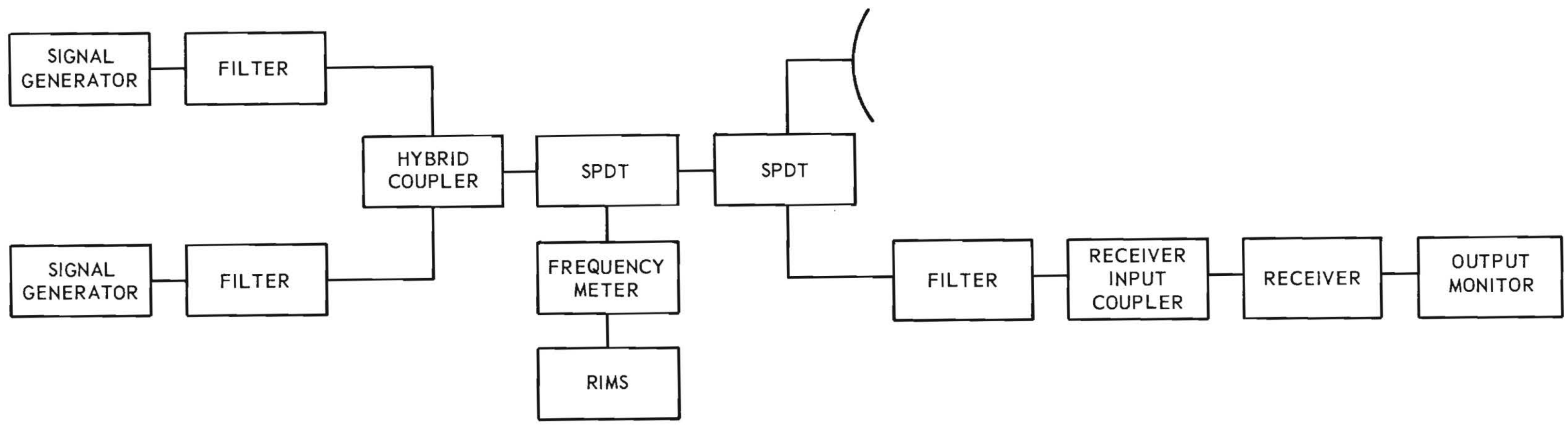

Figure 3. Block diagram of susceptibility tests for waveguide systems.

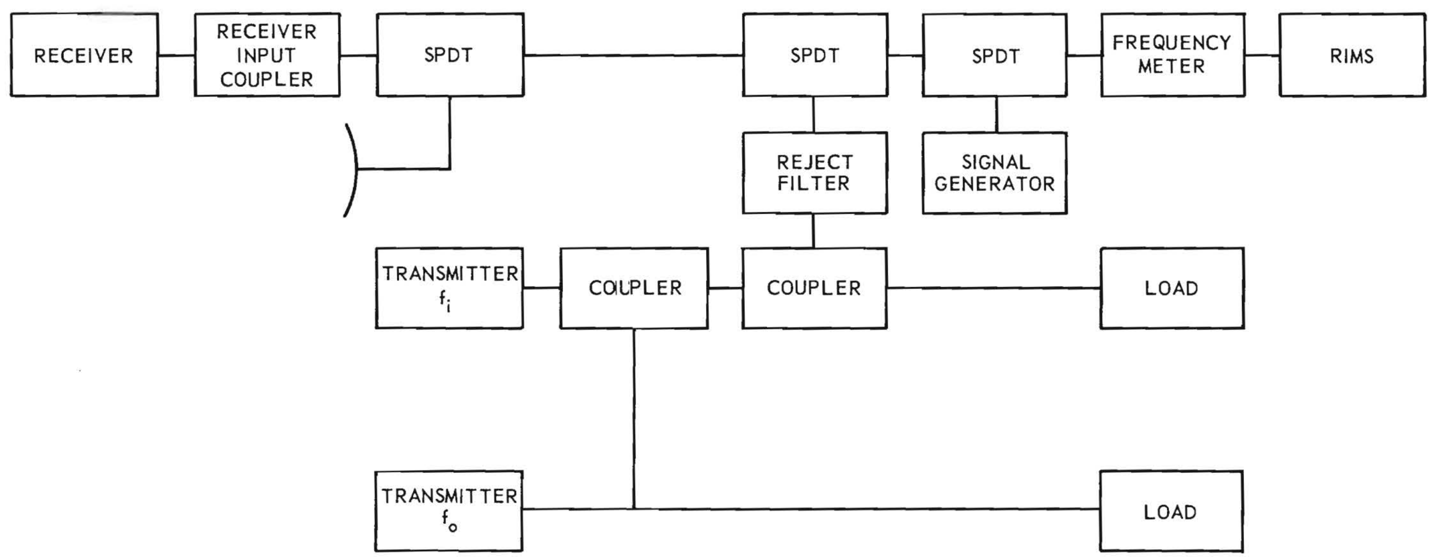

Figure 4. Block diagram of emissions tests for waveguide systems.

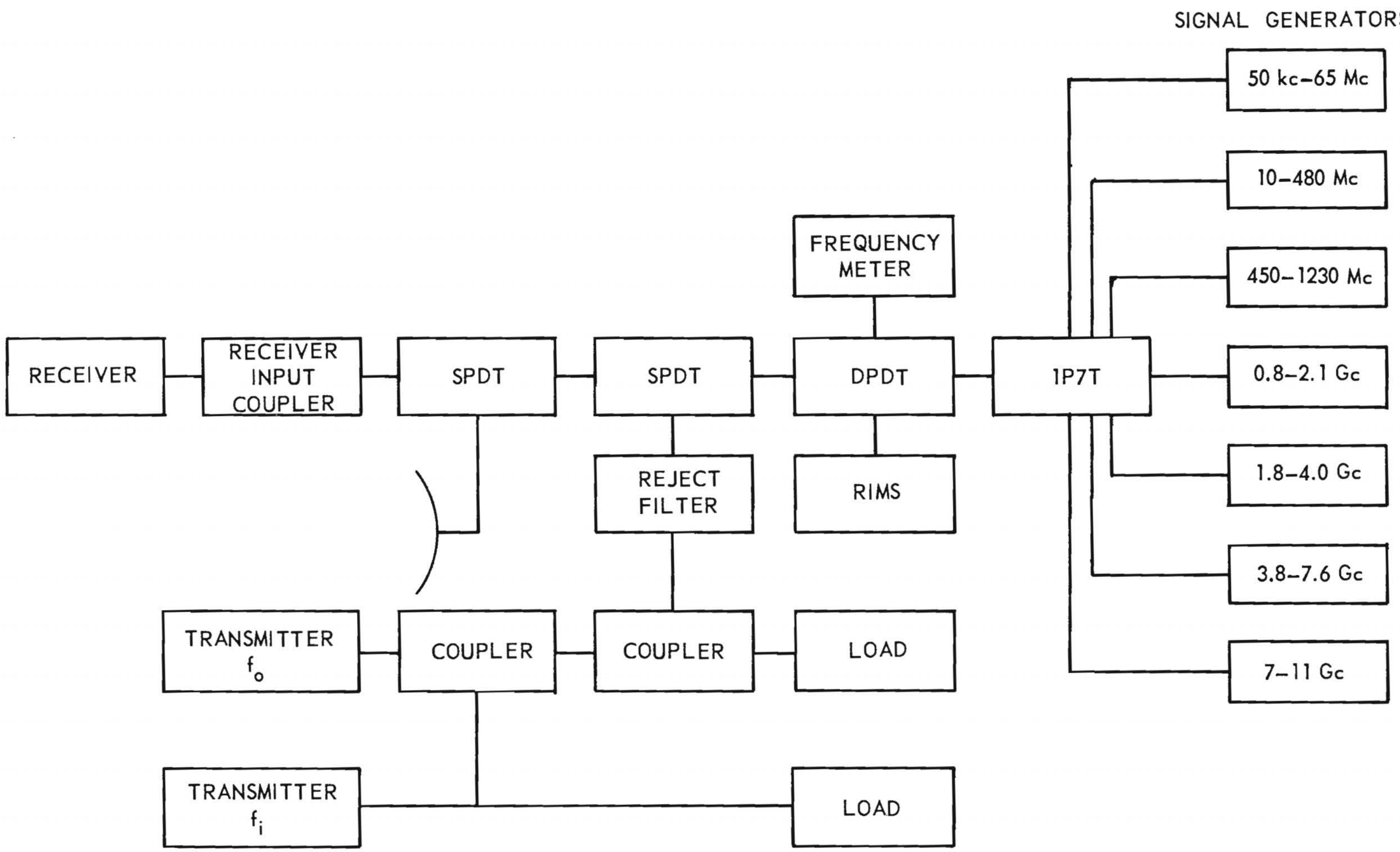

Figure 5. Block diagram of emissions tests for coaxial systems.

Frequency meters consisting of a transfer oscillator and an electronic counter are available to measure frequency accurately up to about 15 Gc. Above this frequency, standard waveguide frequency meters are readily available.

A spectrum analyzer or a deviation detector may be used as an output monitor for transmitters. The output monitor for a receiver may be a distortion analyzer for receivers producing an audio output. The associated display unit may be used for a radar receiver. For integrated systems the associated output accessories may be used as output monitors.

To sample the output of a transmitter at VHF and higher frequencies, commercially available directional couplers are recommended. A survey of available instruments reveals that directional couplers are available from about 250 Mc and up in octave bandwidths and greater. Couplings of 40 db with 20 or 30 db directivity present no problem. A survey of various coupling techniques suggests the use of a high-powered attenuator such as that produced by Rhode and Schwarz. Their UHF Load Resistor Type RBD is available in models to handle 10 kw up to frequencies of 2300 Mc with an output connection providing a signal approximately 30 db below the input signal.

As given in the appendix of Quarterly Report No. 1, a number of dummy loads exist for termination purposes. Information from Chemalloy Electronics Corporation, Santee, California, indicates that this company produces water loads and calorimeters with large power handling capabilities over very broad frequency ranges. If a dummy load of proper power handling capability is not available to terminate a transmitter, the associated antenna could be used. It is assumed that a transmitter with large power output would be a relatively fixed installation and would have an associated antenna available for use.

Techniques for building a small size, high temperature dummy load are under investigation.

A receiver input coupler that is useful to 400 Mc is described in section B of this chapter. For systems of constant impedance or waveguide systems, appropriate attenuators may be used. If the power loss in attenuators is undesirable, an isolator may be used effectively to attenuate the reflected wave up to 20 db. Low-power isolators are generally available in octave bandwidths or with a frequency coverage corresponding to a waveguide band, though not many manufacturers produce isolators to cover complete K and K_a bands.

In any measurement setup consideration must be given to the error produced by mismatches. Usual specifications on devices, such as attenuators, filters, couplers, and the like, specify a maximum VSWR that can be expected over the operating range of frequencies. In the development of this Design Plan, the problem was encountered of estimating the maximum VSWR that could be expected from the contribution of several mismatches. This problem was investigated in some detail and is presented in section E of this chapter. A means of estimating the resultant VSWR from a series of reflecting interfaces evolved from this study. For small voltage reflection coefficients (low VSWR) the maximum ratio of reflected to incident power may be estimated as being approximated by the number of interfaces times the greatest voltage reflection coefficient squared. Symbolically:

$$\frac{P_r}{P_i} \approx n\rho^2$$

B. Experimental work

1. Receiver input coupler

An investigation of the requirements for a coupler to feed into a 300 ohm receiver from a 50 ohm system led to the construction of a minimum-loss resistive pad. Because of the fact that the receiver input coupler must operate from 14 kc to 400 Mc, the possibility of using reactive devices such as transformers is remote. The simplest approach is to use a resistive pad that has flat impedance characteristics throughout the range of interest.

The circuit shown in figure 6 presents a 50 ohm impedance looking from the right when the left terminals are terminated in 300 ohms and vice versa. This circuit was constructed using molded carbon, 10 per cent tolerance resistors. The 273.9 ohms was approximated with 276 ohms and the 53.9 ohms with 54 ohms. These resistors were mounted in a specially constructed mount. Figure 7 is a photograph of the completed pad.

Figure 8 shows the variation of input impedance (from the 50 ohm input terminals) with frequency when terminated with a GR 874-BM 300 ohm termination. Since 300 ohm test equipment was not available to test the pad, another identical pad was constructed and the pair were used in tandem to run insertion loss measurements. Figure 9 shows the insertion loss characteristics for the pair up to 400 Mc. Theoretically, the insertion loss for a single 50 to 300 ohm minimum-loss pad is 13.42 db. Considering the deviation of the resistors used from the proper values, the insertion loss is as expected. The 3.4 db rise from 10 to 150 Mc has not been explained since the behavior is relatively flat to 400 Mc. More suitable resistors have been ordered.

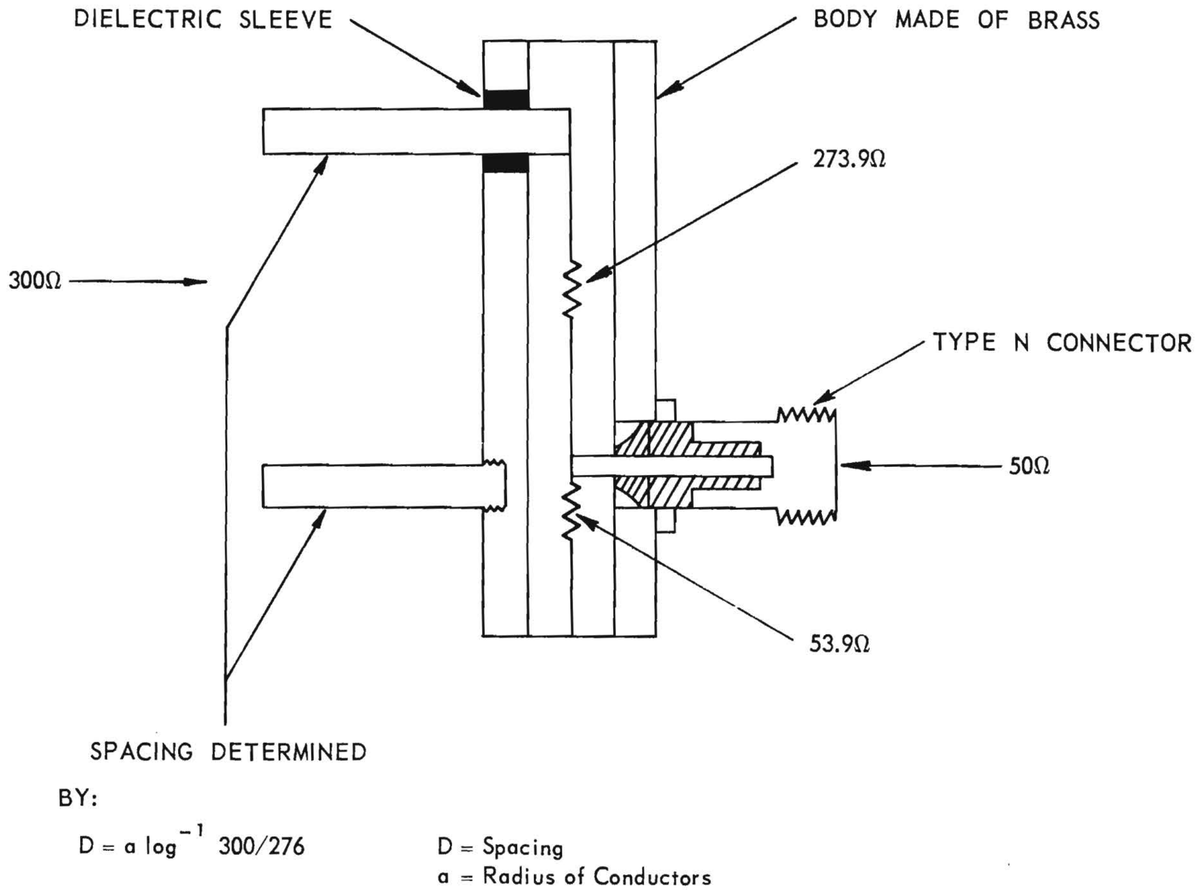

Figure 6. Schematic diagram of minimum-loss pad.

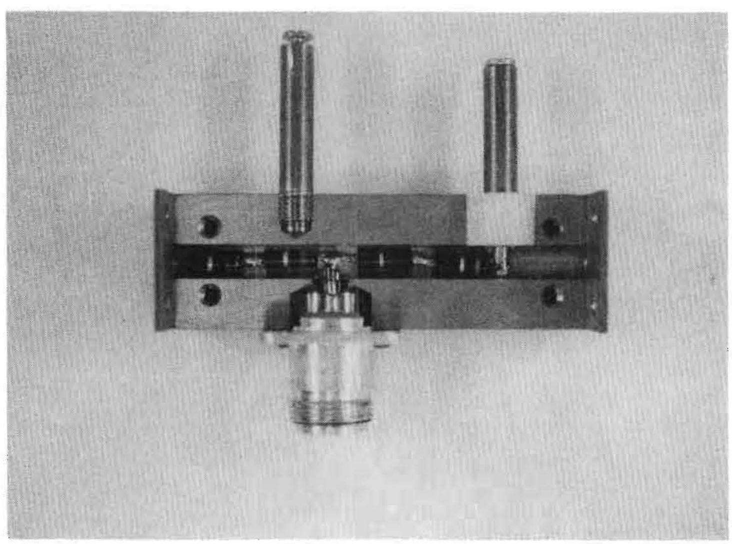

Figure 7. Photograph of receiver input coupler.

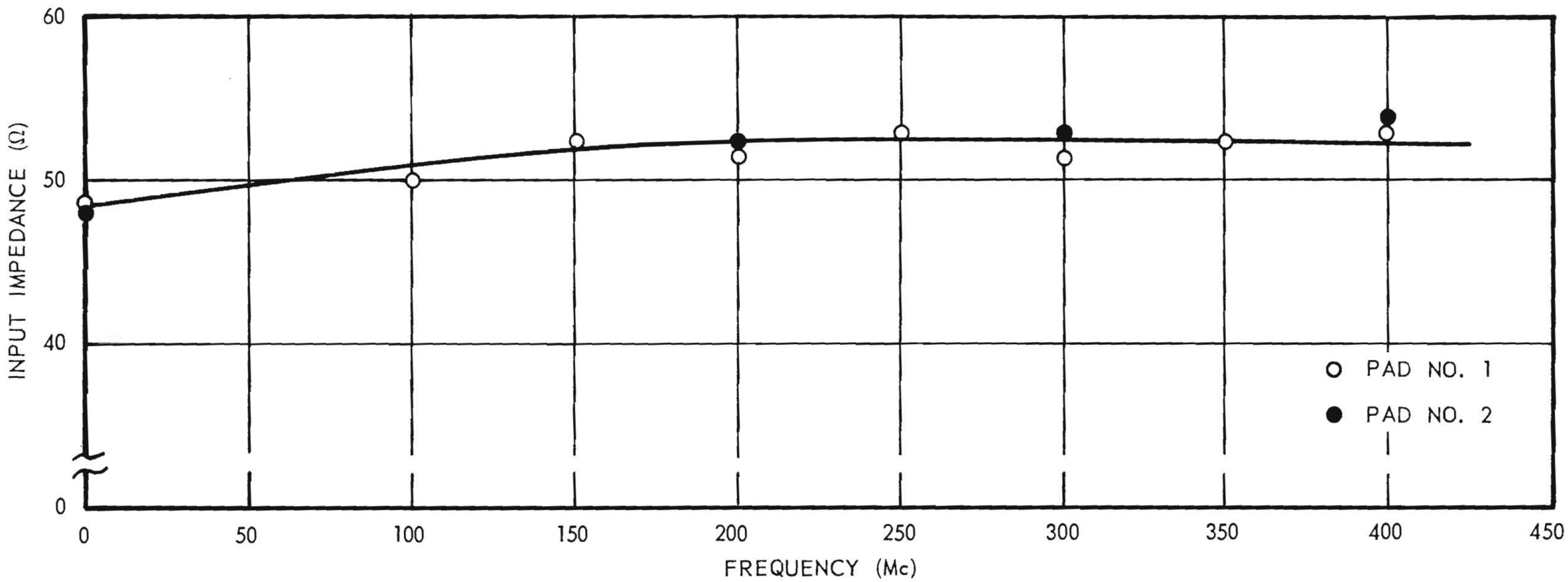

Figure 8. Input impedance versus frequency of receiver input coupler.

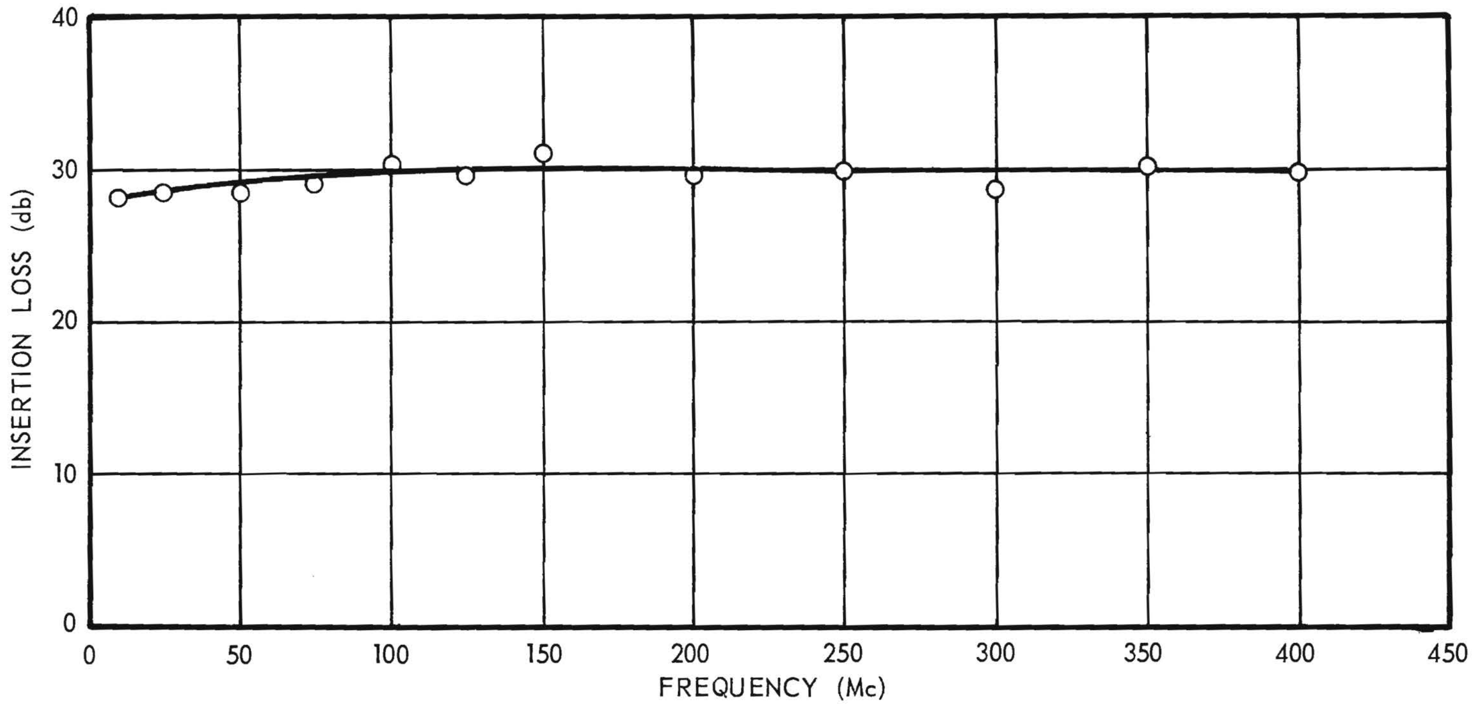

Figure 9. Insertion loss versus frequency for two receiver input couplers in tandem.

2. Thin film load

Dummy load techniques were investigated during the second quarter. Discussion with personnel at the Engineering Experiment Station who have done considerable thin film work resulted in several approaches to a thin film dummy load.

A coaxial tapered load was chosen as the first model. The principal effort was directed toward obtaining the necessary materials and building the prototype. The taper was designed and the load shell constructed. Ceramic rods were ordered for the center conductor. Liquid Bright Gold and Platinum* were obtained for plating purposes. A supply of ceramic cement was obtained for construction purposes. In addition, approval of funds to purchase a muffle oven for high temperature testing is being sought.

The load consists of an electroformed copper shell which forms the outer conductor or body. There is a straight section followed by a taper. The taper is designed to produce even power distribution over its length.[1] The inside diameter of the shell is 0.578 inch with approximately 1/16 inch wall thickness. Figure 10 is a drawing of the load. The center rod is an alumina (American Lava, AlSiMag 614) rod, 0.250 inch in diameter. For a first try the alumina rod over the length of the taper will be coated with platinum because of the ease of deposition of this film from a liquid solution. The resistance of the platinum coating will be adjusted to be 50 ohms over the taper length. The remainder of the rod will be painted with gold resinate solution. This will allow checkout of the taper section and load characteristics as a function

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*Engelhard Industries, Inc., Hanovia Liquid Gold Division, 1 West Central Avenue, East Newark, Harrison P.O., New Jersey.

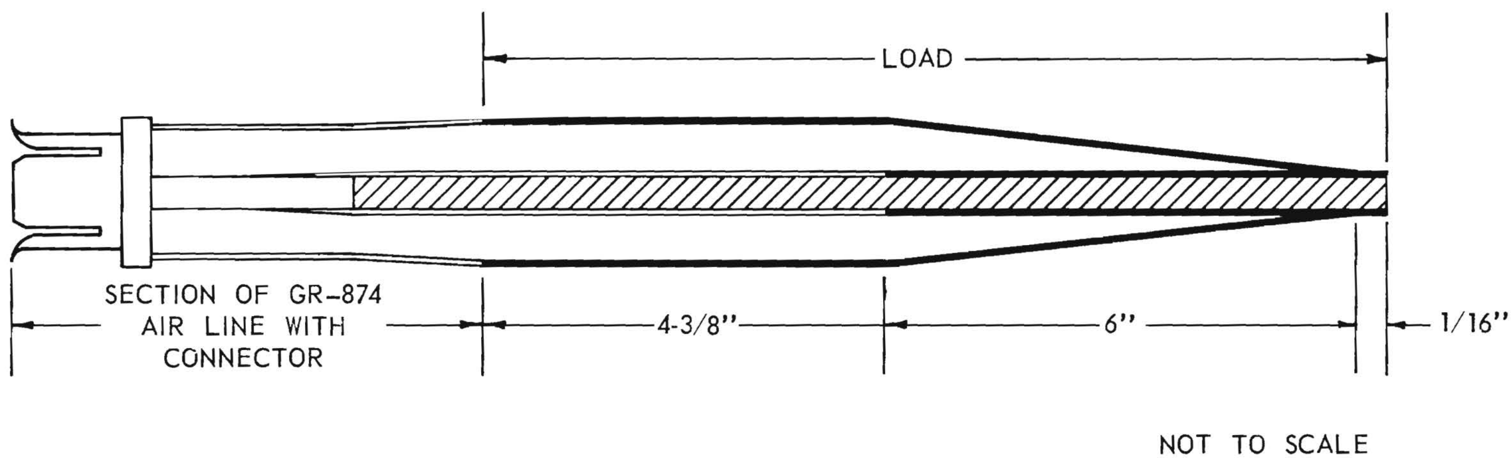


Figure 10. Drawing of dummy load configuration.

of frequency. The inside of the shell of the load will be coated with silver to improve its conductivity.

Experiments will be performed to determine the necessary deposition technique to deposit a film of an alloy of rhenium and platinum which from past experience has exhibited a very low temperature coefficient of resistance.

3. Audio susceptibility tester

Work continued during the second quarter on the audio susceptibility tester transformer and amplifier. The details of the coupling transformer were investigated and information on core materials was collected. It does not seem practical to obtain the required line drop by depending on a low self-inductance of the secondary of the transformer with no dependence on the reflected amplifier output impedance because of the attendant low open circuit inductance of the primary of the coupling transformer and the resulting large reactive current that the amplifier would be required to handle at the lower frequencies. The present approach is to construct a transformer with a turns ratio in the neighborhood of 10:1 and an amplifier with a low output impedance. The use of the high turns ratio reduces the back current that the amplifier must handle.

Several configurations of the amplifier have been investigated but none have displayed desirable thermal characteristics. One amplifier which appears promising and was recently discussed in the literature is the Delco[2] 50 watt audio amplifier. An amplifier similar to this one is presently being constructed and materials for the transformer are being procured.

C. Filters

Variable filters should be used, as filters for interference testing should be as versatile as possible. A moderate literature search revealed several commercial variable filters, the major characteristics of which are tabulated in Table I of the appendix. This table shows that variable low-pass filters are available up to about 4 Gc. Above this, fixed filters must be used. For effective testing, in addition to the variable filters, fixed filters should be available with cutoff frequencies at 6, 8, and 10 Gc. Waffle-iron filters can be designed to produce effective low-pass characteristics in waveguide configurations.

The selection of band-pass filters is adequate to cover the frequency range of interest. Below 125 Mc several manufacturers produce variable band-pass filters. No attempt was made to list them. The selection of fixed-frequency filters may be obtained at any frequency to 40 Gc.

Rejection filters are less plentiful than band-pass filters. A few sources of variable filters are available. The Bureau of Standards filters (see Table I) are apparently excellent filters but a large number of filters are required to cover the frequency range from 14 kc to 1 Gc. The Electro-Mechanics filters cover the same range with three units using plug-in coils. From published specifications, the Bureau of Standards filters exhibit the better characteristics. The Aircraft-Armaments, Inc. filters cover most of the range from 1 to 12 Gc with moderate rejection obtainable. The waveguide technique used may be applicable up to 40 Gc.

Variable high-pass filters have been encountered primarily at audio frequencies. Fixed high-pass filters to cover every situation would be impossible to predetermine. Cutoff frequencies of 500 Mc and 1, 2, 4, and 8 Gc should be useful. For waveguide applications the guide itself is an effective high-pass filter.

A desirable filter type from the standpoint of ease of tuning is the YIG filter. This type of filter is electronically tunable, a useful characteristic in a test set. These filters are currently available in both band-pass and band-reject configurations. At the present time, information on these filters is available from three commercial sources. These data are tabulated in Table II of the appendix.

D. The spurious and harmonic emissions test in waveguide systems

In attempting to measure signals other than the fundamental in a waveguide one encounters the problem of energy propagating in more than one mode. The problem occurs to a lesser degree in coaxial systems. Most interference measurement techniques have more or less ignored the problem of power being in other than the fundamental mode.

At the fundamental frequency of a transmitter, the output stages are generally designed to launch a specific mode in the transmission line. This mode is usually the dominant TE_{10} mode in rectangular guides. The TE_{01} mode is usually used in circular guides. At frequencies above cutoff, energy can propagate in various modes. The number of modes depends upon the size of the guide and the frequency of the signal.

A thorough discussion of possible modes in a waveguide can be found in the better text books on electromagnetic theory and in Quarterly Reports Nos. 1, 2, 3, and 4 by Armour Research Foundation on Contract No. DA 36-039 sc 89102.[3]

The primary obstacle in attempting to measure the power in a multimode signal lies in the field sampling device or technique. Most simple probes and sampling devices are sensitive to one mode primarily. This means that a single fixed probe may not respond accurately to the power that is contained in more than one mode.

A number of techniques have been developed for sampling a multimode field and determining the power contained therein. These methods have been described by Forrer and Tomiyasu,[4] Sharp and Jones,[5] Lewis,[6] Knop and Cohn,[7] and Price.[8] Edson[9] has made a comparative analysis of these five methods.

Forrer and Tomiyasu utilize a moveable electric probe to obtain raw data which are analyzed by Fourier analysis to yield a series of linear equations which in turn are solved by matrix inversion. A computer program is necessary to process the data. The entire test is time consuming and voltage breakdown is a problem with the moveable probe. The accuracy is ±1 db.

Sharp and Jones devised a method which consisted of a series of sampling waveguides mounted on the walls of a rectangular waveguide and coupled by irises to the field in the transmission guide. They reported an accuracy of ±2 to ±5 db. The only problem with voltage breakdown is caused by the edges of the coupling irises. The total power is the average of the powers measured in each of the sampling waveguides. For this method to be most useful, the modes containing power must be known. Otherwise there must be a sampling guide for each possible mode which becomes unwieldy for even low ordered harmonics.

Lewis used mode couplers to sample the power in the guide. This method can yield an accuracy of ±1 db. It is not useful for testing purposes because the mode couplers are frequency sensitive. The method is limited practically to frequencies where no more than five or six modes can propagate.

Price reported a calorimetric method for measuring the power in a multimode waveguide to an accuracy of ±5 db. A calorimeter is employed with an absorptive harmonic filter whose stop bandwidth coincides with either a harmonic frequency or some anharmonic frequency signal propagating in the waveguide. This method suffers from poor sensitivity and lack of precision in determining the frequency.

Knop and Cohn applied a technique similar to that of Forrer and Tomiyasu to coaxial waveguides. Their method is attractive because in typical situations fewer modes propagate in a coaxial line than in a rectangular waveguide. They achieved an accuracy of ±1 db. Their method requires a computer to correlate the raw experimental data, which imposes a limitation for testing purposes.

Price[10] presents another technique for multimode power measurements that is similar to that of Forrer and Tomiyasu. The method utilizes a series of broad-wall and narrow-wall fixed probes instead of a moveable probe, which solves the problem of electrical breakdown. A computer program is required to correlate the experimental data. The author quotes an accuracy of ±1 db.

The most promising technique from the point of view of the Design Plan was reported by Taub.[11] This paper is a report on a project[12] performed by Airborne Instruments Laboratory. The method is said to produce an accuracy of ±1 db or better. High-power breakdown does not present a problem and no computer services are necessary for reduction of data. A test run of a particular frequency can be completed in minutes.

The sampling section consists of a series of electric field probes situated in the broad and narrow walls of an oversized waveguide. The number of probes is not determined by the possible number of modes propagating. The number of probes is fixed and used for all number of modes.

Between the transmitter and the fixed probe waveguide section is a trombone line stretcher and a nonlinear taper. A high-powered multimode load terminates the signal path.

A motor driven commutator successively samples the probes. The output of the commutator goes to a receiver and then to a pulse averaging circuit. The output of the pulse averaging circuit is proportional to the square of the electric field detected by the fixed probes.

For more details the reader is referred to Reference 12. This technique seems to be the most desirable for a piece of versatile test equipment. The accuracy is adequate and the time requirement is not excessive. The receiver used in the equipment setup is a Radio Interference Measuring Set and would be available for use. The greatest objection is that the signal line components become cumbersome and require a lot of space at the larger waveguide sizes. In addition, the sampling commutator and pulse averaging circuit are specially designed components.

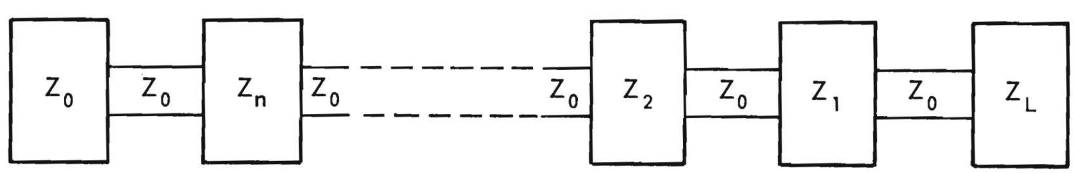
E. The maximum VSWR due to a number of reflections in a line

In the examination of the Design Plan, the problem of selecting a testing setup that would exhibit versatility but introduce minimum error was encountered. The technical requirements specify a maximum VSWR at the output of the Accessory Set of 1.2:1. A literature search failed to yield very much information on the prediction of total reflection due to the contributions of several reflections.

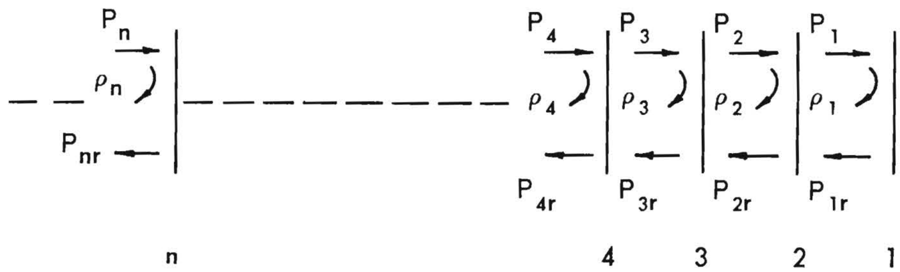
An examination of the problem disclosed that one is confronted with determining the effective characteristic impedance of a composite nonhomogenous transmission line. Further investigation revealed this to be a complex problem.

In the interest of having a method easily applicable to estimating the maximum reflection possible from a series of given maximum VSWR's a different approach was used.

Suppose we represent the transmission system as:



Represent this system as a series of interfaces where reflections occur:



where P_n = incident power on interface n,

ρ_n = voltage reflection coefficient of interface n, and

P_{nr} = reflected power from interface n.

To evaluate the maximum reflected power at interface n we impose the following conditions:

(1) $\rho_1 = \rho_2 --- = \rho_n$, ρ_n = maximum voltage reflection coefficient of any interface.

(2) Reflection occurs only for power flow from left to right—not for power flow from right to left. This means that the incident power is reduced from interface n to interface n-1. The reflected power from interface n-1 does not encounter further reflection when it meets interface n. The total reflected power at interface n is given by:

$$P_{nr} = \rho_n^2 P_n + P_{(n-1)\,r} \quad .$$

From the definition of VSWR (Γ)

$$\Gamma = \frac{|V_i| + |V_r|}{|V_i| - |V_r|} = \frac{1 + \left|\frac{V_r}{V_i}\right|}{1 - \left|\frac{V_r}{V_i}\right|} = \frac{1 + |\rho|}{1 - |\rho|}$$

where V_i = amplitude of incident voltage and

V_r = amplitude of reflected voltage.

From the general expressions for incident power, $P_i = V_i^2$ Re (Y), and reflected power, $P_r = V_r^2$ Re (Y), we may derive

$$\frac{P_r}{P_i} = \frac{V_r^2}{V_i^2} = \rho^2 \quad .$$

Here Y is defined as the admittance of the line at the point of investigation.

The reflected power at successive interfaces may be derived as follows:

at interface 1: $P_{1r} = \rho^2 P_1$; [1]

at interface 2: $P_1 = P_2 - \rho^2 P_2$ [2]

$$P_{2r} = \rho^2 P_2 + P_{1r} = \rho^2 P_2 + \rho^2 (P_2 - \rho^2 P_2)$$

$$P_{2r} = \rho^2 (2 - \rho^2) P_2 \; ; \qquad [3]$$

at interface 3: $P_2 = P_3 - \rho^2 P_3$ [4]

$$P_{3r} = \rho^2 P_3 + P_{2r}$$

$$= \rho^2 P_3 + \rho^2 (2 - \rho^2)(1 - \rho^2) P_3$$

$$= \rho^2 (1 + 2 - 3\rho^2 + \rho^4) P_3$$

$$= \rho^2 (3 - 3\rho^2 + \rho^4) P_3 \quad . \qquad [5]$$

Similarly:

$$P_{4r} = \rho^2 (4 - 6\rho^2 + 4\rho^4 - \rho^6) P_4 \qquad [6]$$

$$P_{5r} = \rho^2 (5 - 10\rho^2 + 10\rho^4 - 5\rho^6 + \rho^8) P_5 \qquad [7]$$

It is observed that these equations are similar to the binomial expansion:

$$(1 \pm x)^n = 1 \pm nx + \frac{n(n-1)}{2!} x^2 \pm \frac{n(n-1)(n-2)}{3!} x^3 + \dots$$

$$+ (-1)^r \frac{n!}{(n-r)!r!} x^r + \dots \qquad [8]$$

If we take $x = \rho^2$

$$(1 - \rho^2)^n = 1 - n\rho^2 + \frac{n(n-1)}{2!} \rho^4 - \frac{n(n-1)(n-2)}{3!} \rho^6 + \dots \qquad [9]$$

It can be proved that the series for the binomial expansion is convergent for $-1 \leqq x \leqq 1$.

Rewriting [9]

$$1 - (1 - \rho^2)^n = \rho^2 \left[n - \frac{n(n-1)}{2!} \rho^2 + \frac{n(n-1)(n-2)}{3!} \rho^6 - \dots \right] \qquad [10]$$

This expression is convergent in a similar region as [8].

For realizable values for ρ, it can be seen that the expressions obtained are valid at the limit points $\rho = 0$ and $\rho = 1$. These limit points result in

$$\frac{P_r}{P_i} = 0 \text{ and } \frac{P_r}{P_i} = 1 \quad \text{for } \rho = 0 \text{ and } \rho = 1, \text{ respectively.}$$

The coefficients of P_{nr} can be readily obtained by the use of Pascal's Triangle, which is shown in figure 11. For instance,

$$P_{10r} = \rho^2 (10 - 45\rho^2 + 120\rho^4 - 210\rho^6 + 252\rho^8 - 210\rho^{10} + 120\rho^{12} - 45\rho^{14} + 10\rho^{16} - \rho^{18}) P_{10} \quad . \qquad [11]$$

The behavior of P_{nr}/P_n for selected values of ρ was computed and graphically portrayed for n = 1, 2, 3, ..., 10. The results are shown in figure 12.

At this point it may be observed that if several sources of reflection must be used, the maximum reflection due to any one must remain fairly small to avoid the possibility of excessive Γ. This is not to say that a large Γ will result from a given combination but that the possibility exists.

From the graph, it may be observed that a good estimate of the maximum reflected power ratio for small ρ ($\rho < 0.2$) is

$$\frac{P_{nr}}{P_n} \approx n\rho^2. \qquad [12]$$

Parts I and II of figure 12 may be used in conjunction with the conversion graph, figure 13, to estimate the maximum Γ that can be expected in any one system for a known number of components.

To illustrate the use of these graphs, suppose there are four components plus an imperfect termination. These would result in nine reflecting interfaces. Suppose the maximum Γ of any (or all) of the interfaces is 1.2. Figure 13 shows that this represents $\rho = 0.1$. Figure 12, Part II shows that $P_r/P_i \approx 0.09$. for n = 9 and $\rho = 0.1$; Part I shows that this represents a Γ of 1.85.

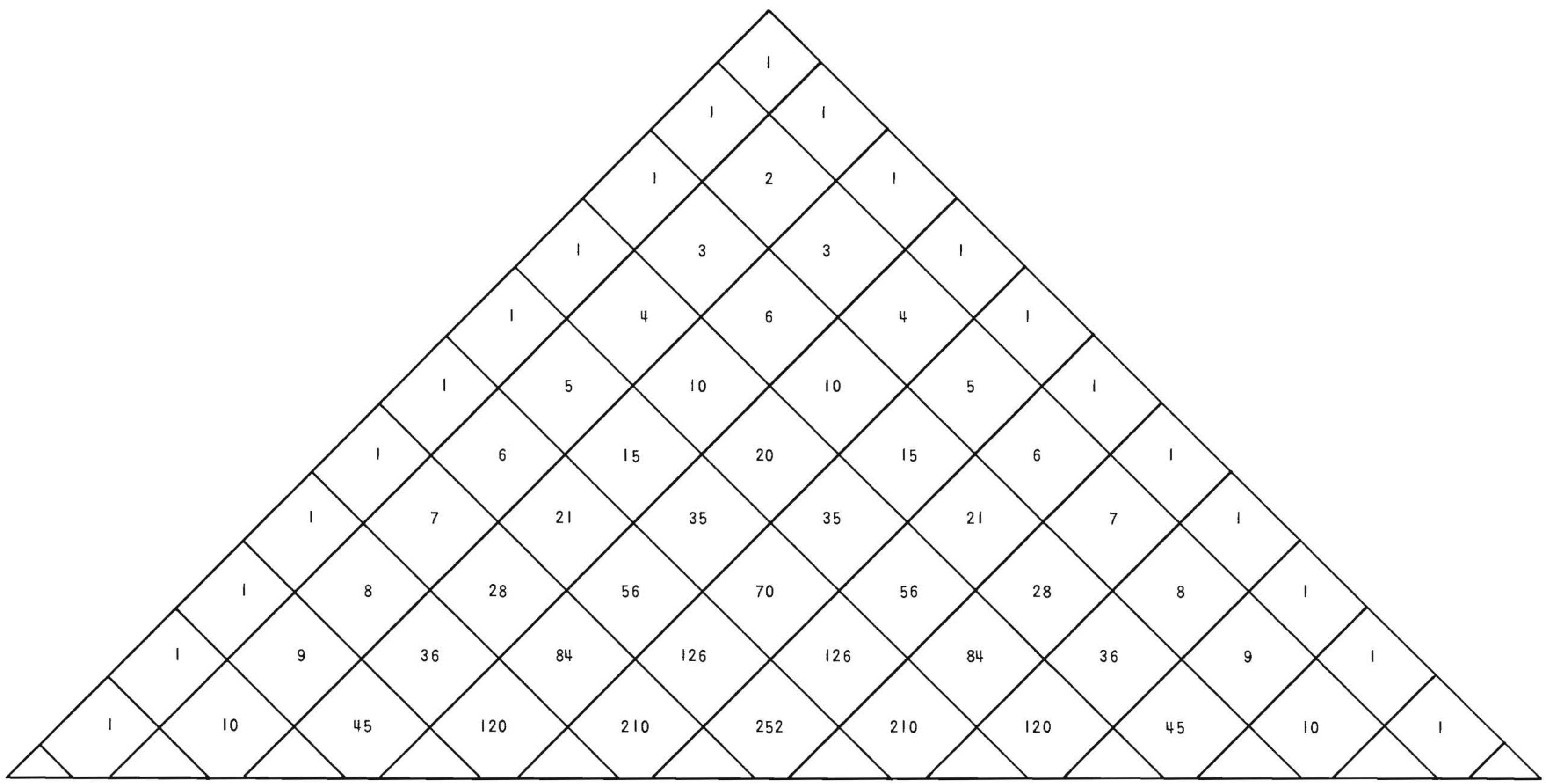


Figure 11. Pascal's triangle of order 10.

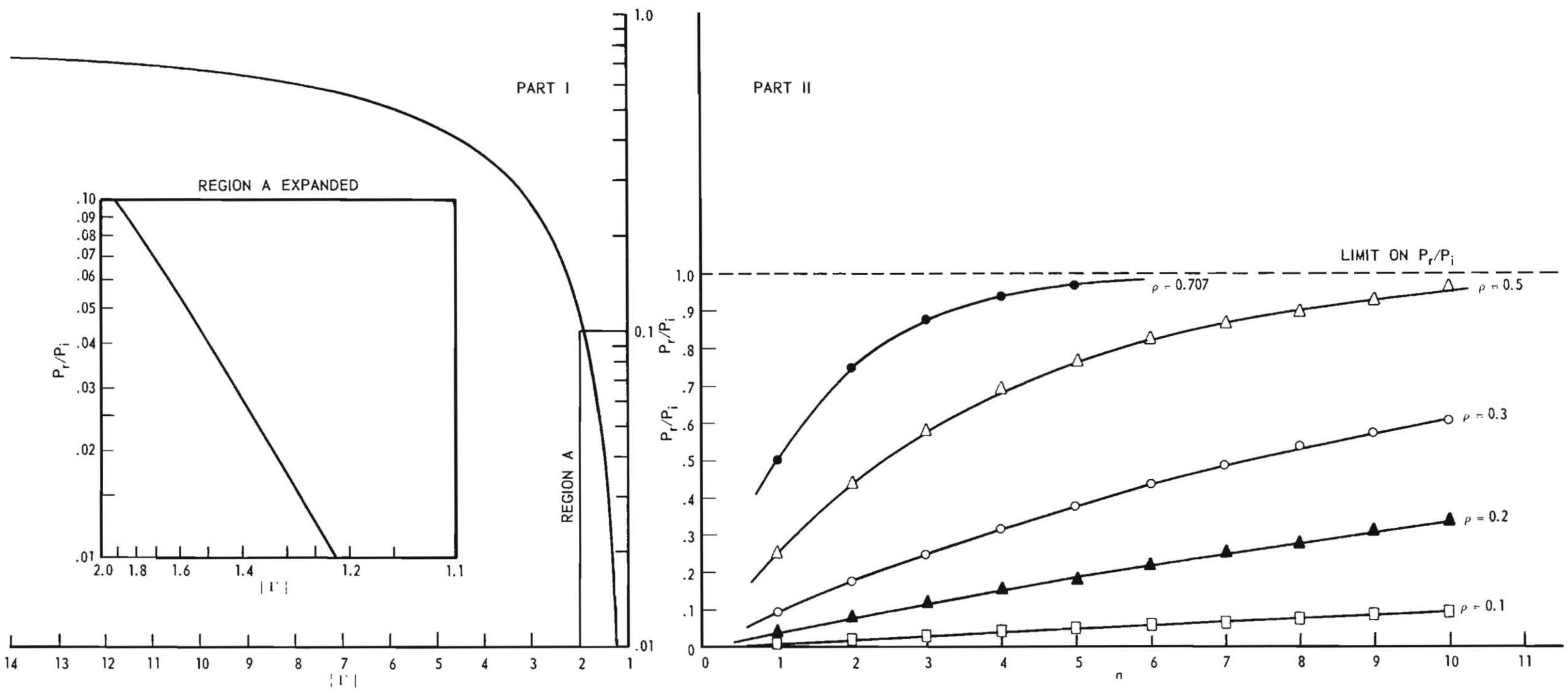


Figure 12. Nomograph for the prediction of maximum VSWR.

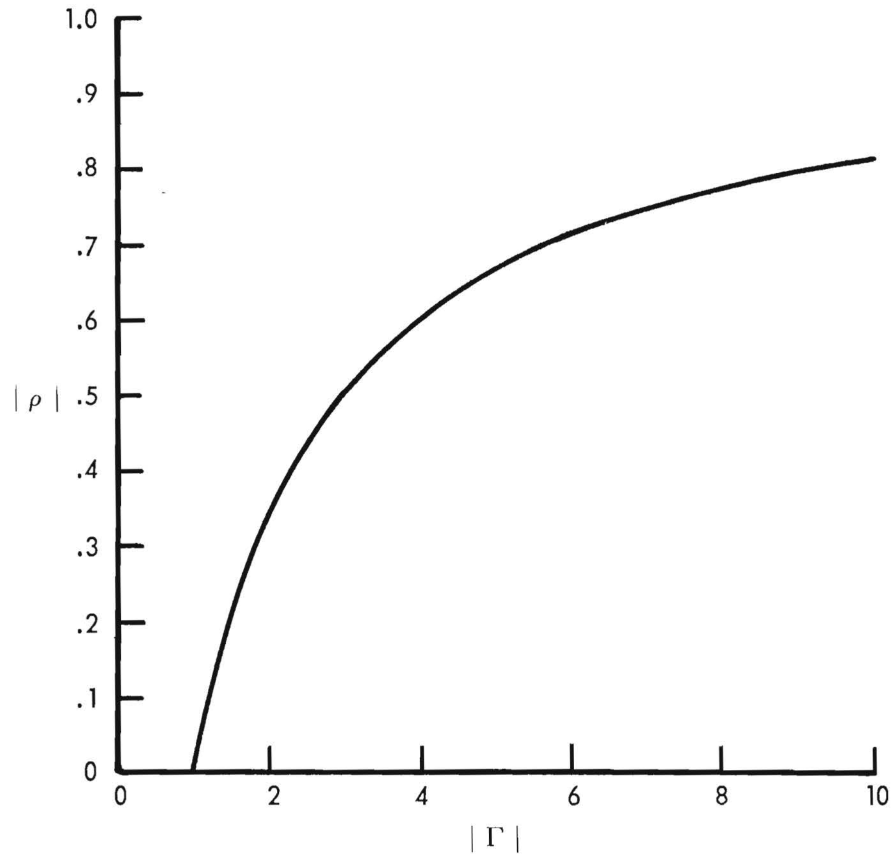


Figure 13. $|\rho|$ versus $|\Gamma|$.

V. CONCLUSIONS

From a study of the various tests and test setups required by military specification MIL-I-11748B it has been shown to be feasible to combine various parts of the test setups into units that can be switched in and out of the different setups and therefore eliminate duplication of components and save setup time.

All techniques for the measurement of spurious and harmonic emissions in waveguides discussed in the literature involve considerable equipment and some require appreciable measurement time. Continuation of the presently used methods for the measurement of spurious and harmonic emissions may have to continue in use until a method suitable for field use is developed.

Various methods for the construction of a thin film dummy load have been studied and the deposition of a thin film of an alloy of gold and platinum or rhenium and platinum should provide a usable temperature coefficient of resistance for the resistive element over a wide temperature range.

As a result of experimental work and theoretical considerations, a tentative design has been selected for the audio susceptibility amplifier and transformer.

A first design of a minimum loss 50 to 300 ohm matching pad has been tested and insertion loss was found to vary approximately 1.5 db for frequencies up to 400 Mc. Better resistors and refinements of the housing should improve this situation.

A method for predicting the worst case VSWR situation when a group of components are connected together in a transmission line has been derived and will provide a criterion for the selection of system components.

VI. PROGRAM FOR NEXT INTERVAL

During the next quarter, work on the outline of tests required will continue as will work on the combining of the test setups into an integral system.

Work on the audio susceptibility tester amplifier and transformer will continue.

Various techniques will be tried to produce a thin film load. These will include the deposition of thin films and the investigation of their resistance and temperature coefficient of resistance properties.

Evaluation of the Electro-Mechanics rejection filter will be performed.

VII. IDENTIFICATION OF KEY TECHNICAL PERSONNEL

Name	Title	Approximate Hours
Hugh W. Denny	Research Assistant	448
Neil T. Huddleston	Graduate Research Assistant	444
D. W. Robertson	Head, Communications Branch	40
Joseph R. Walsh, Jr.	Project Director	360
W. Bruce Warren	Research Engineer	9
E. Wendell Wood	Assistant Research Engineer	58

VIII. REFERENCES

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IX. APPENDIX

TABLE I

VARIABLE FILTERS

Type	Manufacturer	Model	Range	Insertion Loss (db)	Notes
Low-pass	Microlab	LV-02N	200 Mc - 500 Mc	1	Tuned line continuously variable
	Microlab	LV-04N	400 Mc - 1 Gc	1	Tuned line continuously variable
	Rhode & Schwarz	PTV BN 49131	0 - 1.35 Gc		12 ranges
	Microlab	LV-08N	800 Mc - 2 Gc	1	Tuned line continuously variable
	Microlab	LV-16N	1.6 Gc - 3.6 Gc	1	Tuned line continuously variable
Band-pass	Telonic	Series TTF	125 Mc - 250 Mc	0.5	
	Telonic	Series TTF	250 Mc - 500 Mc	0.5	
	Telonic	Series TTF	500 Mc - 1000 Mc	0.5	
	Telonic	Series TTF	1000 Mc - 2000 Mc	0.5	
	Frequency Engineering Labs (FEL)	A 50 BC	500 Mc - 1000 Mc	1.5	The B series is a 2-section filter. They are available in 3- and 4-section filters. The insertion loss increases with the addition of more sections.
	FEL	A 100 BC	1 Gc - 2 Gc	1.5	
	FEL	A 200 BC	2 Gc - 4 Gc	2.0	
	FEL	A 400 BC	4 Gc - 6 Gc	2.0	

(Continued)

TABLE I (Concluded)

VARIABLE FILTERS

Type	Manufacturer	Model	Range	Insertion Loss (db)	Notes
Band-pass	FEL	A 600 BW	6 Gc - 8.2 Gc	2.5	The B series is a 2-section filter. They are available in 3- and 4-section filters. The insertion loss increases with the addition of more sections.
	FEL	A 820 BW	8.2 Gc - 12.4 Gc	3.5	
	FEL	A 1240 BW	12.4 Gc - 18 Gc	3.5	
	FEL	A 1800 BW	18 Gc - 26.5 Gc	5.0	
	FEL	A 2650 BW	26.5 Gc - 40 Gc	7.0	
Band-reject	National Bureau of Standards	F-643(XN-1)/URM to F-659(XN-1)/URM	14 Kc - 1 Gc		This range is covered by 17 octave tunable filters.
	Electro-Mechanics Co.	LF	14 Kc - 100 Mc		
		MF	100 Mc - 400 Mc		
		HF	400 Mc - 1 kMc		
					Rejection (db)
	Aircraft-Armament, Inc.	5067 L	1 Gc - 2 Gc		30
		5067 S	2 Gc - 4 Gc		34
		5067 C_{LO}	5.0 Gc - 7.0 Gc		40
		5067 C_{HI}	5.7 Gc - 7.0 Gc		40
		5067 X_{LO}	8.5 Gc - 10.0 Gc		36
		5067 X_{HI}	9.5 Gc - 12.0 Gc		36

TABLE II

YIG FILTERS

Manufacturer*	Type	Range (Gc)	Bandwidth** (Mc)	Insertion Loss** (db)
L	Band-pass	0.5-1	25	4
L		1-2	30	3
L		2-4	50	3
L		4-8	65	2
L		8-12	80	2
P		2-4	18	1.5
P		8-12	30	2
W		1-2	30	3
W		2-4	30	3
W		4-8	30	3
W		8.2-12.4	30	3
W		12-18	30	3
W		18-26	50	2
W		26-40	50	2
W		40-85	200	2
W	Band-reject	1-2	30	Rejection 50
W		2-4	30	Rejection 50
W		4-8	30	Rejection 50
W		8.2-12.4	30	Rejection 50

*L—Loral Electronics Corporation, 825 Bronx River Avenue, The Bronx, New York, 10472.

P—Physical Electronics Laboratories, 1185 O'Brien Drive, Menlo Park, California.

W—Watkins - Johnson Company, 3333 Hillview Avenue, Stanford Industrial Park, Palo Alto, California.

**The bandwidth and insertion loss data are for one-resonator filters except the Physical Electronics Laboratories units which are two-resonator filters.

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1	IIT Research Institute, ATTN: Mr. J. Judwig, 10 West 35th Street, Chicago 16, Illinois

A-693

QUARTERLY REPORT NO. 3

PROJECT A-693

RADIO FREQUENCY COMPATIBILITY (RFC) ACCESSORY EQUIPMENT SET (U)

H. W. DENNY, W. R. FREE, AND J. R. WALSH, JR.

CONTRACT NO. DA 36-039 AMC-02223(E)
DEPARTMENT OF THE ARMY PROJECT: 1G620501D449

Placed by the
U. S. Army Electronics Research
and Development Laboratories
Fort Monmouth, New Jersey

15 October 1963 to 15 January 1964

1964

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY REPORT NO. 3

PROJECT NO. A-693

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By

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CONTRACT NO. DA 36-039 AMC-02223(E)
DEPARTMENT OF THE ARMY PROJECT: 1G620501D449

SIGNAL CORPS TECHNICAL REQUIREMENT
SCL-7687, dtd. 28 Sept. 1962

The object of this research is to prepare a Design Plan for a Radio Frequency Compatibility Accessory Set.

15 OCTOBER 1963 to 15 JANUARY 1964

PLACED BY THE U. S. ARMY
ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORIES
FORT MONMOUTH, NEW JERSEY

FOREWORD

This report was prepared at the Georgia Tech Engineering Experiment Station on Contract No. DA 36-039 AMC-02223(E). The report covers the activity and results of the third quarter's effort on a study project leading to the establishment of a Design Plan for accessory equipments to be used with Radio Interference Measuring Sets.

Respectfully Submitted:

J. R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

TABLE OF CONTENTS

This report contains 43 pages.

LIST OF FIGURES

LIST OF TABLES

I. PURPOSE

The purpose of this project is to conduct a study leading to a Design Plan for accessory equipment to be used with Radio Interference Measuring Sets and signal generators. The accessory equipment includes the complementary devices necessary to determine radio frequency interference characteristics of U. S. Army electrical and electronic equipment in accordance with military specification MIL-I-11748. The frequency range of interest is 0.014 to 40,000 Mc. It is also the purpose of the project to investigate two items of equipment. These are a receiver input coupler and an audio susceptibility tester.

The areas of investigation on this project are divided into three tasks as follows:

I. Evaluation of state-of-the-art items and techniques from the viewpoint of modifying or extending them to fill the Design Plan requirements.

II. Investigation of new techniques and materials when the Design Plan requirements cannot be met by state-of-the-art items or techniques.

III. Verification of findings and conclusions by experimental work when necessary.

II. ABSTRACT

A discussion is presented of several of the items of equipment necessary in a radio frequency compatibility accessory equipment set designed for performing measurements as specified in military specification MIL-I-11748. Major items discussed are the frequency measurement system and a standard response indicator for both CW and pulse systems. The specifications for other accessory items such as directional couplers, isolators, attenuators, dummy loads, and filters are also reviewed.

Experimental work on the deposition of thin film alloys to obtain a film with a temperature coefficient of resistance which exhibits a minimum change of resistance over the temperature range of interest was conducted. Results of this work are shown.

A receiver input coupler which provides for coupling from 50 to 300 ohm transmission systems was designed and its characteristics are shown. The problems associated with the audio susceptibility tester are discussed.

Results of the evaluation of a rejection filter operating in the frequency range 100 to 400 Mc are presented.

III. PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

The Ninth TRI-SERVICE Conference on Electromagnetic Compatibility held in Chicago, Illinois, on 15-17 October 1963, was attended by Mr. J. R. Walsh, Jr.

Mr. H. W. Denny, Mr. W. R. Free, and Mr. J. R. Walsh, Jr. attended a conference held at USAELRDL, Fort Monmouth, New Jersey, 26 November 1963, to discuss details of the Design Plan and possible areas of needed developmental work.

Mr. Sidney Weitz and Mr. Guy Johnson visited Georgia Tech on 16 December 1963 to discuss project technical matters.

IV. FACTUAL DATA

A. Accessory set components

Development of the Design Plan continued with primary emphasis being placed on details of the accessory items. This resulted in the specification of the more important characteristics of these items deemed necessary for the Test Set. Generally the specifications conform to the present state-of-the-art. In some cases available components are not adequate and the specifications are those which are considered desirable for testing purposes.

1. Frequency measuring system

MIL-I-11748 does not require an extremely precise determination of frequency; however, in the interest of providing a test set that will be of maximum usefulness it is desirable to supply frequency measuring capabilities that will meet the requirements of MIL-STD-449A as far as possible. MIL-STD-449A requires the determination of frequency to an accuracy of one part in 10^6.

Using a transfer oscillator, accuracies of this degree can be obtained to 12 Gc. In the waveguide bands above 12 Gc frequency meters are generally accurate to one part in 10^3. Hewlett-Packard in one of their application notes[1] describes a frequency measuring system that provides much better accuracy in waveguide bands and is useful from dc to 40 Gc. This system uses a standard transfer oscillator to produce harmonics to 12.4 Gc which affords direct measurement to this frequency. An auxiliary output from the harmonic oscillator is amplified and subsequently applied again to other mixers to produce harmonics from 12.4 to 40 Gc. A minor problem exists in the use of the system in that the determination of the harmonic number of the signal supplying the beat note may be difficult for inexperienced personnel. Perhaps further investigation could develop a simplified method for readily determining the harmonic number.

2. Standard response indicators

In order to perform the majority of the receiver spectrum signature measurements described in MIL-I-11748 and MIL-STD-449A, it is necessary that an output monitoring device or standard response indicator be connected to the output video or audio terminals of a unit under test to determine the presence or absence of a desired signal-to-noise ratio under various interference conditions. Since instruments to satisfactorily accomplish this function have not been found to be readily available, the requirements and proposed configurations for such instruments or an integrated instrument are discussed in the following paragraphs.

a. Pulsed systems. A block diagram of a proposed standard response indicator for use with pulsed systems is shown in Figure 1. Two input signals are required for the instrument—a video input from the output of the receiver under test and a pulse repetition frequency (PRF) synchronizing signal from the modulator of the simulated radiator (the signal generator supplying the desired signal). The desired video, interfering signal, or signals, and noise are amplified in the video amplifier. The output from the video amplifier is split into two channels—a noise channel and a pulse channel. The noise gate samples the noise and interference immediately preceding each desired pulse. This noise sample is applied to a noise threshold amplifier which has an adjustable threshold which determines the noise and interference level which will be maintained at the output of the video amplifier. That portion of the noise and interference sample which exceeds the

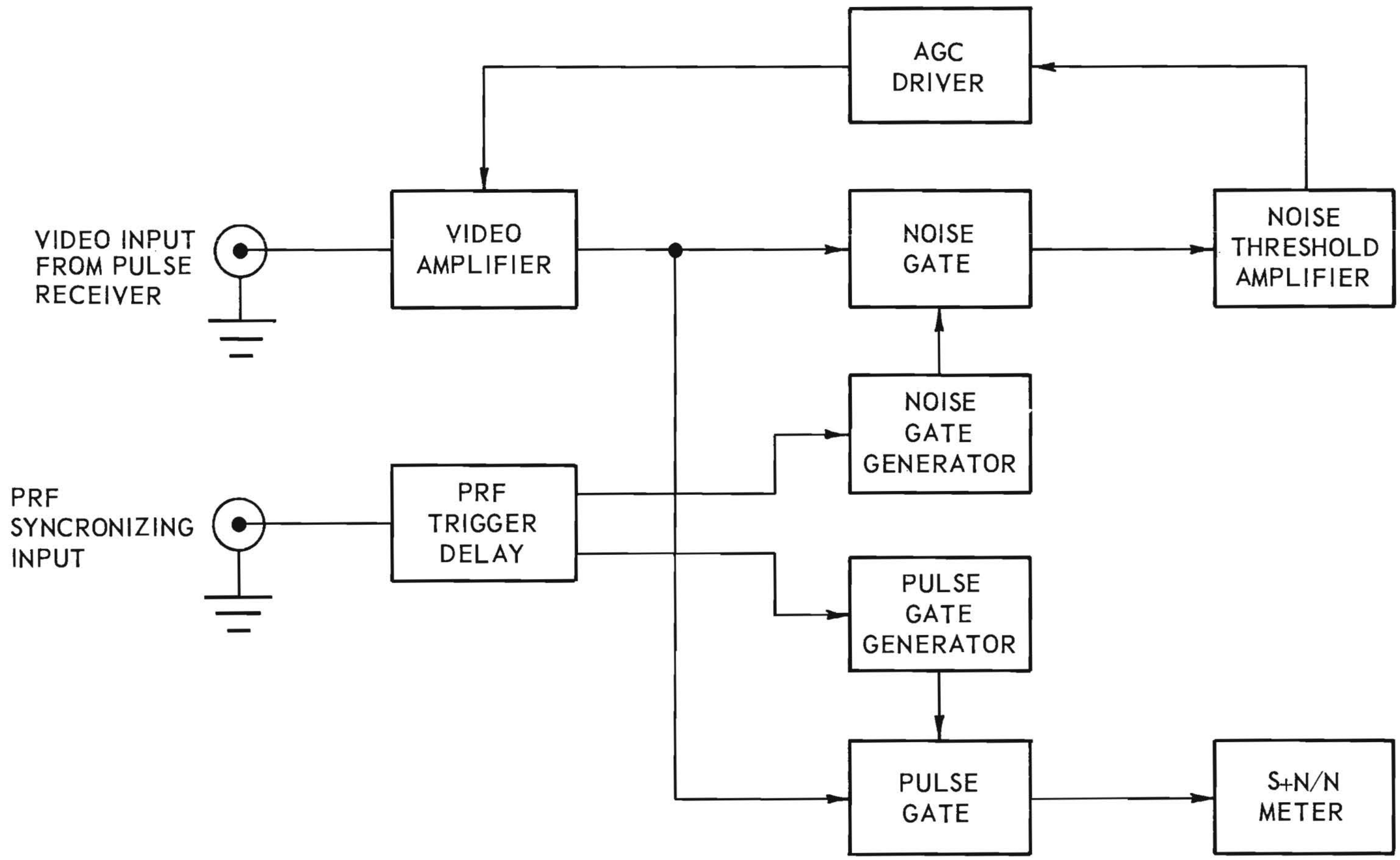


Figure 1. Block Diagram of a Standard Response Indicator for Pulsed Systems.

selected threshold level is amplified and applied to the automatic gain control (AGC) driver stage. The amplified noise samples are integrated and converted into a dc voltage in the AGC driver stage. This AGC voltage controls the gain of the input video amplifier to maintain the noise and interference level at the output of the video amplifier at a desired level, independent of the input level.

It is apparent from the above discussion that the combination of the input video amplifier and the AGC loop results in a known, constant level of noise and interference being maintained at the input of the pulse channel, independent of the level of the noise and interference level at the input of the video amplifier. Since the amplitude of the desired pulse is changed proportionally to the input noise and interference level in the common video amplifier, it is only necessary to measure the pulse amplitude to establish the $\frac{S+N}{N}$ ratio of the input video signal.

The desired pulse is gated into the pulse channel by means of the pulse gate. The gated pulses are applied to a peak voltmeter which provides a continuous, direct reading of $\frac{S+N}{N}$ ratio in decibels on a front panel meter.

A PRF synchronizing waveform is required to maintain the proper timing of the various gating waveforms. The relative timing, position, and shape of the various waveforms required for the proper operation of this instrument are shown in Figure 2. The PRF trigger delay circuit generates a trigger in response to each PRF synchronizing pulse. This trigger is delayed from the leading edge of the PRF pulse which triggered its generation by the proper amount to position it 25 μsec before the next PRF pulse. The delay range over which the circuit must operate is determined by the PRF range over which it is desired to operate. Assuming a 100 to 20,000 pps PRF range, which appears adequate to cover the vast majority of systems presently in the

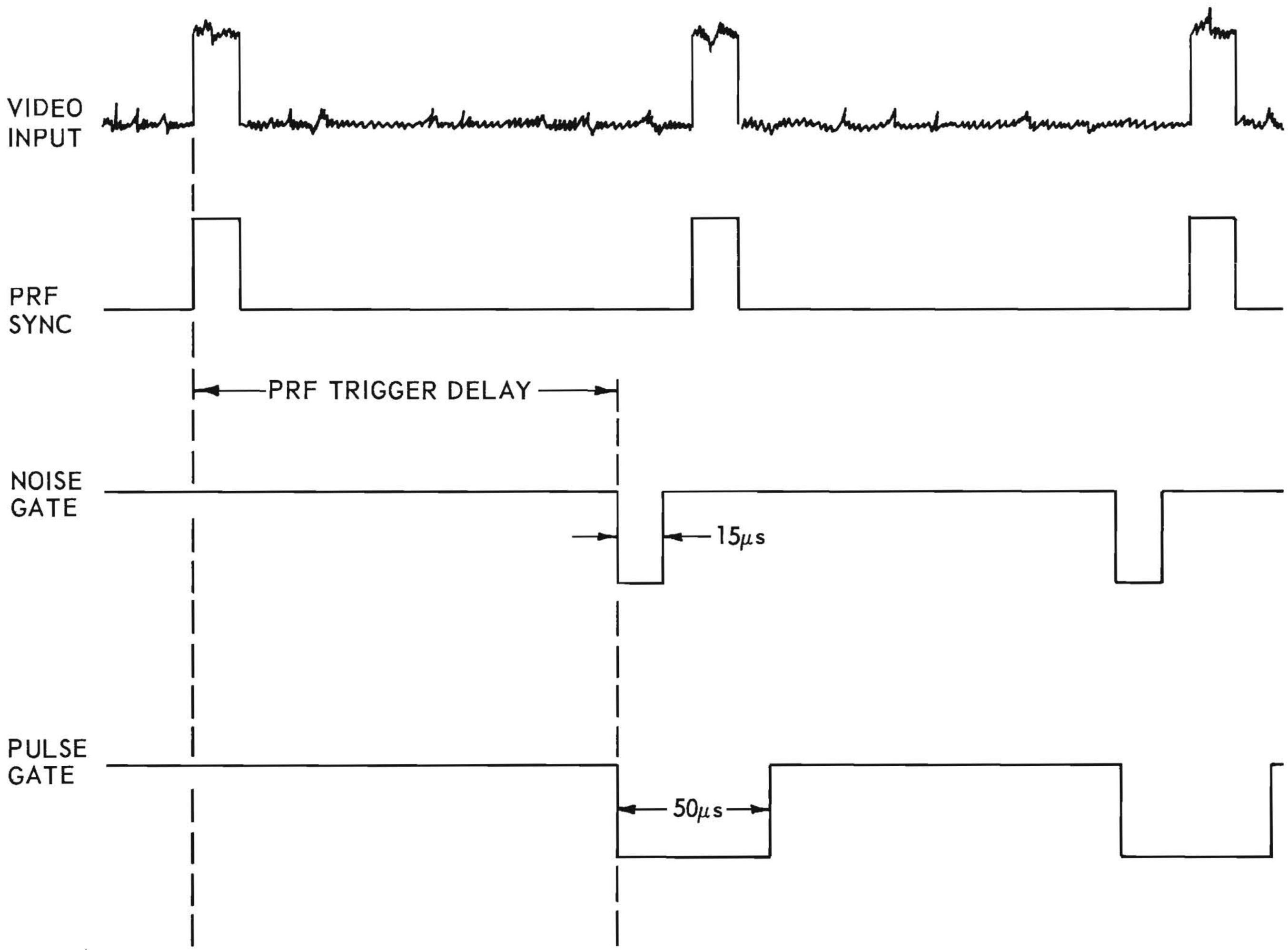


Figure 2. Waveforms for Standard Response Indicator.

field, the delay range required would be 25 μsec to 10 msec. A delay circuit capable of covering this range is readily obtainable. The delayed trigger from the PRF trigger delay circuit triggers the noise and pulse gate generators. The noise gate generator provides a 15 μsec noise gate starting 25 μsec before the next PRF pulse and ending 10 μsec before the pulse. The 15 μsec gate width is recommended on the basis that it is a sufficiently wide sample to drive the AGC driver and sufficiently narrow to be compatible with the minimum inter-pulse spacing at a PRF of 20,000 pps. The 10 μsec spacing between the trailing edge of the noise gate and the leading edge of the PRF pulse is felt sufficient to accommodate the gate turn-off time, the delay circuit jitter, and the PRF jitter. The pulse gate generator provides a 50 μsec pulse gate starting 25 μsec before the next PRF pulse and ending 25 μsec after the start of the PRF pulse. The 50 μsec pulse width is suggested on the assumption that all PRF pulses encountered will have a rise time of less than 25 μsec, and in addition, will reach their maximum amplitude during this period. On the other hand, the 50 μsec width is compatible with the minimum inter-pulse spacing at the maximum PRF. If all pulses will not reach their maximum applitude within 25 μsec, it will be necessary to make the pulse gate width variable. However, this will complicate the circuitry, controls, and operation and should be provided only if essential.

A more sophisticated, fully transistorized standard response indicator based on this same basic technique has been described in the literature.[2] The instrument described provides a Go/NoGo output signal in addition to the front panel meter reading. This feature would be necessary for radiated receiver measurements and, in some cases, for conducted measurements where the operator is required to be located at a point remote from the receiver-under-test. This instrument also includes a pulse position indicator circuit which makes it possible to accurately position the gates without an external oscilloscope or an extremely precise calibration of the delay dial (the delay must be positioned to an accuracy of approximately ± 5 μsec over the range from 25 μsec to 10 msec). These features can be added to the system described without too much difficulty, and their inclusion in any system to be developed should be considered.

<u>b. CW, AM, and FM systems.</u> A block diagram of a proposed standard response indicator for use with CW, AM, and FM systems is shown in Figure 3. Only one signal input is required for this instrument—the audio output from the receiver under test. The desired audio, interfering signals, distortion components, and noise are amplified in the input audio amplifier. The output from the audio amplifier is split into two channels, a noise channel and a signal-plus-noise channel. The noise amplifier in the noise channel contains a tunable notch filter which notches out the desired audio signal (desired test tone) and amplifies all other components. The amplified noise-plus-interference-plus-distortion sample is routed to a noise threshold amplifier which has an adjustable threshold which determines the noise and interference level which will be maintained at the output of the input audio amplifier. That portion of the noise and interference sample which exceeds this threshold is amplified and routed to the AGC driver stage. This stage integrates and converts the input signal into a dc AGC voltage. This AGC voltage controls the gain of the input audio amplifier to maintain the noise-plus-interference-plus-distortion level at the output of the audio amplifier

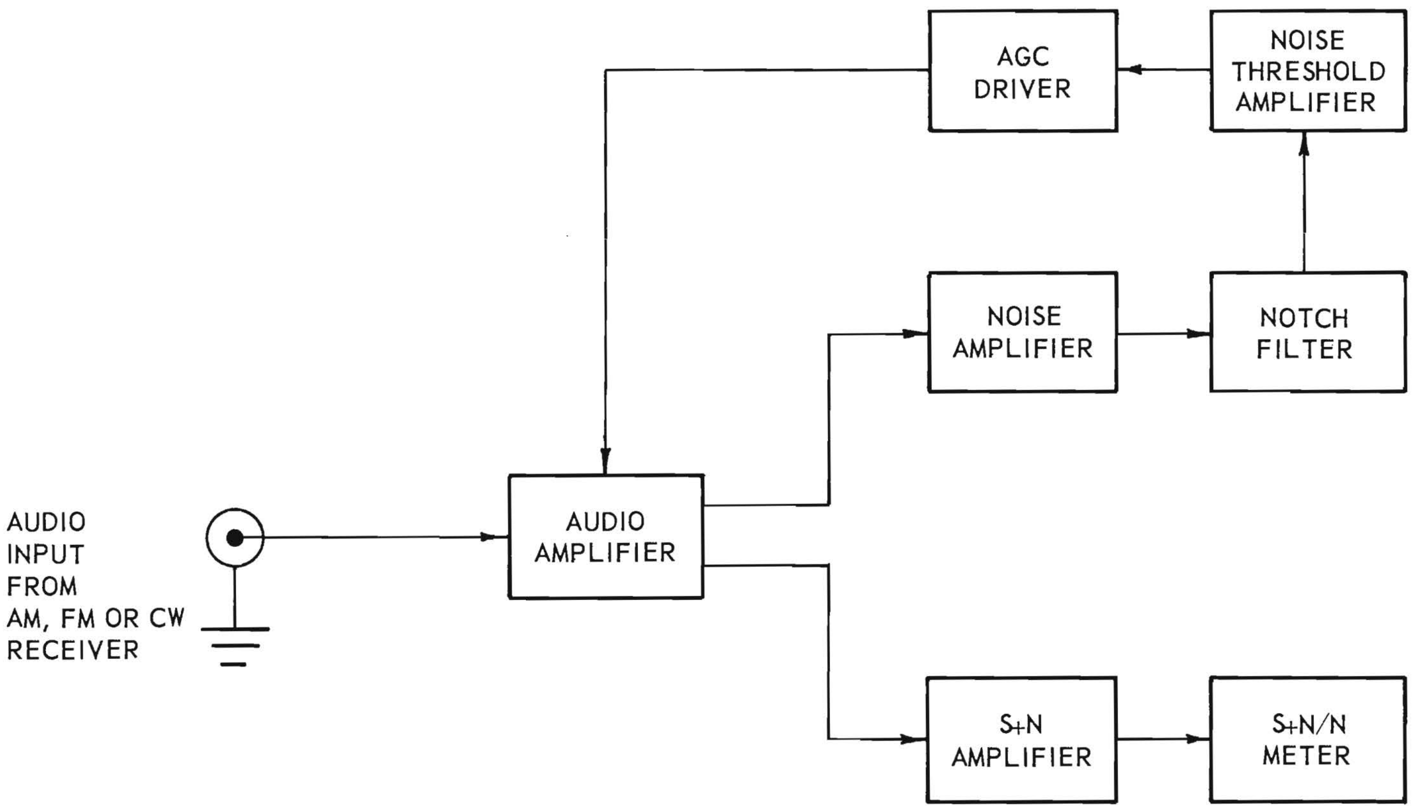


Figure 3. Block Diagram of a Standard Response Indicator for AM, FM, and CW Systems.

at a desired level, independent of the input level.

The noise-plus-interference-plus-distortion level at the input of the signal-plus-noise channel is a known, constant level, and hence, since the amplitude of the desired signal is changed proportionally to the noise level in the common input audio amplifier, it is only necessary to measure the amplitude of the composite signal to establish the $\frac{S+N}{N}$ ratio of the input audio signal. The total audio signal, including the desired signal, is amplified in the signal-plus-noise amplifier, and the output is applied to a voltmeter. The voltmeter provides a continuous, direct reading of $\frac{S+N}{N}$ ratio in decibels on a front panel meter.

This system utilizes the same basic technique that has been utilized in distortion analyzers for some time. However, providing two separate channels and the AGC loop makes it possible to obtain a continuous, direct reading of $\frac{S+N}{N}$ ratio without the inconvenience of switching from "notch in" to "notch out" positions, adjusting the input level, and determining the difference between two meter readings. In addition, a simple circuit to provide a Go/NoGo output signal to permit remote operation can be readily added to this system, but presents a real problem with the distortion analyzer. It would probably be desirable to add a two-pole switch to (1) open the AGC loop and (2) disconnect the S+N amplifier output from the voltmeter and connect the noise threshold amplifier output to the voltmeter during tuning of the notch filter. This would allow the notch filter to be tuned to the desired signal frequency by tuning for a dip on the meter.

It is apparent from the above discussions of the two proposed standard response indicators that two different techniques are required to operate with pulsed and CW, AM, and FM systems. Pulsed systems require a time division multiplex technique while CW, AM, and FM systems require a frequency division multiplex technique. However, in order to obtain a general purpose standard response indicator, the two techniques can be integrated into a single instrument as shown in Figure 4. Not only does this approach provide a general purpose instrument, but a significant amount of the circuitry (power supplies, output voltmeter, etc.) can be shared between the two functions.

Based on the information available[2] it appears that a fully transistorized, portable general purpose standard response indicator is quite feasible. It is anticipated that such an instrument will significantly improve the accuracy, repeatability, and correlation of spectrum signature measurements on pulse, CW, AM, and FM receivers since it will permit a given signal-to-noise ratio to be established more accurately, a given ratio to be reestablished any number of times over both short and long periods of time, and provide a common standard for various measurement teams operating at remote locations.

3. Directional couplers

A general discussion of the requirements of signal samplers was included in Quarterly Report No. 1. Directional couplers in particular seem to be the most useful sampling device at frequencies where they are usable.

Since couplers are needed to sample the transmitter output signal, their power handling capabilities are of prime importance. Ideally they should be capable of handling the rated power of the transmission system which is the case for waveguide narrow wall couplers. Narrow wall couplers also meet the 40 db coupling criterion as established in Quarterly Report No. 1 and are available commercially to cover waveguide bands through 40 Gc.

Commercial coaxial couplers are generally rated at 1,000 watts or less which is lower than the rating of the coaxial line. Octave bandwidths are available above 240 Mc.

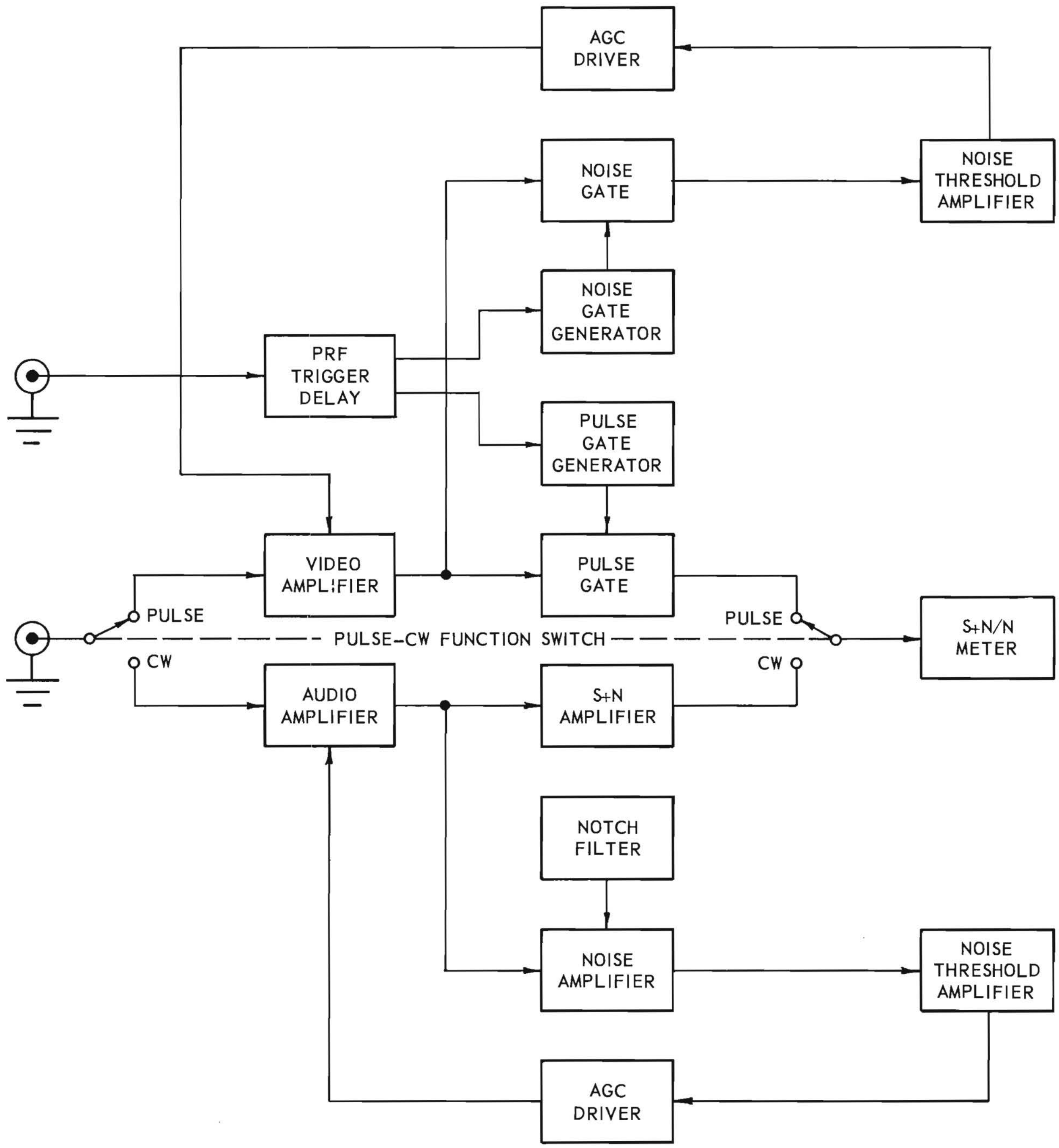


Figure 4. Block Diagram of an Integrated Pulse-CW Standard Response Indicator.

A variable probe coupler such as the General Radio Model 874 GAL coupler could be used from 100 to 240 Mc. This coupler possesses a power handling capability of approximately 1,000 watts at 100 Mc which decreases inversely as the square root of the frequency.

In Quarterly Report No. 2 the conclusion was reached that a high powered attenuator would be useful as a sampling device from 14 kc to 100 Mc. If space requirements or heat dissipation presents a problem as it might in a field setup, the resistive coupler referred to in Quarterly Report No. 1 would be more appropriate. Further evaluation of this resistive sampling technique needs to be done before selecting this method.

Merrimac Research and Development, Inc. advertises two models of an IF directional coupler that collectively will cover from 0.15 to 200 Mc with a nominal coupling of 15 db. The severest limitation on these couplers is the one watt power rating, but it is quite likely that the power rating can be raised and the coupling value increased.

Desirable specifications for coupling devices are as follows:

a. Waveguide

Bandwidth: standard waveguide band

Power rating: rating of waveguide

Coupling: 40 db ± 3 db

Type: narrow wall

Directivity: 20 db

VSWR: 1.10:1

Insertion loss: 1 db

Secondary line VSWR: 1.3:1

b. Coaxial:

Bandwidth: octave coverage (minimum)

Power rating: 1000 watts

Coupling: 40 db

Directivity: 30 db (nominal)

VSWR: 1.3:1

Insertion loss: 1.0 db

Secondary line VSWR: 1.3:1

Impedance: 50 ohms

4. Isolators

In Quarterly Report No. 2 reference was made to the usage of isolators to reduce undesired reflections at the input of a receiver. An isolator could be used to reduce an excessive VSWR by attenuating the reflected wave. Isolators may be used effectively to minimize generator intermodulation that is a problem in conducting the receiver intermodulation test. The placement of an isolator in each signal path attenuates the interfering signal and reduces the possibility of product frequency generation in the signal generators.

Coaxial isolators are generally available in octave bandwidths or greater above 500 Mc. Waveguide models are available that cover a waveguide band.

Specifications:

a. Waveguide

Bandwidth: standard waveguide band

Isolation: 20 db

Insertion loss: 1 db

VSWR: 1.15:1

Power (avg): 10 watts

b. Coaxial

Bandwidth: octave (minimum)

Insertion loss: 1 db

VSWR: 1.25:1

Power (avg): 10 watts

Isolation: 20 db

Impedance: 50 ohms

5. Attenuators

Attenuators are useful in any measuring setup for extending the range of power measuring instruments. They may also be used to provide a reference impedance for insertion loss measurements and to reduce reflections occurring in a mismatched system.

Two basic techniques are used in building a coaxial attenuator that is broadband. The lower frequency type which is useful from dc to 4 kMc is a resistive T section network consisting of a disc resistor between two rod resistors in a coaxial line. The higher frequency model which is useful to 11 kMc is a distributed element attenuator conisiting of a matched resistive element in the center conductor of a coaxial line.

One type of waveguide attenuator utilizes a section of resistive material parallel to the electric field lines in a rectangular guide. The attenuation is adjusted by appropriate placement in the electric field region.

The power handling capabilities for a given size attenuator are generally determined by the temperature characteristics of the resistive material. Special construction techniques providing for better heat dissipation make possible higher powered attenuators. For the purpose of the Design Plan, 1 watt attenuators will probably be adequate since they will be used after the coupler or other signal sampler.

The data from some manufacturers indicate that closely matched attenuators are available that exhibit small variations from their nominal attenuation over limited frequency ranges. The typical characteristic curves indicate that the specifications on the variation of attenuation are relaxed in an attempt to extend the frequency coverage.

The typical VSWR specification is in the neighborhood of 1.5:1. More closely matched units are necessary to avoid exceeding the 1.3:1 specified for the Test Set. If the attenuator is to be used to correct mismatches, its residual VSWR must be low enough to permit correction to within the desired limits.

Desirable specifications for fixed attenuators are:

a. Waveguide

Frequency range: waveguide band

VSWR: 1.15:1

Attenuation: 10 db ± 1 db

Power (avg): 1 watt

b. Coaxial

Frequency range: 0 to 11 Gc

VSWR: 1.3:1

Attenuation: 6 db ± 0.5 db

Power (avg): 1 watt

Impedance: 50 ohms

6. Dummy Loads

The selection of a dummy load is influenced by a number of factors. Although a specification of the Design Plan is a 10 kw CW power handling capability, a termination of this capacity is not practical or necessary in most cases. The physical size alone would be incompatible with the rest of the accessory items. In addition, present state-of-the-art does not include such power handling capabilities above 1500 or 2000 Mc.

A review of the testing setups reveals that limitations of other accessory items make extremely large terminations unnecessary. The main line and secondary line power rating of coaxial directional couplers place an upper limit on power requirements for loads unless higher power couplers become available. For instance, a 1 kw main line rating on couplers would negate any higher power requirements on terminations. A higher powered transmitter would require that its output be radiated in order to perform spurious emissions tests and other tests involving the higher power transmitter output.

A problem is also encountered in transmitter intermodulation tests in that the amount of power that can be handled by the secondary line of a directional coupler is generally much less than the capacity of the main line. This is true for both coaxial and waveguide models. Coupling of higher powered transmitters must then be done by radiation, which removes the need for terminations. The power line tests and emissions tests on waveguide systems could be done as readily with the transmitter loaded with its associated antenna. The main-line power limitation of couplers for waveguide systems does not seem to be a problem since narrow wall directional couplers are capable of handling the rated power of the guide.

Dry loads, either air-cooled or liquid-cooled, are generally limited in their frequency coverage from dc to 10 Gc (or less) or to a waveguide band. Above 1 kw capacity they become rather large. Water loads are smaller in size, allow the greatest dissipation of power in the microwave region, and provide a wider useful frequency range. An adequate water supply is required which may not always be available in a field test setup. Water reservoirs and cooling units of a practical size limit the capacity of such loads to 2 kw in the absence of a large supply of water.

Thus, on the basis of the considerations of excessive physical size, limitations in state-of-the-art, and characteristics of the test setups a termination capable of handling 10 kw is neither necessary nor practical. A 1 kw load should be adequate for the Test Set. At the higher waveguide bands, transitions could be used to adapt the guide to lower band load. The frequency characteristics of the load must be compatible with the frequency of the signal to be absorbed.

Specifications:

Type: unspecified

Frequency: as wide as the state-of-the-art permits

VSWR: 1.1:1 (maximum)

Power: 1 kw

This nebulus frequency coverage specification is intended to encourage the selection of a load that will absorb as many harmonics of a signal as possible. Proper termination of a transmitter through at least its tenth or higher harmonic permits more accurate measurements to be made.

7. Filters

Quarterly Reports Nos. 1 and 2 discussed several considerations in the selection of filters along with some aspects of their commercial availability.

Although variable low-pass and high-pass filters are desirable, improved performance of fixed frequency filters may be the deciding factor in the final selection. Trade literature indicates a marked improvement in skirt characteristics as well as extended out-of-band performance. The number of fixed filters is of course larger than the number of variable filters to cover the same range. The consideration of fewer pieces of equipment is offset by the generally slower cutoff characteristics of the variable filters.

Band-pass and band-reject filters must be variable because of the impracticality of predetermining where in the testing range that the filters would be required. Trade literature does not permit a complete determination of the commercial availability of adequate filters.

Throughout the coaxial range low-pass and high-pass filters should be chosen with cutoff frequencies that will insure differentation between the fundamental and the second harmonic. If the cutoff frequency is chosen to be about 1.8 times the next lower cutoff frequency, sufficient overlap is provided. The skirt attenuation should rise rapidly enough to reach at least 60 db within 5 per cent of the cutoff frequency.

The following specifications are considered desirable, though not necessarily optimum, for filters to be used in test work:

a. Low-pass

Passband attenuation: 1 db

Stopband attenuation: 60 db

Skirt attenuation: 60 db within 5 per cent of f_c

Extent of stopband: 6 f_c

Spurious responses: none within stopband

Power rating: 2 watts

VSWR: 1.2:1 (see note)

b. High-pass

All specifications identical to those for low-pass filters except the passband should extend to 2 f_c.

c. Band-pass

Type: variable

Tuning range: octave or standard waveguide band

Bandwidth: 1 per cent of the tuned frequency

Out-of-band attenuation: 60 db within 1 per cent of f_c

Power rating: 2 watts

VSWR: 1.2:1 (see note)

d. Band-reject

Type: variable

Tuning range: octave or standard waveguide band

Bandwidth: 1 per cent of the tuned frequency

Skirt attenuation: maximum of 6 db within 1 per cent of f_c

Power rating: 2 watts

VSWR: 1.2:1 (see note)

The present state-of-the-art may be hard pressed to meet some of the specifications on the variable band-pass and band-reject filters. The specificiations were selected to be of maximum usefulness in a test program.

Note: Most filter specifications give the passband or tuned frequency characteristic impedance or maximum VSWR. For testing purposes it is desirable to know the out-of-band impedance or mismatch. A constant impedance filter would provide the most reliability in that its effect on out-of-band signals would be of a more predictable nature.

B. Experimental work

1. Thin film load

Increased effort was devoted to the thin film load this report period. Quarterly Report No. 2 presented a discussion of a possible configuration for a coaxial load. Before a final configuration can be selected and evaluated, characteristics of the power absorbing element must be known. Therefore, before directing additional effort toward the configuration, further evaluation of thin film resistors has proceeded.

A number of methods for producing a metal film on a substrate are known in the present-state-of-the-art. Firing, electroplating, evaporation, sputtering, and pyrolytic deposition are some of the well known techniques. Evaporation and sputtering have long been used for producing precise films over a small area; these processes can be used to deposit most metals and nonmetals. For the purposes of this effort, they are not easily applicable due to the requirement for a vacuum system capable of enclosing the substrate.

Pyrolytic deposition is an attractive technique because of its adaptability to larger surfaces. The only compounds available to the project were those of molybdenum and tungsten, both of which require an inert atmosphere during the process. Adequate information was not available on the quality control obtainable when applying the material to a large surface.

The firing process involves depositing the desired metal by applying a resinate solution to the substrate and then removing the carrier by heating. It is a simple process to use from an equipment requirements standpoint. Quality control is a matter of art in that it greatly depends upon the experience of the individual applying the film of resinate solution.

For the purposes of investigation to this point in the development, the firing process was chosen as being the most readily available, most easily applied, and least expensive to use. Using this technique, investigations of the temperature coefficient of resistance (TCR) of several samples of metal combinations were performed with a minimum of time.

Platinum and gold resinate solutions were applied to alumina substrates in varying combinations and fired. Table I presents a summary of the results

TABLE I

ELECTRICAL RESISTANCE DATA ON THIN FILM RESISTORS

Sample No.	Composition+	Substrate	Resistance++	TCR
1	1-0	Alumina+++	42.4	.00189
2	1-1	"	5.9	.00035
3	1-1	"	20.8	.00039
4	1-2	"	301.5	.00031
5	2-1	"	16.0	.00048
6	1-1.5	"	18.1	.00042
7	1-3	"	41.5	.00066
8	1-1	"	40.4	.00037
9	1-1	Fuzed Quartz	12.7	.00044

\+ This column gives the ratio of the volume of platinum resinate solution to gold resinate solution respectively. These resinate solutions are supplied by Engelhard Industries, Inc.

++ Resistance at room temperature after any annealing was done.

+++American Lava Company, AlSiMag 614.

of nine samples. It is of interest to note that the alloys of metals exhibit a lower TCR than does the single-metal sample. The lowest TCR's are produced by approximately volumetrically-equal solutions of platinum and gold.

Sample 9 was fired on a fuzed quartz substrate. The slightly higher TCR is characteristic of films applied to smooth substrates as opposed to rough surfaces.

Figure 5 shows the resistance versus temperature behavior of five samples which demonstrate the typical behavior. The definitely greater temperature dependence of the single-metal resistance is shown by sample 1. Figure 6 shows the per cent change in resistance versus temperature for selected samples. Room temperature (25° C) is taken as the reference temperature. These curves are from data that were taken after annealing of the film.

Attempts were made to fire rhenium resinate but difficulties were encountered due to the absence of a firing procedure. Rhenium oxidizes at about 350° C and above this temperature an inert atmosphere must be supplied. Platinum-rhenium alloys produce very low TCR's and for this reason rhenium is being investigated.

Palladium has demonstrated a low TCR[3] for a pure metal. No reports of experiments with a platinum-palladium alloy have been found. Palladium is a relatively inert metal with a melting point near that of platinum, and it should be easier to fire than rhenium. In view of these characteristics, some palladium resinate solution has been ordered. Further examination of palladium and rhenium alloying with platinum will be conducted upon receipt of the resinate and required firing procedure for the rhenium.

Power dissipation tests were conducted on samples 3 and 9 by applying 60 cps power to the sample. A hot spot developed near the center of sample

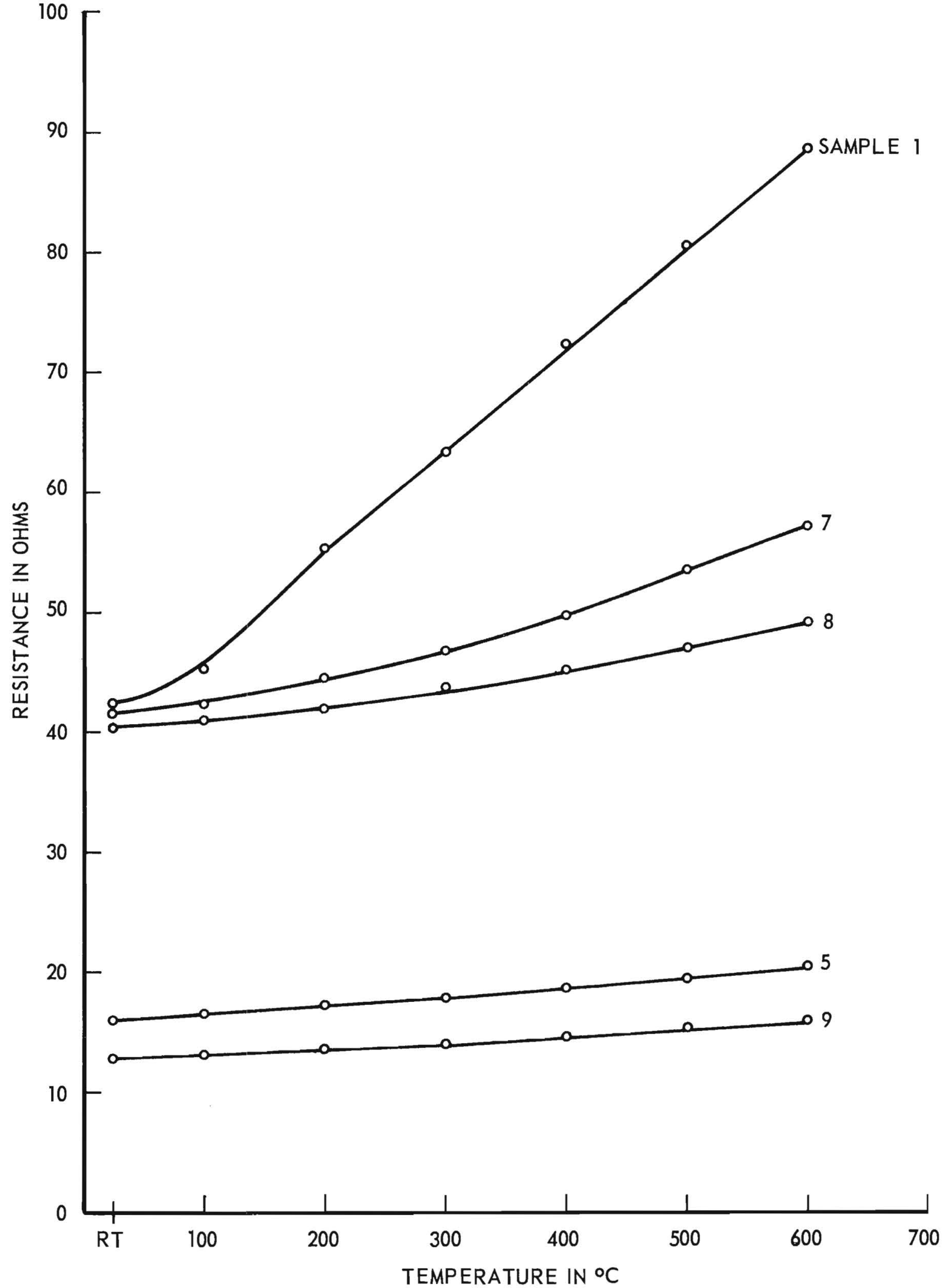


Figure 5. Resistance Versus Temperature Behavior for Five Fired Resistance Samples.

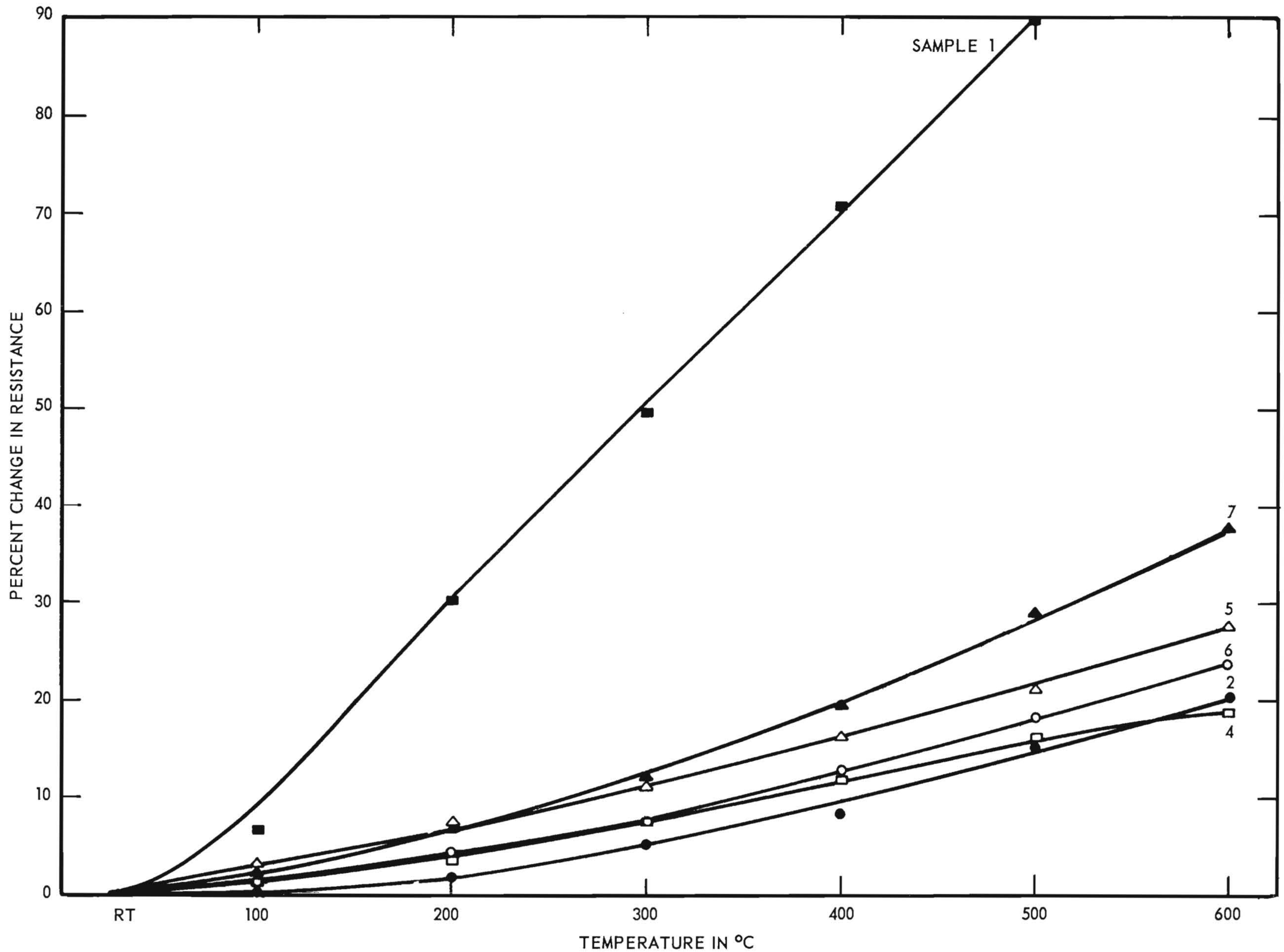


Figure 6. Per Cent Change in Resistance Versus Temperature for Six Fired Resistance Samples.

3 which resulted in a crack developing around the unit. It appeared as though the localized heating caused an increase in resistance and the two effects cascaded to failure. The power test was run on sample 9 to observe the differences in the quartz and alumina substrates. More even heating occurred over the sample but this could have been due primarily to a more uniform film on the smooth surface. Film failure appeared to be in the nature of film agglomeration. Agglomeration has been found[3] to occur at about half the melting temperature. Probably agglomeration of the gold used in the film resulted in failure. This particular effect was the primary factor prompting the consideration of higher melting point metals such as rhenium and palladium as the alloying material for platinum.

The power dissipation tests resulted in a revaluation of the load configuration presented in Quarterly Report No. 2. The two samples tested failed at less than 300 watts applied power. The first configuration requires the heat developed in the resistor to be predominantly radiated to the shell and then removed by convection and radiation. At the temperature allowable, radiation is not an efficient mode of heat transfer. To provide a larger dissipating surface it may be necessary to plate the resistive element on the outer conductor and taper the inner conductor.

2. Receiver input coupler

Quarterly Report No. 2 reported the development of a minimum-loss resistive coupler that could be used to match a 50 ohm system to a 300 ohm system. This coupler exhibited an insertion loss rise up to 150 Mc which then leveled off at about 15 db.

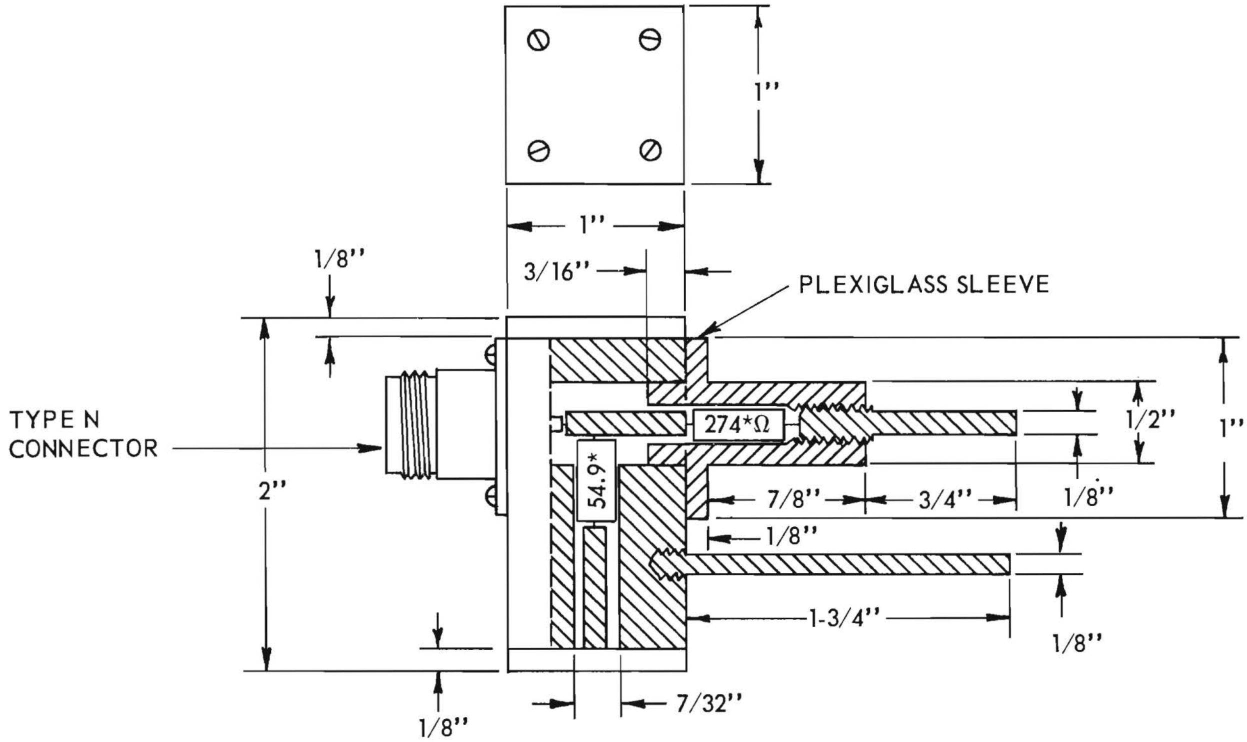
This quarter the holder was redesigned and precision resistors were purchased. International Resistance Company, Type MEB, 1 per cent tolerance, resistors were obtained.

Experimental investigations revealed that the 274 ohm resistor in series with the 300 ohm line must be placed exterior to the metal body to flatten the insertion loss characteristic. This was accomplished by placing the resistor inside a plexiglass sleeve support that affords adequate mechanical rigidity to the 300 ohm terminals. Figures 7 and 8 show more clearly the construction of the coupler.

Figure 9 shows how the insertion losses for two units in tandem and the input impedance for one unit vary with frequency. The total insertion loss for the two units is 26.5 db on the average from 14 kc to 400 Mc. Attributing half of the total loss to each coupler, each unit has a 13.25 db insertion loss, which agrees favorably with the idealized figure of 13.42 db for a minimum loss resistive pad. The maximum input impedance shown on the curve represents a VSWR of 1.2 in a 50 ohm system.

3. Audio susceptibility tester

Work continued during the third quarter on the audio susceptibility amplifier and transformer. Several designs of transistorized power amplifiers to furnish the audio susceptibility testing voltage were considered. An amplifier was constructed and tests are presently underway on this unit. This amplifier consists of a driver and power output stage. The power output stage is a conventional arrangement of PNP power transistors in a bridge configuration, one half of the bridge being made up of a series connection of the power transistors and the other half of the bridge being the positive and negative power supplies. The load is connected between the midpoint of the power supplies and the power transistors in such a manner that the dc current can be balanced out of the load. Additional sets of power transistors may



COUPLER BODY & 300 OHM TERMINALS MADE OF BRASS

*IRC TYPE MEB RESISTORS

Figure 7. Partial Cutaway Drawing of Receiver Input Coupler.

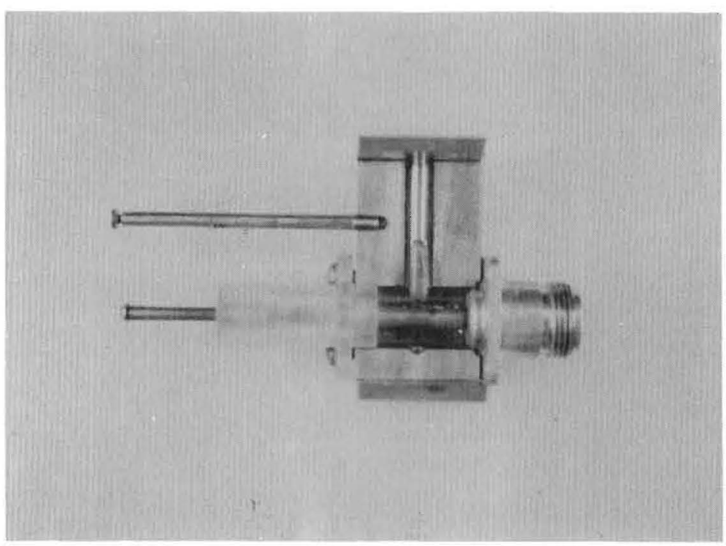


Figure 8. Photograph of One of the Receiver Input Couplers.

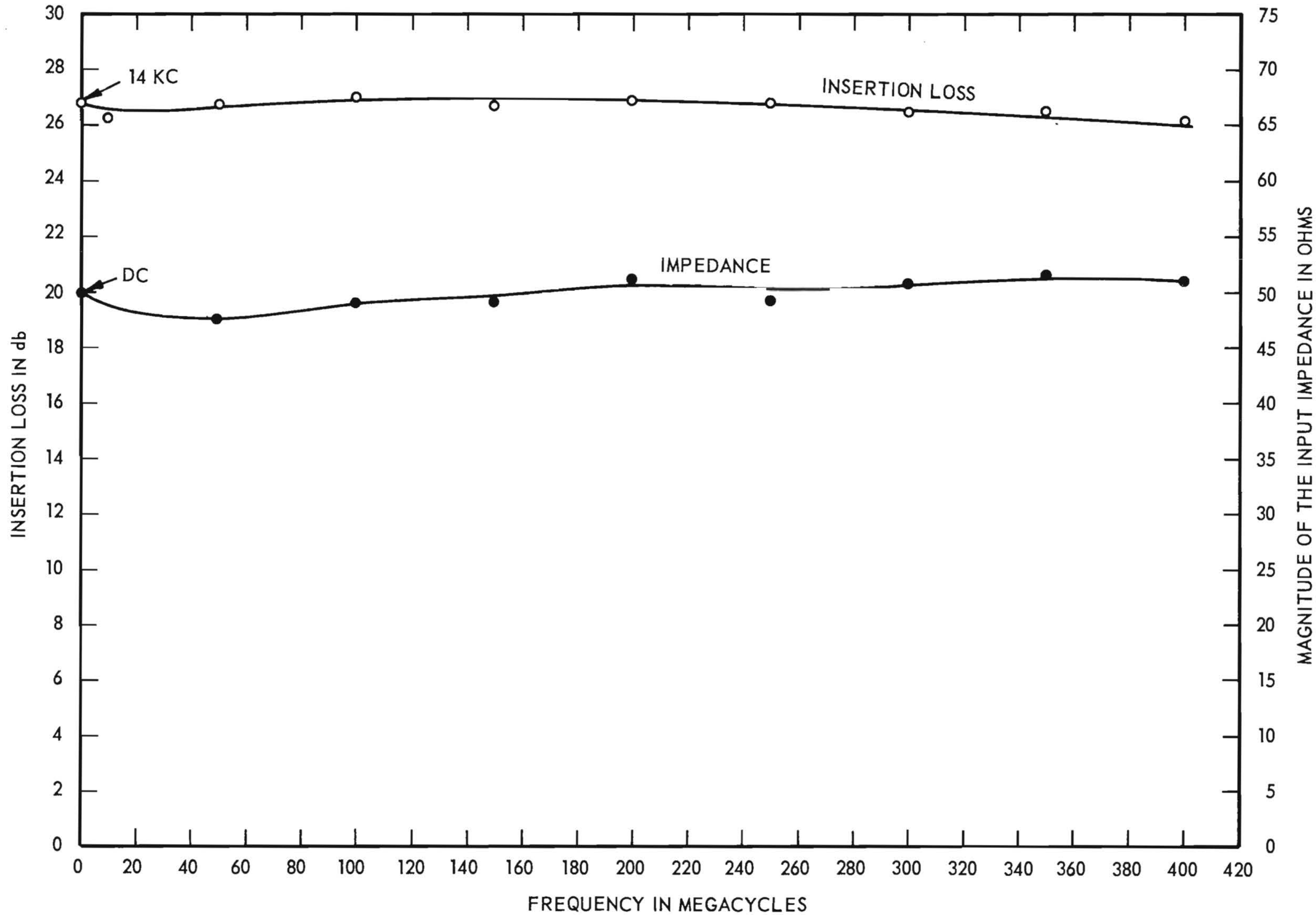


Figure 9. Insertion Loss and Input Impedance Variations with Frequency for the Receiver Input Coupler.

be paralleled with those in the power output stage to increase the power handling capababilities. A transformer was constructed to obtain the phase relationship of the driving signal required by the output stage because of the use of all PNP transistors. This amplifier has operated at a 30 watt level with what appears to be an adequate thermal margin.

Consideration is being given to the possible operation of the transistors in a series configuration of two transistors to replace one transistor to obtain a higher breakdown voltage. The problem of transients which may be passed back through the transformer and their effect on the amplifier has been considered. Several methods of possible protection of the amplifier include the use of zener diodes, or surge suppressing selenium rectifiers, to limit the voltage of transients on the primary of the coupling transformer. Protection of the amplifier in case of the loss of the low electronic output impedance must be considered also since it is this impedance which is depended upon to keep the power frequency voltage drop on the secondary of the coupling transformer within the specified limits. Loss of the low amplifier output impedance could result in a high voltage being applied to the amplifier.

A possible method which may be used to protect against the steady state situation under these conditions is to short circuit the transformer winding on the amplifier side with a set of relay contacts when the amplifier power source is lost. The methods depend on the transient suppressors to protect the amplifier until the relay can operate.

The audio susceptibility tester transformer is presently being constructed, procurement of materials for the present design having been completed. This design will yield a transformer with a maximum turns ratio of

10:1 and with low leakage reactance, the conductors being copper foil and the winding configuration being bifiliar.

C. Evaluation of EMCO rejection filter

In performing emissions tests on transmitters it is often necessary to attenuate the fundamental to allow measurements of adjacent signals which are much lower in amplitude. For this reason rejection filters are useful in extending the dynamic range of the measurement system and avoiding damage to sensitive measuring instruments. At the beginning of this contract two principal sources of rejection filter designs were available in the 14 kc to 1 kMc range. The Bureau of Standards developed a set of seventeen different filters to cover this frequency range.[4] Filters developed by the Electro-Mechanics Company, Austin, Texas, cover this range with three filter units using plug-in-coils. One of these units was purchased and evaluated for possible use in the Accessory Set.

The following are the published specifications:

Model: MF

Serial Number: 1105

Tuning range: 100 to 400 Mc

Number of bands: 3

Characteristic impedance: 50 ohms

Attenuation: 120 db or more at rejection frequency; 40 db or less at 10 per cent removed

Dimensions: 8-1/2" high
11-1/2" wide
11" deep

The insertion loss versus frequency characteristic for a tuned frequency at the center of each coil range was obtained and the results are shown in Figure 10. Two important features are to be noted on these curves. One is that the maximum rejection obtainable by project personnel adjusting the filter was less than 100 db at best and only about 81 db at one point. A possible contributor to this less-than-specified rejection could be a broad skirt to the spectrum of the output of the signal generator. If this signal extends beyond the bandwidth of the rejection filter and feeds into the IF of the measuring instrument the rejection figure will be degraded. In the opinion of project personnel, the primary problem lies in the precise adjustment required on the potentiometer and capacitor controls of the filter.

From 400 to 1000 Mc the attenuation begins to rise and develop peaks as high as 20 db in the neighborhood of 700 Mc. From the reoccurrence of these peaks with each coil they appear to be due to resonances in the body cavity of the filter enclosure.

A pseudo-sweep system was constructed by mechanically coupling a slow speed synchronous motor to the capcitor control. The motor was equipped with start-stop and reversing switches. Curve tracing was accomplished by recording the output of an Empire Devices Noise and Field Intensity Meter, Model NF105, while the filter was swept across its region of maximum rejection. In this manner the mechanical backlash in the controls was graphically displayed. From these graphs and recorded dial readings, Figure 11, which demonstrates the backlash in the capacitor adjustment, was constructed.

The chart recording shown in Figure 12 is a sample of the effects caused by jarring and by introducing additional capacitance into the body

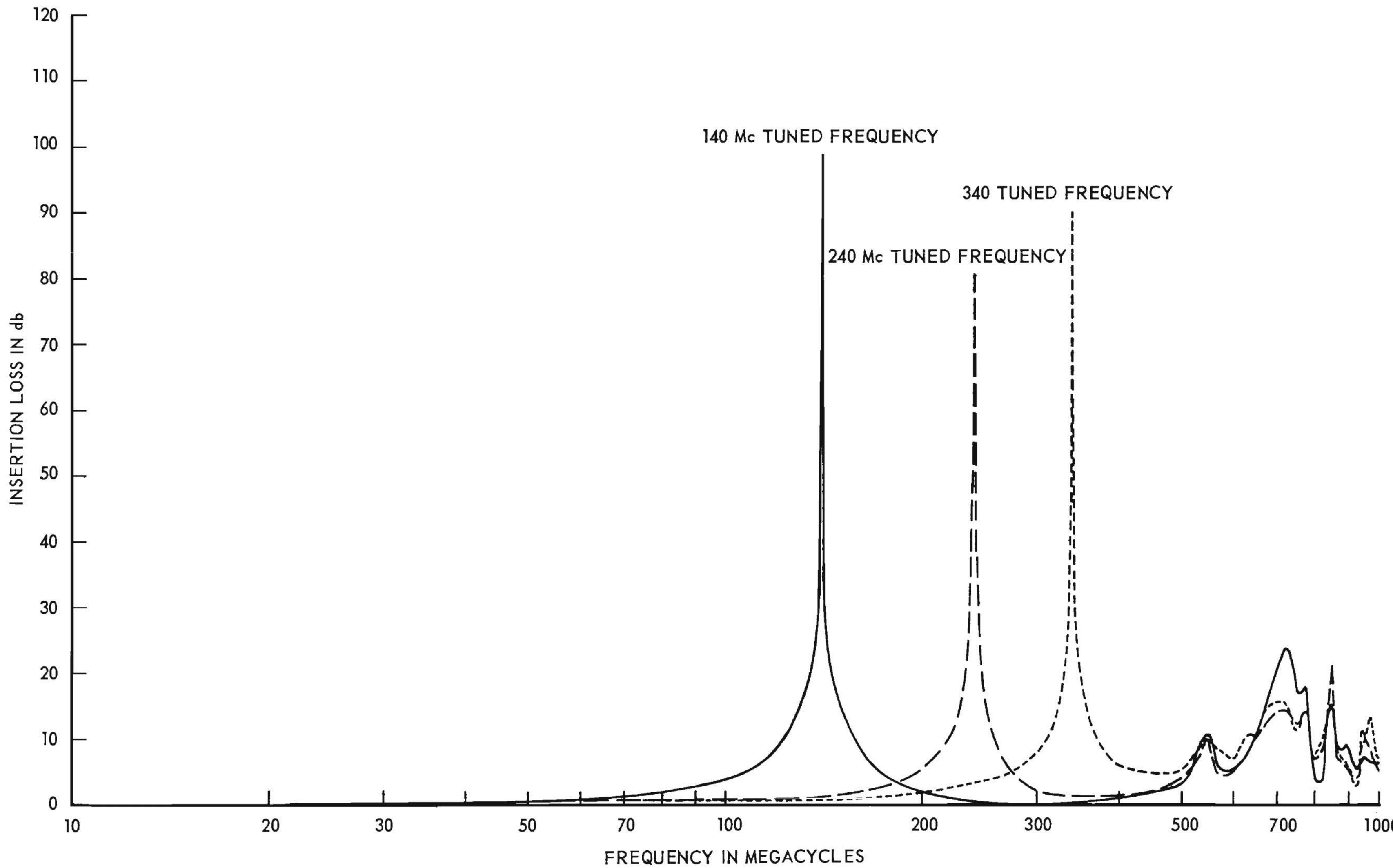


Figure 10. Insertion Loss Versus Frequency Characteristics of the EMCO Rejection Filter.

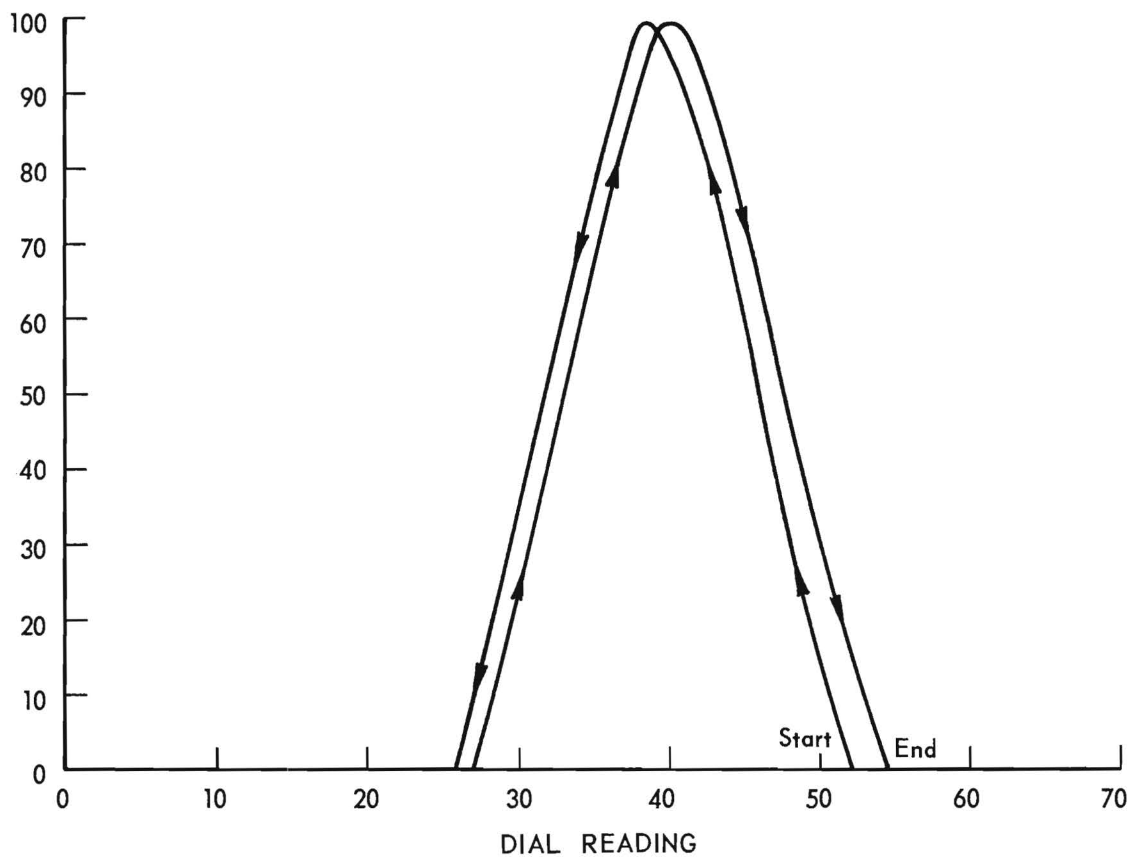


Figure 11. Backlash Behavior of the Capacitor Tuning Control.

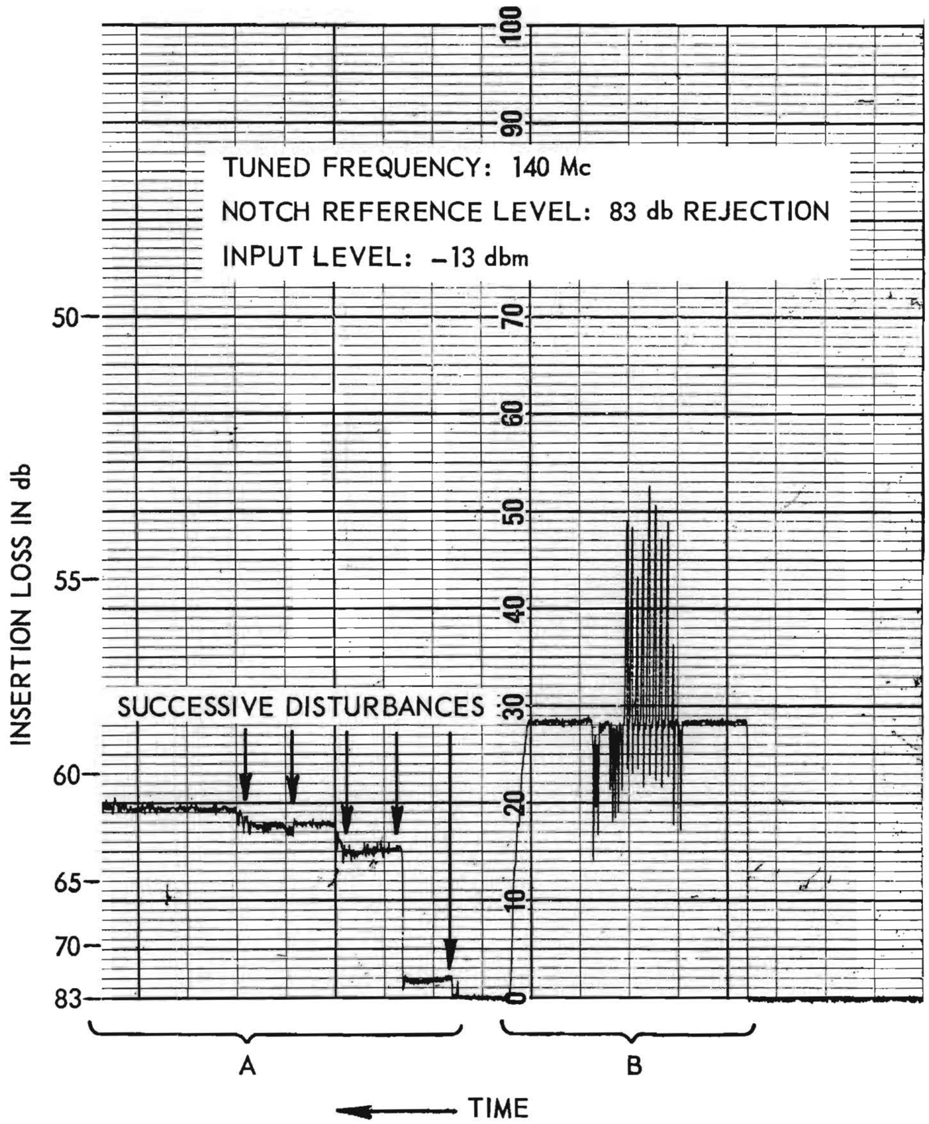


Figure 12. Chart Recording Showing the Effects of Jarring the Filter and Adding Capacitance to the Body Cavity.

cavity. The tuning did not return to its original position after being jarred off. Region A shows the effect on the output caused by jarring the filter. Note that a change in the rejection of more than 20 db was caused by disturbing the filter in this manner. Region B shows the necessity for always maintaining the coil holder on the filter because changes inside the cavity cause several decibels of variation in the rejection. The 25 db change in rejection was caused by the removal of the coil holder.

In conclusion, it appears that this filter is not entirely satisfactory for this Design Plan because (1) extreme care is required to obtain rejection of 80 db or more; (2) mechanical backlash in the tuning controls render tuning even more difficult; and (3) skirt attenuation is too broad for measurement of adjacent signals.

V. CONCLUSIONS

Several items of accessory equipment can be designated at present as fulfilling requirements for the final accessory set or that should be developed for use in the accessory set. A frequency measurement system meeting accuracy requirements suitable for most spurious response identification purposes and general frequency measurement requirements of MIL-I-11748 is presently available. Such a system is described in Hewlett-Packard Application Note No. 2 and is suitable for measurement of frequencies throughout the range of interest for the accessory set. Some work needs to be done to perfect simple operating procedures for this system. Another item of equipment which would provide a faster and more repeatable measurement of a standard response at the output of a receiver is the pulse and CW standard response indicator. This system would remove much of the labor of making measurements as well as improve their accuracy by removing operator judgement from the measurement. Several other items of accessory equipment for which the specifications can be outlined at present were discussed.

Films of gold and platinum alloys do not appear capable of withstanding the desired operating temperatures. Additionally, the resistance change over the temperature range is too great for the intended use. Further investigation into other materials and plating techniques will be required to lower the TCR and increase the temperature range of operation.

A receiver input coupler was constructed which allows matching 300 to 50 ohm systems by use of a minimum loss pad. Tests on this pad indicate that its characteristics are within the specifications imposed by the technical requirements.

A transistorized audio susceptibility amplifier has been operated at a 30 watt level with good thermal characteristics. The problem of protection of this amplifier against transients was considered from several viewpoints.

An EMCO rejection filter was evaluated. It appears that this filter is not entirely satisfactory for the purposes of the accessory set because of the tuning difficulties encountered to obtain a rejection of 80 db or more, mechanical backlash in the tuning mechanism, and attenuation of the filter near its rejection frequency being too high.

VI. PROGRAM FOR NEXT INTERVAL

During the next quarter work on the design plan will be continued so that it can be finalized.

Work on the audio susceptibility tester will continue.

Additional alloys and techniques of deposition of thin films will proceed as time permits.

VII. IDENTIFICATION OF KEY TECHNICAL PERSONNEL

Name	Title	Approximate Hours
Hugh W. Denny	Research Assistant	456
William R. Free	Research Engineer	47
Neil T. Huddleston	Graduate Research Assistant	344
D. W. Robertson	Head, Communications Branch	47
Joseph R. Walsh, Jr.	Project Director	311
W. Bruce Warren	Research Engineer	3
E. Wendell Wood	Assistant Research Engineer	60

Mr. Free joined the project in November 1963. He received a B.S. degree in Electrical Engineering in 1954 and a M.S. degree in Electrical Engineering in 1959, both from the Georgia Institute of Technology. His previous experience includes 3 years as an Electronic Engineer with Sperry Gyroscope Company at Great Neck, New York; 3 years as an Assistant Research Engineer with the Engineering Experiment Station, Georgia Tech; and 4-1/2 years as a Senior Staff Engineer with Sperry Microwave Electronics Company at Clearwater, Florida. Mr. Free's experience has been in the fields of Communications, RFI, and Pulse Circuit Design.

VIII. REFERENCES

1. "Measuring Frequency From VHF Up to and Above 18 Gc With Transfer Oscillator/Counter Techniques," Application Note 2, Hewlett-Packard Company, Palo Alto, California, May 2, 1963.

2. W. R. Free and L. A. Hill, "A Standard Response Indicator for Pulsed Systems," Proceedings of the Ninth TRI-SERVICE Conference on Electromagnetic Compatibility, October 1963.

3. Richard B. Belser and Walter H. Hicklin, "Electrical Conductivity Studies of Metallic Films," Project A-303, Contract No. AF 33(616)-3870, Georgia Institute of Technology, Engineering Experiment Station, WADC Technical Report 57-660, ASTIA Document No. AD-155 573, December 1957.

4. "Instruction Manual for Filters, Tunable Rejection," National Bureau of Standards, BuShips Contract 1700R-629-59.

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1	Director, Electromagnetic Compatibility Analysis Center, ATTN: Lt. Col. John A. Gahr, U. S. Navy Marine Engineering Laboratory, Annapolis, Maryland 21402

A-693

DESIGN PLAN FOR A RADIO FREQUENCY COMPATIBILITY (RFC) ACCESSORY EQUIPMENT SET (U)

PROJECT A-693

H. W. DENNY AND J. R. WALSH, JR.

Contract DA 36-039 AMC-02223(E)
Department of the Army Project: 1G620501D449

15 June 1964

Prepared for
U. S. Army
Electronics Laboratories
Fort Monmouth, New Jersey

1964

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

FOREWORD

This report was prepared at the Georgia Tech Engineering Experiment Station on Contract No. DA 36-039 AMC-02223(E). The report discusses the results of a study project leading to the establishment of a Design Plan for accessory equipments to be used with radio interference measuring sets and other test equipment.

Respectfully submitted:

J. R. Walsh, Jr.
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

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(Continued)

LIST OF FIGURES (Concluded)

LIST OF TABLES

I. PURPOSE

The purpose of this project was to conduct a study leading to a Design Plan for accessory equipment to be used with radio interference measuring sets and signal generators. The accessory equipment includes the complementary devices necessary to determine radio frequency interference characteristics of U. S. Army electrical and electronic equipment in accordance with military specification MIL-I-11748. The frequency range of interest is 0.014 to 40,000 Mc. It was also the purpose of the project to investigate two items of equipment. These were a receiver input coupler and an audio susceptibility tester.

II. ABSTRACT

The results of a program to develop a Design Plan for accessory equipment to be used with radio interference measuring sets and signal generators is presented. The plan provides for establishing the various test setups required to make interference measurements in accordance with military specification MIL-I-11748.

Emphasis is placed on Class I equipment but many of the measurements required for Class II and Class III equipment can also be made with little or no modifications. Tests required have been analyzed and the configurations of test equipment required for each of these tests is presented in block diagram form.

From the individual test block diagrams, integrated block diagrams of accessory items are presented which show the configuration of switches and components necessary to provide for making the required measurements using a single system.

Areas where further development will be required or where deficiencies in present accessory equipment exist are pointed out.

The designs of two items of accessory equipment are summarized. These are a receiver input coupler and an audio susceptibility tester consisting of a coupling transformer and amplifier.

III. DESIGN PLAN

A. Introduction

This Design Plan is for the purpose of specifying the accessory equipment to be used with radio interference measuring sets and signal generators for determining radio frequency interference characteristics of U. S. Army electrical and electronic equipment in accordance with MIL-I-11748. This specification establishes the interference limits that equipment must meet to be acceptable. From the tests described in the document, considerable latitude is afforded in the details of test procedure. In the preparation of this Design Plan a previous Georgia Tech publication[1] and MIL-STD-449B were used as the source of detailed test setups. These documents should be consulted for the testing procedures when using the setups described herein.

MIL-I-11748 classifies electrical and electronic equipment into three classes as follows:

> "Class I. Equipment for generating, amplifying, transmitting, receiving, or utilizing radio-frequency electrical energy, within the frequency range covered by this specification, for purposes of communication in any form by wire or radio methods, or for test or maintenance of such communication equipment....
>
> "Class II. Equipment for generating, amplifying, controlling or utilizing radio-frequency energy for purposes other than covered by Class I, and of which any of the fundamental or other output falls within the frequency range covered by this specification....
>
> "Class III. Equipment capable of unintentionally generating radio-frequency energy while utilizing mechanical or non-radio-frequency electric power in the performance of its intended function."

Class I equipments have been considered primarily in designing the test setups since these are of predominant interest. Classes II and III equipments can be tested with the accessory set with little or no modifications.

An analysis of MIL-I-11748 indicates that the required tests on Class I equipments can be conveniently classified as follows:

(1) power line conducted emissions

(2) power line and nonsignal line conducted susceptibility

(3) nonsignal line audio susceptibility

(4) antenna and signal line conducted susceptibility - receiver

  a. narrow band
  b. broad band

(5) antenna conducted emissions - transmitter

  a. stand-by
  b. operating

(6) antenna conducted emissions - receiver

(7) intermodulation

(8) case and cable radiation

  a. narrow band
  b. broad band

(9) radiated susceptibility

  a. CW only
  b. CW modulated

(10) antenna radiated extraneous outputs, integral systems

These ten tests are delineations from the two general categories of conducted and radiated tests as described in MIL-I-11748. This breakdown enables an analysis of the test to be made and the establishment of equipment requirements.

B. Test setups

The individual test setups are presented here for reference purposes when examining in detail the final equipment setup for all the tests. Only block diagrams are presented. For detailed equipment requirements and test procedures reference should be made to MIL-STD-449B and other test procedures.[1]

1. Power line conducted emissions

Any large signal voltages that exist in a piece of equipment may couple into adjacent equipments through power lines (and other nonsignal lines) and cause interference. This test is designed to measure the frequencies and amplitudes of all signals which emanate from the equipment under test and appear on these lines.

Figures 1a and 1b show the block diagrams of the equipment setups for performing this test on receivers and transmitters, respectively.

2. Power line and nonsignal line conducted susceptibility

Signals capable of producing interference may be conducted into the equipment by the power lines or other nonsignal leads. Figures 2a and 2b are block diagrams of the equipment setups for measuring this form of susceptibility.

3. Nonsignal line audio susceptibility

The audio susceptibility test is a procedure wherein an audio signal voltage is inserted in series with a nonsignal line of a piece of equipment in order to determine whether or not these signals, so inserted, will degrade the performance of the equipment under test. Figure 3 shows the test setup for this test. The audio amplifier and isolation transformer are not readily available items at this time. Developmental work on these two items has been conducted under this contract and is summarized in the appendix and described in the final report[2] for this project.

4. Antenna and signal line conducted susceptibility

This test is applicable only to receivers and is essentially the spurious response test. This test setup is as shown in figure 4.

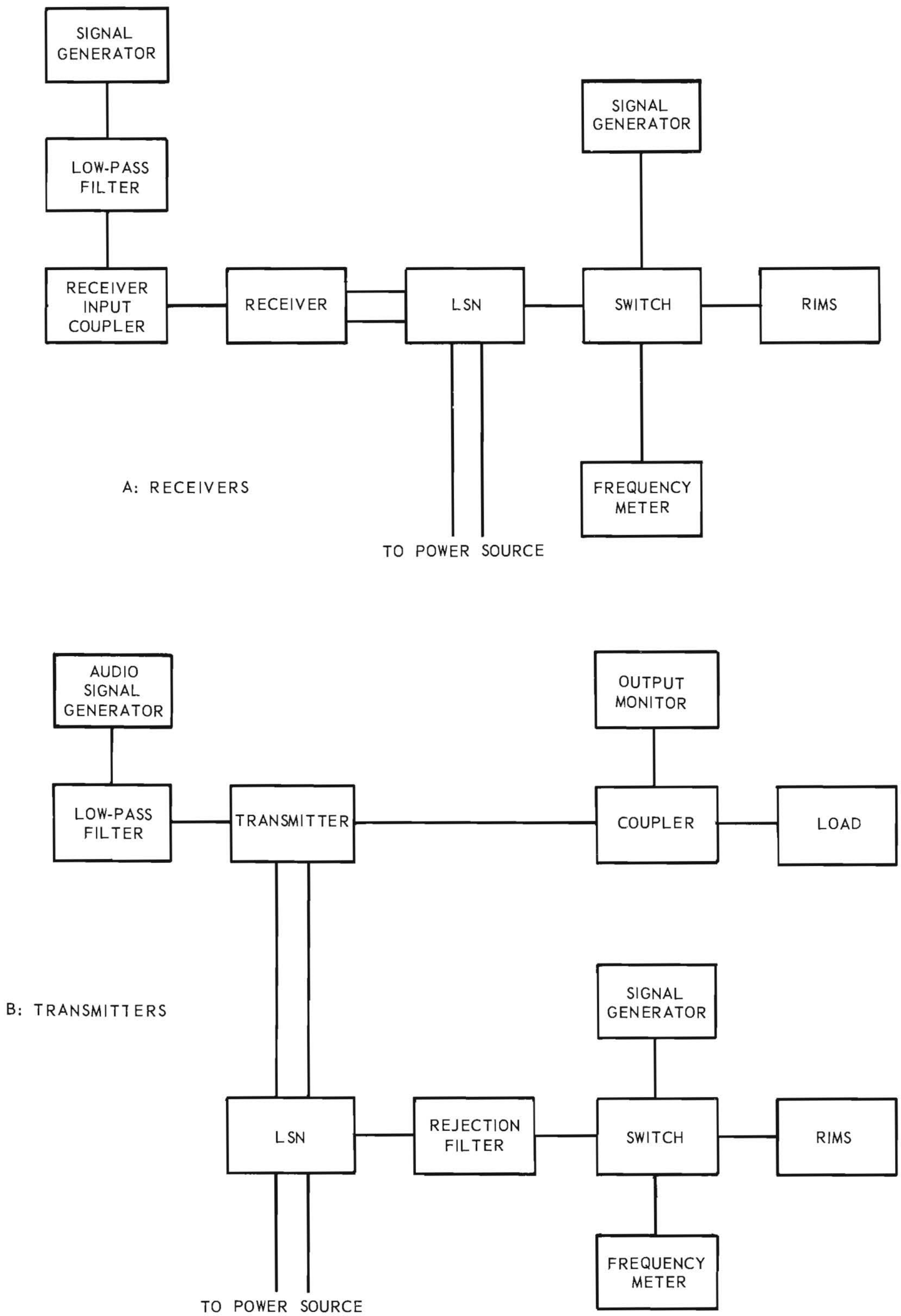

Figure 1. Block diagram of power line conducted emissions test setups.

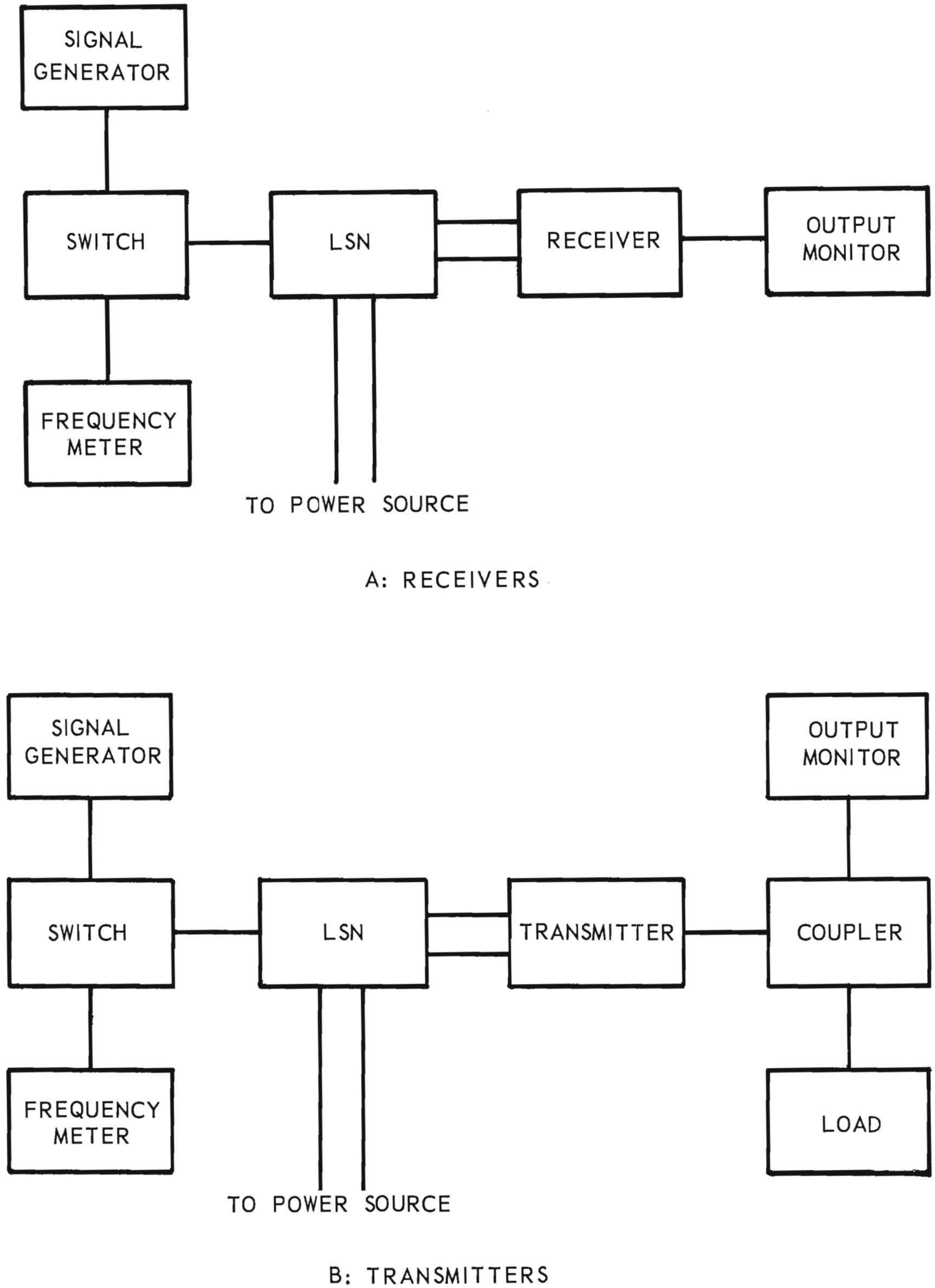

Figure 2. Block diagram of power line and nonsignal line conducted susceptibility test setups.

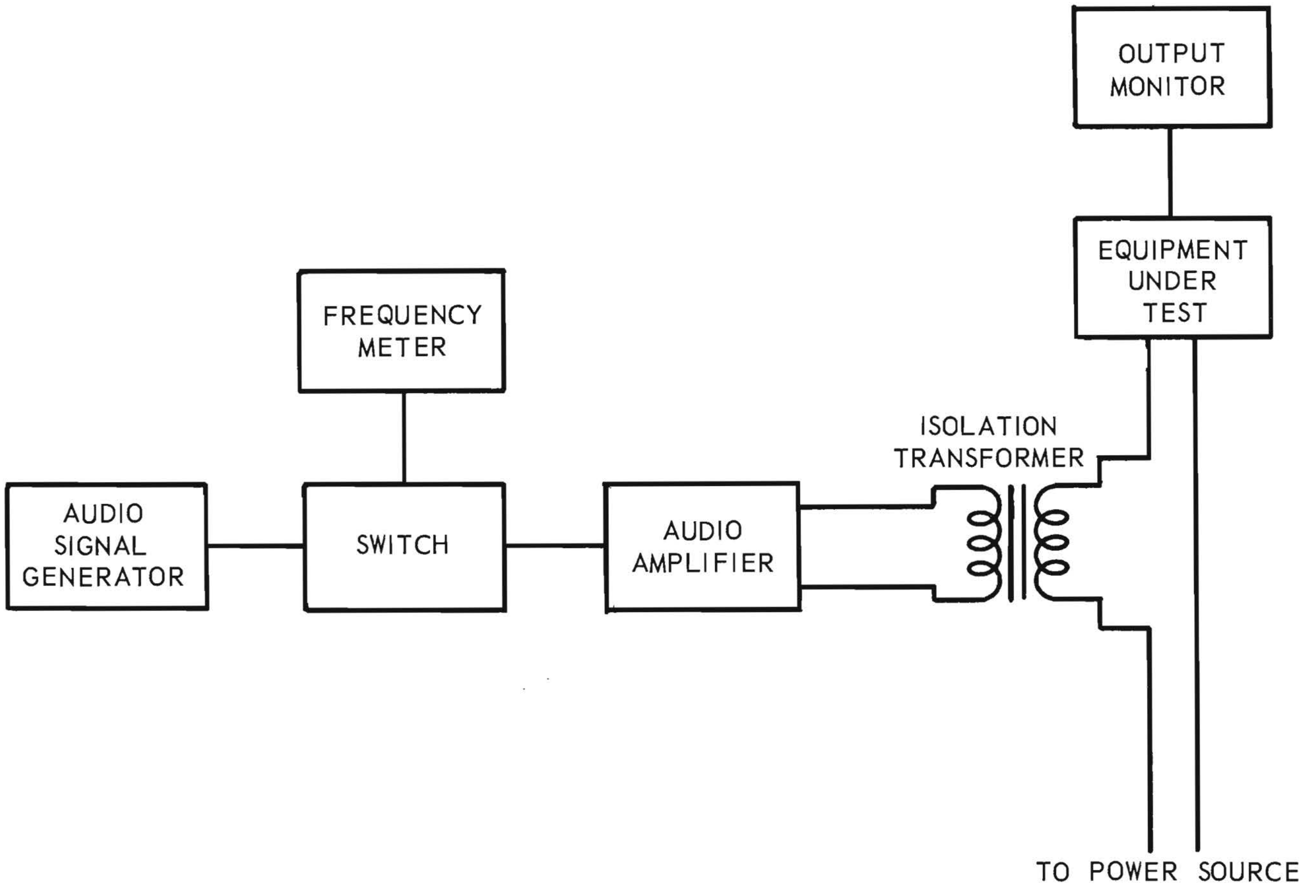

Figure 3. Block diagram of nonsignal line audio susceptibility test setup.

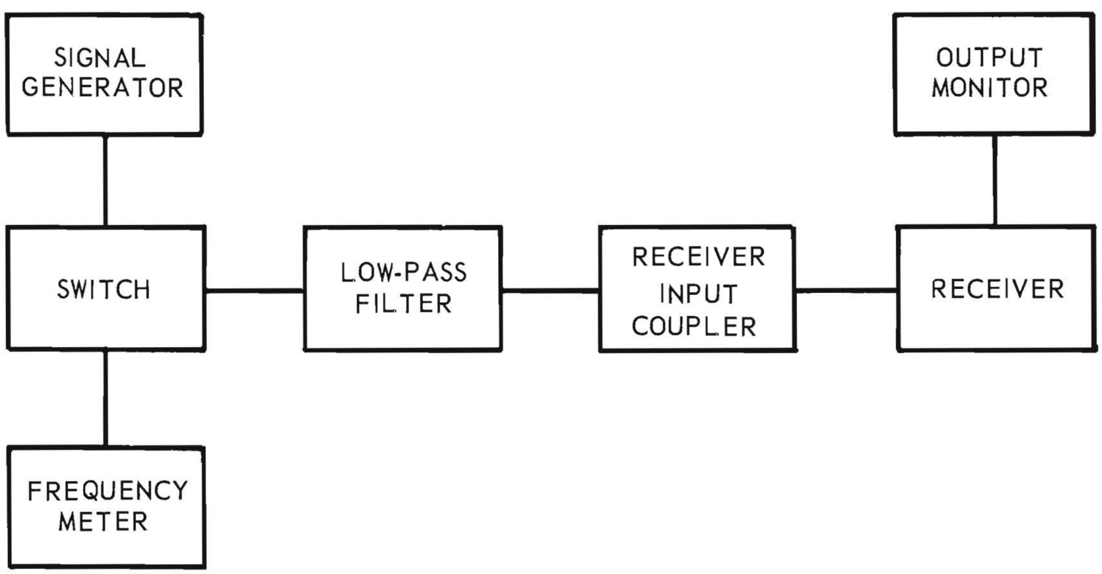

Figure 4. Block diagram of antenna and signal line conducted susceptibility test setup.

5. Antenna conducted emissions

This test is for the purposes of detecting, identifying, and measuring any signal that appears at the antenna terminals of a receiver or transmitter. The transmitter portion of this test is normally called the Spurious and Harmonic Emissions Test. Figures 5a and 5b show the test setups for the receiver and transmitter portions of this test.

6. Intermodulation

Figures 6a and 6b give the block diagrams of the test setups necessary to conduct the intermodulation tests on receivers and transmitters. Any time that two or more signals can reach a common nonlinearity there is a possibility of product frequency generation occurring. Since two or more signals are necessary to conduct this test there is always a problem of obtaining erroneous results due to intermodulation occurring in the generators when testing receivers, and in interference measuring sets when testing transmitters. This problem can be minimized by the proper use of isolators, hybrids, or filters. For high powered transmitters, coupling of interfering signals may have to be accomplished by use of the equipment antennas.

7. Case and cable radiation

The object of this test is to determine the frequency, source, and field strength of radiation from the equipment case and associated cables. Figure 7 gives the equipment arrangement for the performance of this test.

8. Radiated susceptibility

This test is to determine the susceptibility of equipment to radiated signals that penetrate the case or are picked up by the cables. The block diagram showing the equipment setup for this test is shown in figure 8.

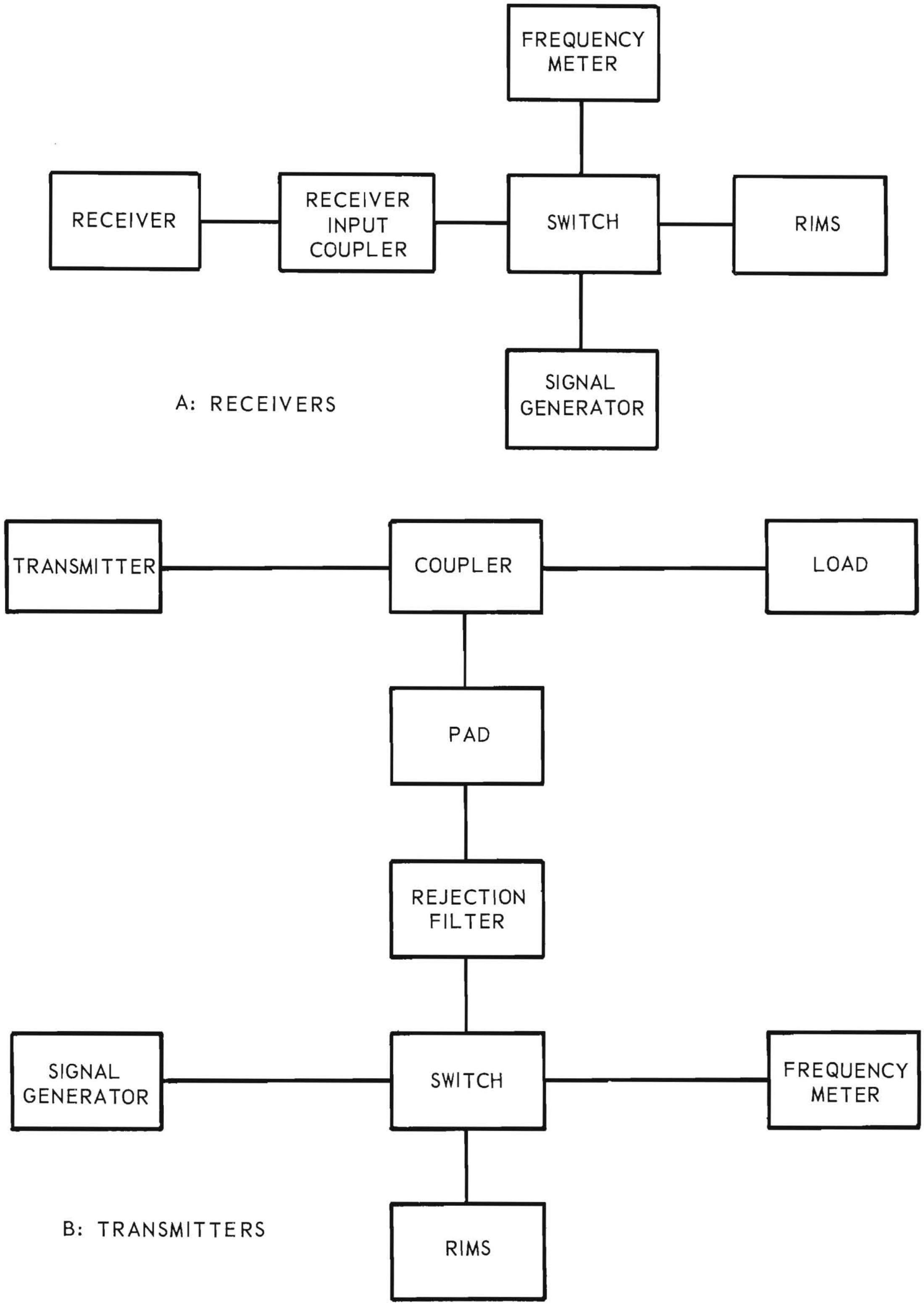

Figure 5. Block diagram of antenna conducted emissions test setups.

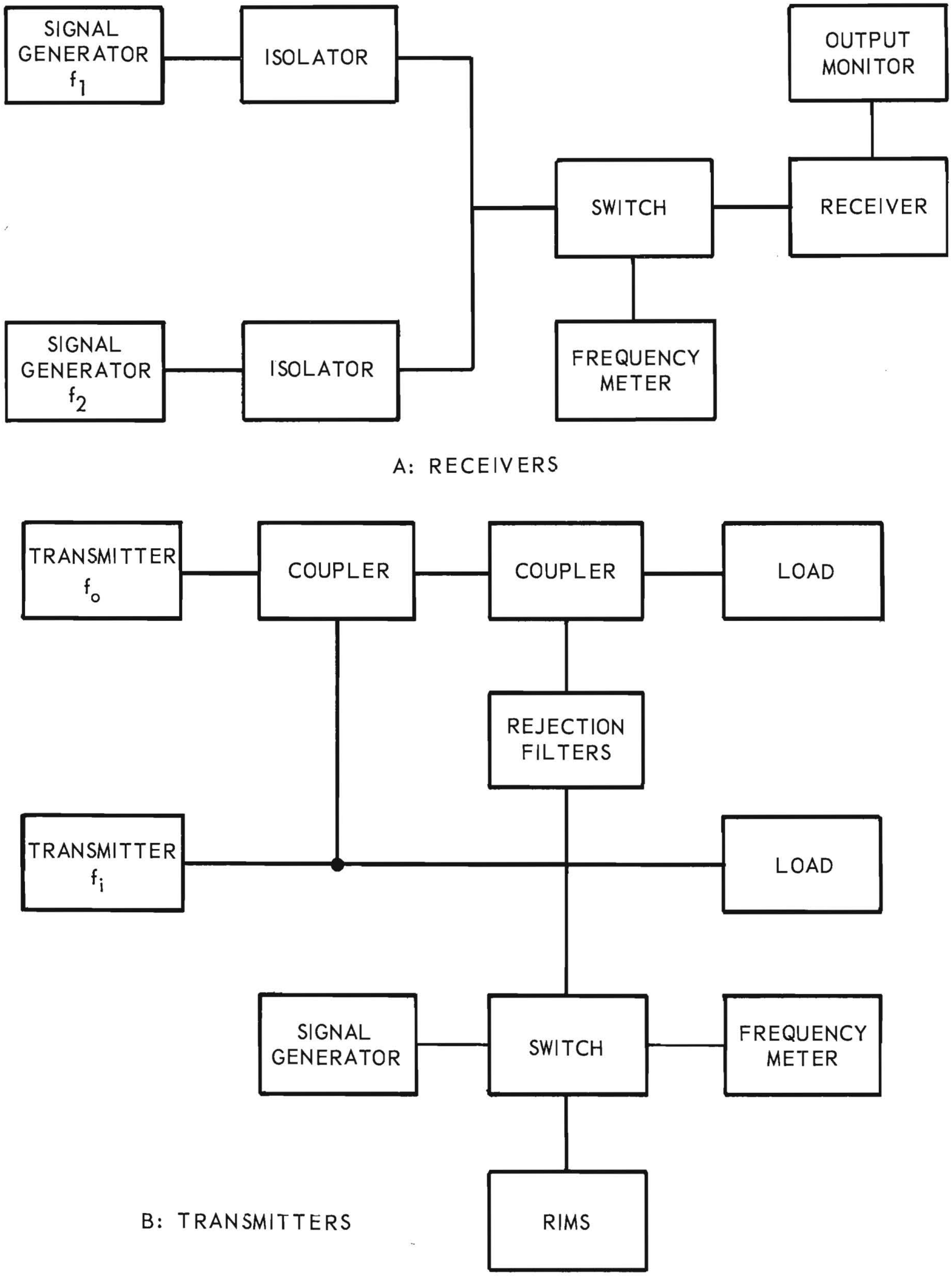

Figure 6. Block diagram of intermodulation test setups.

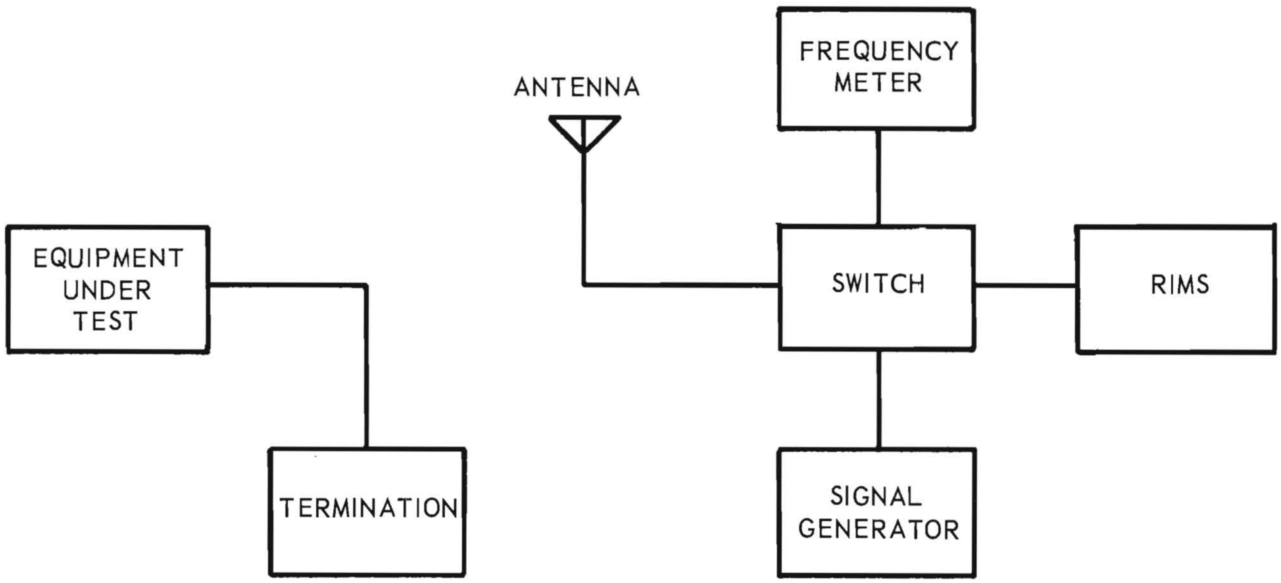

Figure 7. Block diagram of case and cable radiation test setup.

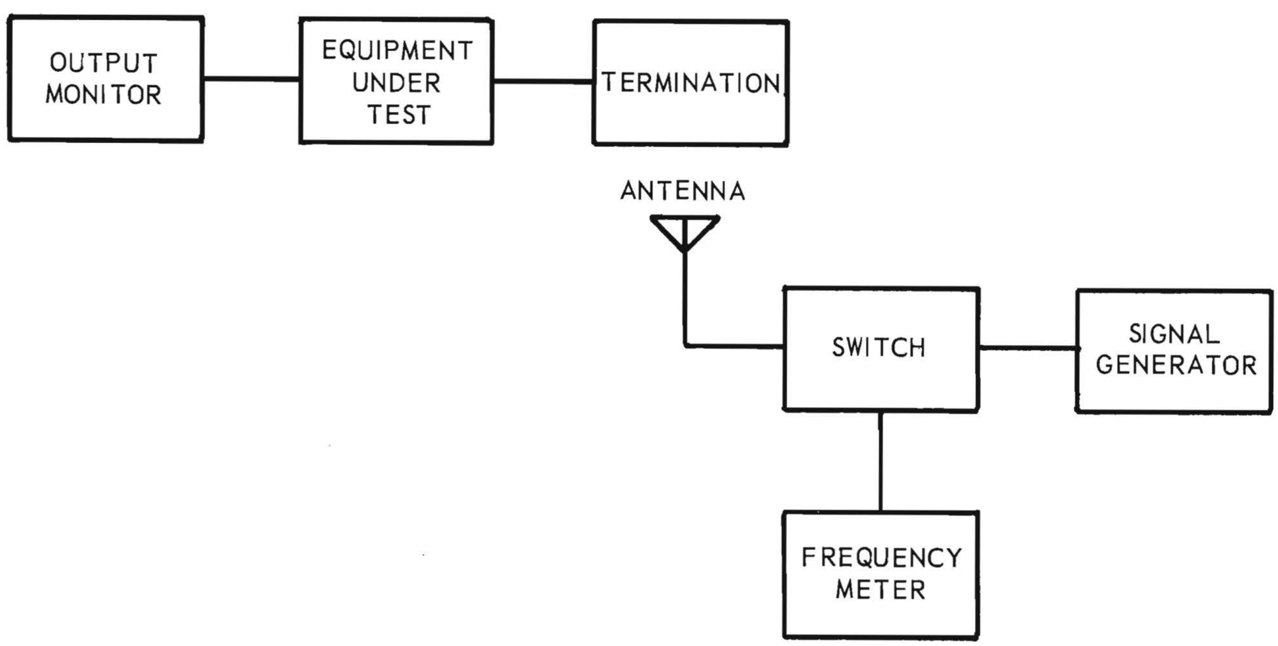

Figure 8. Block diagram of radiated susceptibility test setup.

9. Antenna radiated extraneous outputs, integral systems

Where it is not practical to detach the antenna from a system and operate into a dummy load, all tests must be performed on a radiated basis. The test setups are essentially no different than those presented in the two preceding tests.

C. Accessory items

1. Sampling networks

The purpose of using a sampling device in testing is to obtain a sample of the transmitter output and to reduce the power level of the test signal to avoid having excessive power requirements on all test equipment. Directional couplers are the most practical sampling network for use in the accessory set. Their severest limitation is nonavailability below 250 Mc. At lower frequencies, a high powered attenuator could perform the same function.

General considerations[3] of the maximum power requirements and of the estimated system sensitivity required result in 40 db of coupling being the nominal value that would be most useful. This value of coupling enables the use of components without excessive power ratings. The level of the smallest signal required to be measured by MIL-I-11748 is of sufficient magnitude to allow the addition of other required components for filtering, matching, or other purposes and still retain the required sensitivity.

The power rating of the coupler should be commensurate with the main signal line. Waveguide directional couplers in the narrow wall configuration have the same power rating as the same size waveguide. Coaxial (5/8 inch) couplers are normally rated at 1 kw or less.

2. Attenuators

Attenuators are useful in any measuring setup for extending the range of power measuring instruments. They may also be used to provide a reference impedance for insertion loss measurements and to reduce reflections occurring in a mismatched system.

For the purposes of this Design Plan, 1 watt attenuators will probably be adequate since they will be used after the signal sampler. When used as a signal sampler as mentioned above the power rating will of course be greater, but this applies to only one unit. The typical VSWR specification is in the neighborhood of 1.5:1. More closely matched units are necessary to avoid exceeding the 1.3:1 specified for the test set. If the attenuator is to be used to correct mismatches, its residual VSWR must be low enough to permit correction to within the desired limits.

3. Dummy loads

Many of the tests of equipment require that they be properly terminated in an appropriate load. As the operating frequency and output power level of transmitters increase, the problems of heat dissipation and matching become more severe than at the low frequencies.

The selection of a dummy load is influenced by a number of factors. Although a specification of the Design Plan is 10 kw CW power handling capability, a termination of this capacity is not practical or necessary in most cases. The physical size alone would be incompatible with the rest of the accessory items.

A review of the testing setups reveals that limitations of other accessory items make extremely large terminations unnecessary.[4] A 1 kw load should be adequate for the test set. At the higher waveguide bands, transitions could be used to adapt the guide to a lower band load. The frequency characteristics of the load must be compatible with the frequency of the signal to be absorbed.

4. Switches

To facilitate rapid measurements, switches are necessary to minimize the time spent in connecting and disconnecting cables and test equipment. As many switches as were deemed practical were included in the test set design. Since there are so many switches, it is imperative that those models exhibiting the lowest VSWR and insertion loss be included in the set. To minimize sources of error, as much isolation as possible between ports is highly desirable. About 60 db of isolation seems to be the highest practical value in present state-of-the-art.

5. Isolators

Isolators would be useful to perform several functions, one of these being the reduction of undesired reflections at the input of a receiver without the penalty in power level reduction that occurs when using attenuators. Generally, in cases of excessive VSWR, an isolator may be used to attenuate the reflected wave. Isolators may be used effectively to minimize the generator intermodulation that is a problem in conducting the receiver intermodulation test. The proper placement of an isolator in each signal path attenuates the interfering signal and reduces the possibility of product frequency generation in the signal generators. Further evaluation of isolators relative to their nonlinear properties should be done before using them unreservedly.

Wideband isolators are fairly low powered devices but this presents no problem since they would be used following the signal sampling network. Octave bandwidths are available from 250 Mc. The isolation capabilities decrease at the lower frequencies.

6. Filters

Although tunable low-pass and high-pass filters are desirable, improved performance of fixed frequency filters may be the deciding factor in the final selection. Trade literature indicates a marked improvement in skirt characteristics as well as extended out-of-band performance. The number of fixed filters is of course larger than the number of variable filters to cover the same range. The consideration of fewer pieces of equipment is offset by the generally slower cutoff characteristics of the variable filters.

Band-pass and band-reject filters must be variable because of the impracticality of predetermining where in the testing range that the filters would be required. A desirable filter type from the standpoint of ease of tuning is the YIG filter. This type of filter is electronically tunable and currently available in both band-pass and band-reject configurations.

Throughout the coaxial range low-pass and high-pass filters should be chosen with cutoff frequencies that will insure differentation between the fundamental and the second harmonic. If the cutoff frequency is chosen to be about 1.8 times the next lower cutoff frequency, sufficient overlap is provided. The skirt attenuation should rise rapidly enough to reach at least 60 db within 10 per cent of the cutoff frequency.

D. Accessory set

1. Design

Early in the study an analysis was made of MIL-I-11748 to determine the tests required and the parameters, with their magnitudes, that needed to be measured. On the basis of this analysis, test setups were diagrammed in block form and the equipment requirements enumerated. Next, classification and integration of the tests were performed to permit maximum utilization of equipment without duplication, and to require a minimum of operator time. Then investigation was made into the feasibility of an equipment configuration which would allow the equipment to be used in a mobile van test setup.

To achieve a feasible van-mounted facility, the test setups were divided into two parts. One part is the measurement portion which includes switches, measuring instruments, and signal sources. This portion of the setup is included inside a shielded room in the van. For a static, laboratory-type setup, this part of the measurement system would be located inside a conventional screen room. The other part of the test setup contains the signal sampling elements such as antennas and coupling devices plus terminations. A smaller, less critically shielded room provides space for the pickup devices as well as medium sized pieces of equipment that are to be tested. Antennas and dummy loads should be mounted exterior to the van.

Figure 9 is a simplified flow diagram of the measurement portion of the test setups. These elements are located inside the shielded room of the van.

Figure 10 is the first of several detailed block diagrams of the measurement system. This figure gives the breakdown of the coaxial subsystem with connections to some of the measurement instruments of the waveguide systems indicated. The range from 14 kc to 15.5 Gc is shown as being covered by two radio interference measuring sets (RIMS). Commercial units* are available from 14 kc to 10 Gc with built-in radio frequency heads that may be selected with

*Noise and Field Intensity Meter, Model NF-105-F, The Singer Company, Metrics Division, Bridgeport, Conn., and NM-62A, Stoddart Aircraft Radio Company, 6644 Santa Monica Blvd., Hollywood 38, California.

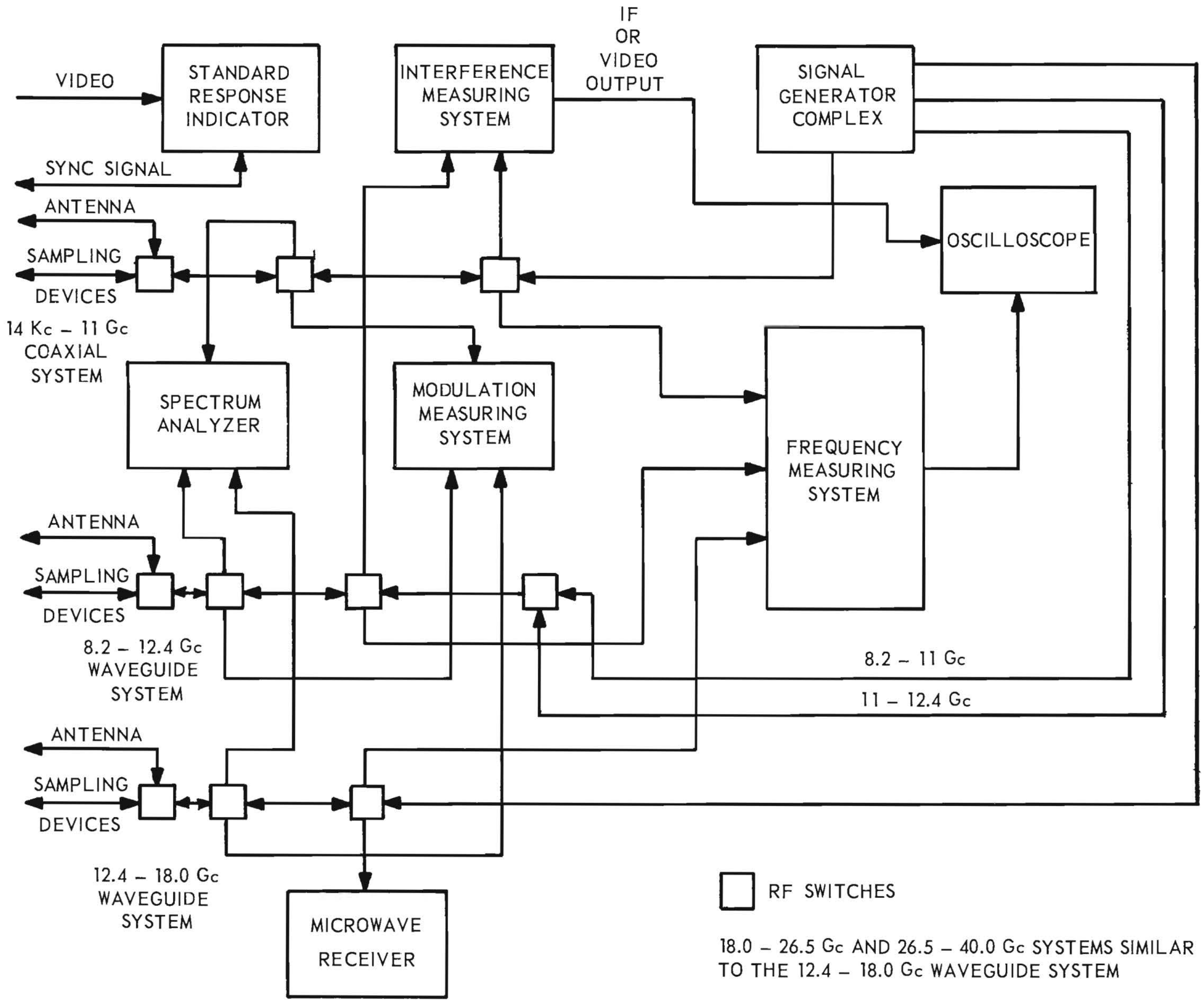

Figure 9. Simplified flow diagram of interference measurement system.

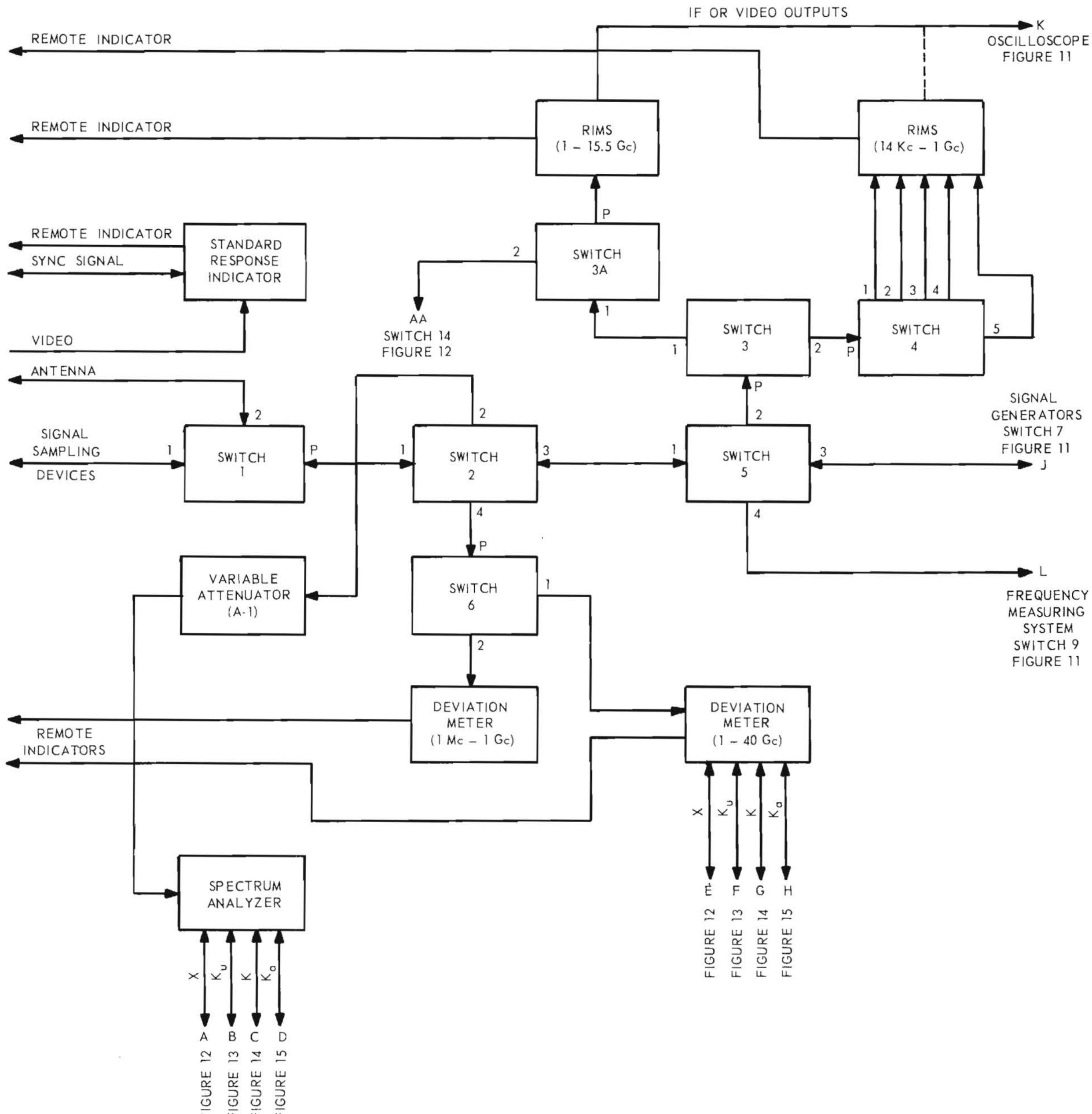

Figure 10. Interconnection diagram of measurement instruments and a portion of the coaxial subsystem.

appropriate rf switches. At present, extension to 15.5 Gc is possible only with plug-in heads.* To avoid a separate unit to cover X-band, the unit with the plug-in heads is considered in this design.

The deviation meters are shown as two units because commercial instruments** provide measurement capability to 1 Gc while further development is required to provide coverage to 40 Gc. A summary of a possible approach is given in the appendix of this Design Plan.

Spectrum analyzers are available to cover from 10 Mc to 40 Gc without modification. Since most spectrum analyzers provide only a coaxial input to 12 Gc, an additional switch may be required to accomodate the two inputs at X-band—one from the coaxial system and one from the waveguide system.

A possible approach to the standard response indicator is summarized in the appendix. A distortion analyzer and a standard response indicator for pulsed systems† may perform the required functions in the absence of the integrated unit herein described.

Remote indicators are shown located in the test area for tuning purposes and for the power line tests. Some measuring instruments have facilities for remote indicators while others may have to be modified to provide this capability.

Figure 11 is a block diagram of the signal generator complex and a portion of the frequency measurement system. The signal generators are shown having frequency ranges which are characteristic of instruments of this type in use

---

*Noise and Field Intensity Meter, Model NF-112, The Singer Company, Metrics Division, Bridgeport, Conn.

**Model 1102 FM Deviation Meter System, Advanced Measurement Instruments, Inc., Somerville, Massachusetts, and Model TF-791D Carrier Deviation Meter, Marconi Instruments, Englewood, New Jersey.

†Model C2A1 Standard Response Indicator, Sperry Microwave Electronics Co., Clearwater, Florida.

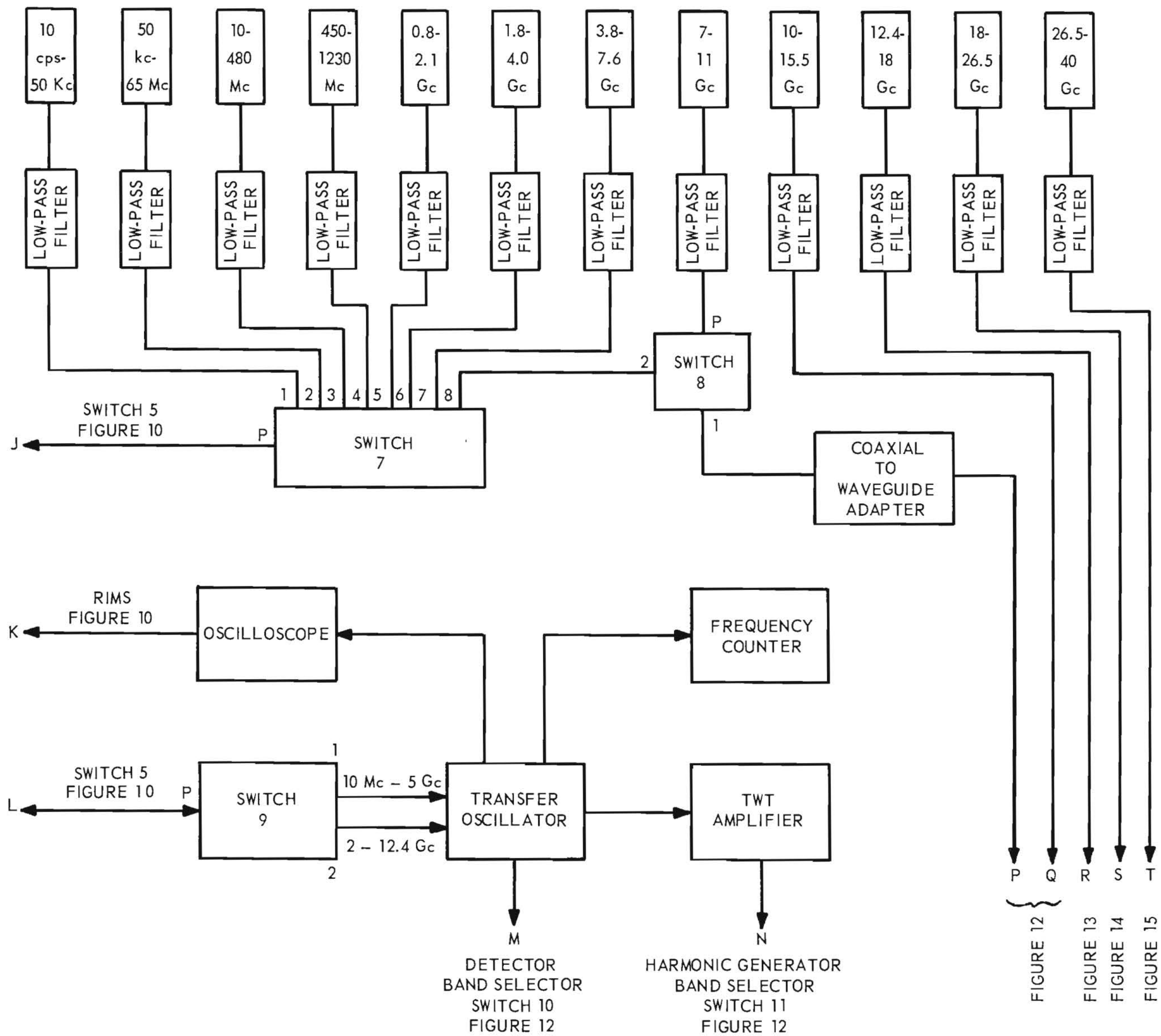

Figure 11. Signal generator complex and a portion of the frequency measurement system.

at the present time. There can possibly be much more efficient coverage of the frequency range with different equipment combinations since signal generators are becoming available with wider frequency ranges than those shown. Low-pass filters are shown at the outputs of the signal generators for the purpose of attenuating the harmonics of the desired signal. It may not always be necessary to do this. Practically, the permanent location of filters here may be difficult as most generators cover more than an octave band of frequencies. This means that variable (tunable) filters would be required or that the fixed cutoff frequency filters must be changed during operation. Facilities for switching the filters in and out become complex—requiring a great number of switches. Therefore, although switched low-pass filters would be desirable at the generator outputs, the complexity involved may well defeat the purpose.

The oscilloscope is useful for pulse system frequency measurements and as a general purpose indicator. An internal oscilloscope is provided in the transfer oscillator for CW frequency measurements. A recently released plug-in head* allows the oscilloscope to be used as an IF centered spectrum analyzer. This type unit could be used to observe spectrums below 10 Gc or at any other frequency desired when used in conjunction with the RIMS by observing the IF spectrum.

Figure 12 gives a breakdown of the X-band waveguide subsystem. Although coaxial components are generally usable through X-band, the waveguide system was included for two reasons: (1) the preponderance of X-band waveguide equipment now in common use, and (2) the high attenuation of coaxial line in this frequency range. The system is a hybrid one of waveguide and coaxial lines.

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*Pentrix Corporation, 860 Shepherd Avenue, Brooklyn, N. Y.

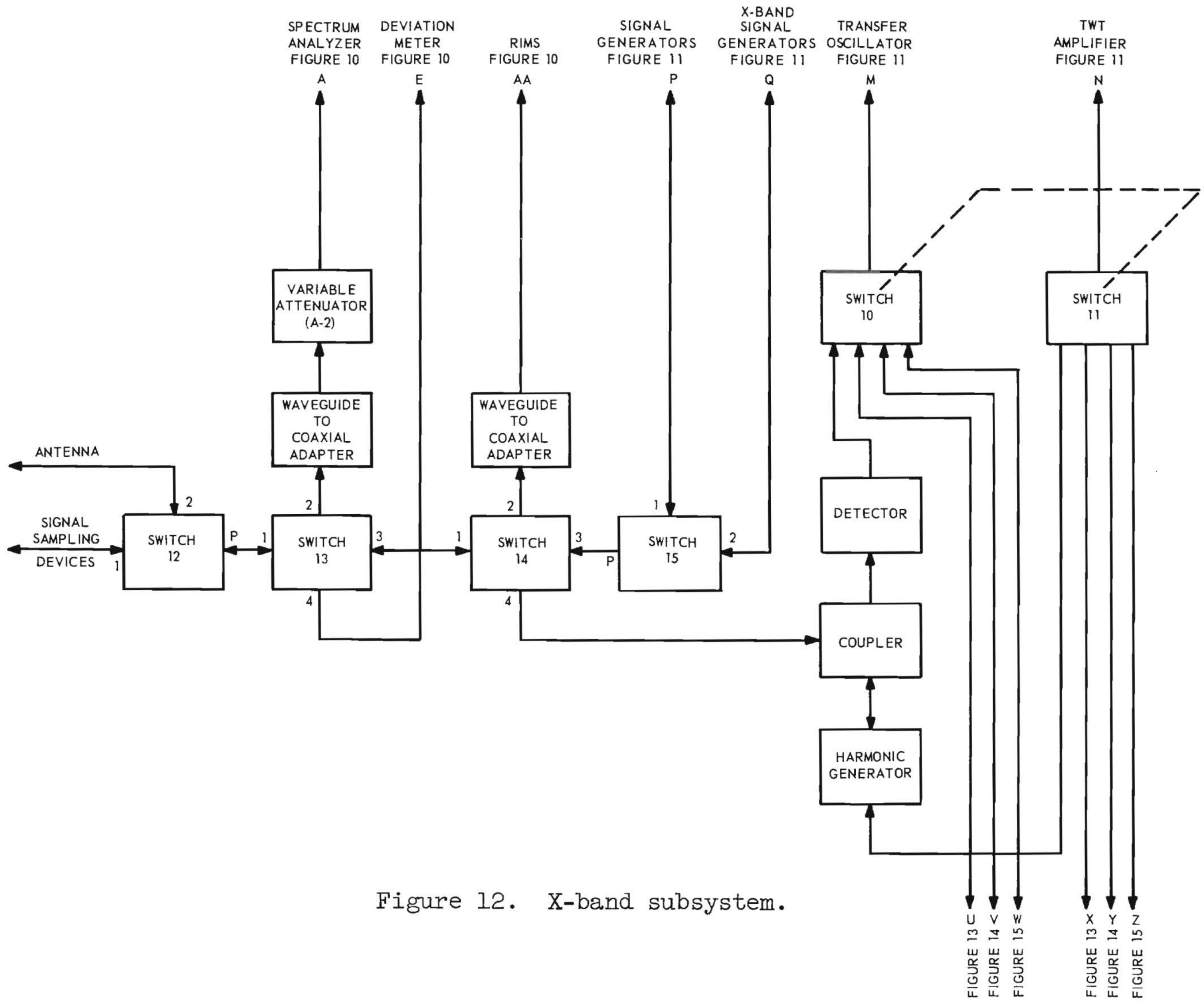

Figure 12. X-band subsystem.

Coaxial cable lengths are to be kept short. All switches are waveguide components. The variable attenuator is also a waveguide type as it exhibits better characteristics than coaxial attenuators above 10 Gc.

Also shown in figure 12 is the switch combination that enables the selection of the different ranges when making frequency measurements. Switch no. 11 selects the desired system to which the mixing signal is applied to beat with the signal to be measured. At the same time switch no. 10 selects the associated detected beat note. The harmonic generator, coupler, and detector are frequency compatible with their associated subsystems.

Figure 13 gives the block diagram of the K_u-band (12.4 to 18 Gc) subsystems. This system is entirely composed of waveguide components. The RIMS is shown as an integral unit of this system to keep signal paths as short as possible.

Figures 14 and 15 are identical in their format to figure 13. The only difference in the three systems is the different waveguide sizes.

All of the measuring subsystems are identical in their functional approach. To describe the operation of the subsystems, the coaxial system (figures 9 and 10) will be used as the example for convenience in designating switches. There are two radio frequency lines per subsystem into the shielded measuring room. One of these goes to an externally located antenna for radiated measurements. The other goes to the receiver or transmitter in the closed system tests. One of these rf lines is selected by switch no. 1 which is of SPDT configuration. From switch no. 1 the path goes to switch no. 2. This four port, three position switch is connected to switch no. 5, the deviation measuring system, and the spectrum analyzer. The path to the RIMS is from switch no. 2 to no. 5. Switch no. 5 is another four port, three position switch that allows an unknown signal to be directed to the RIMS; or allows the signal generator to be directed to the

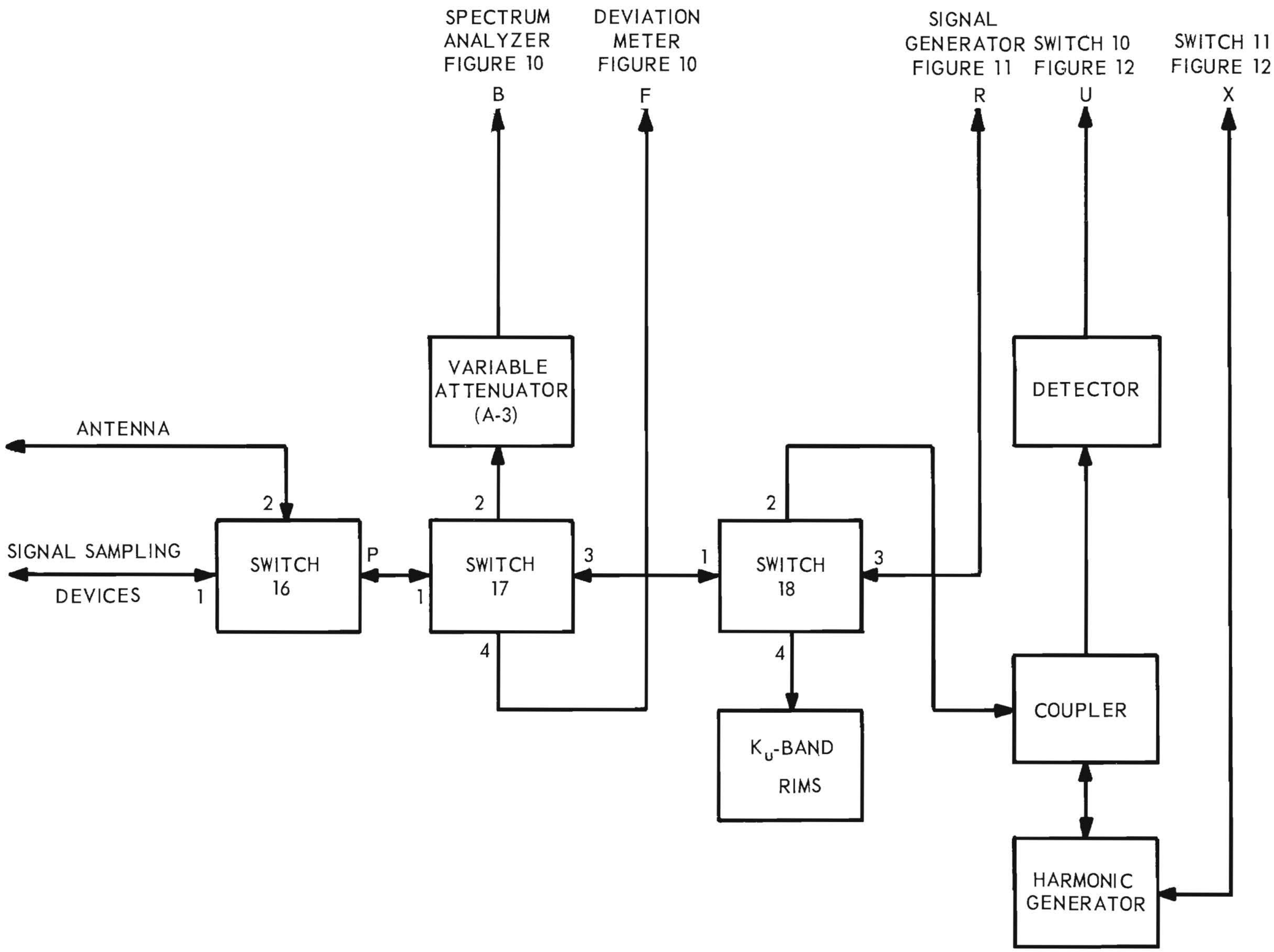

Figure 13. K_u-band subsystem.

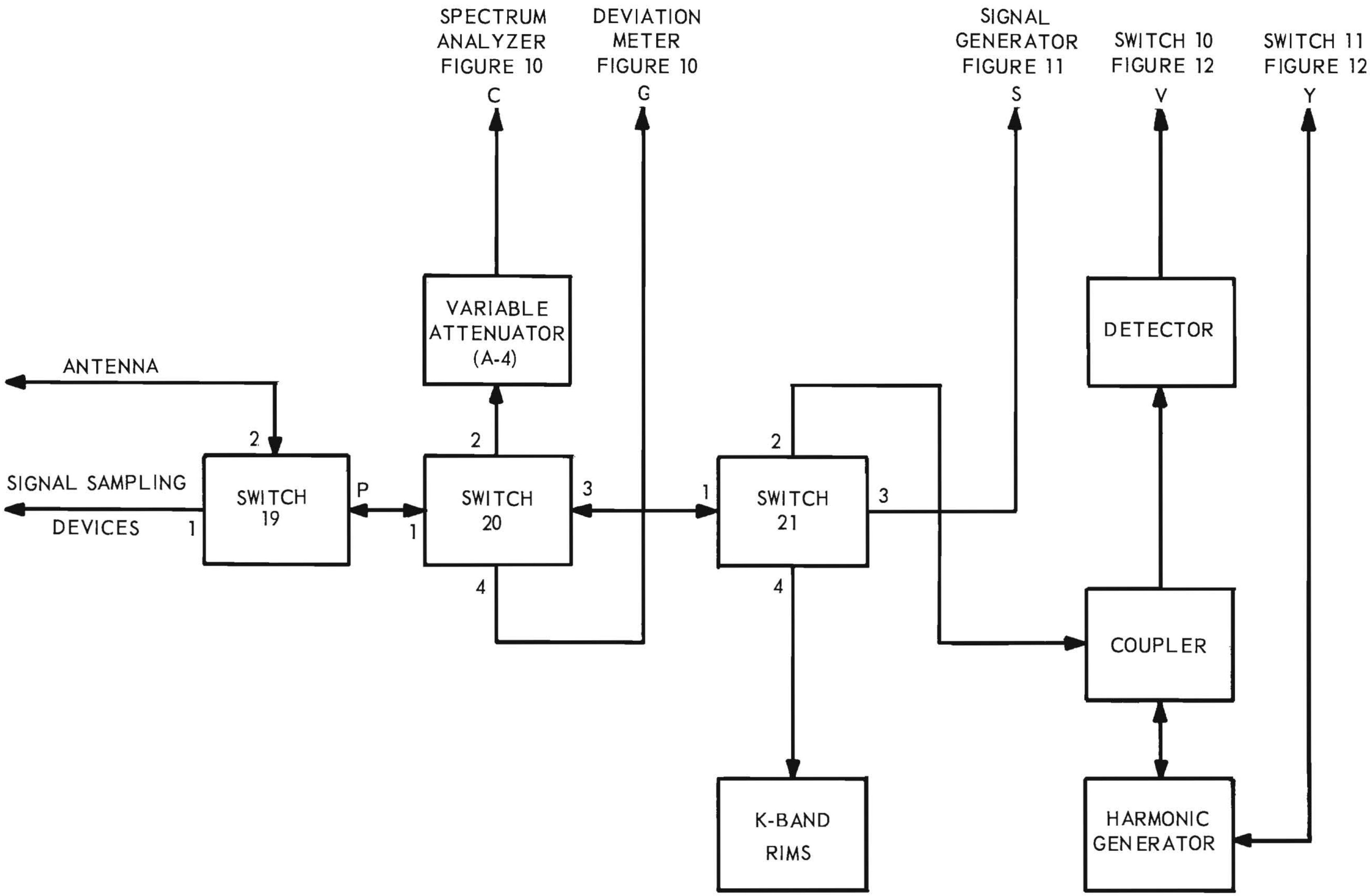

Figure 14. K-band subsystem.

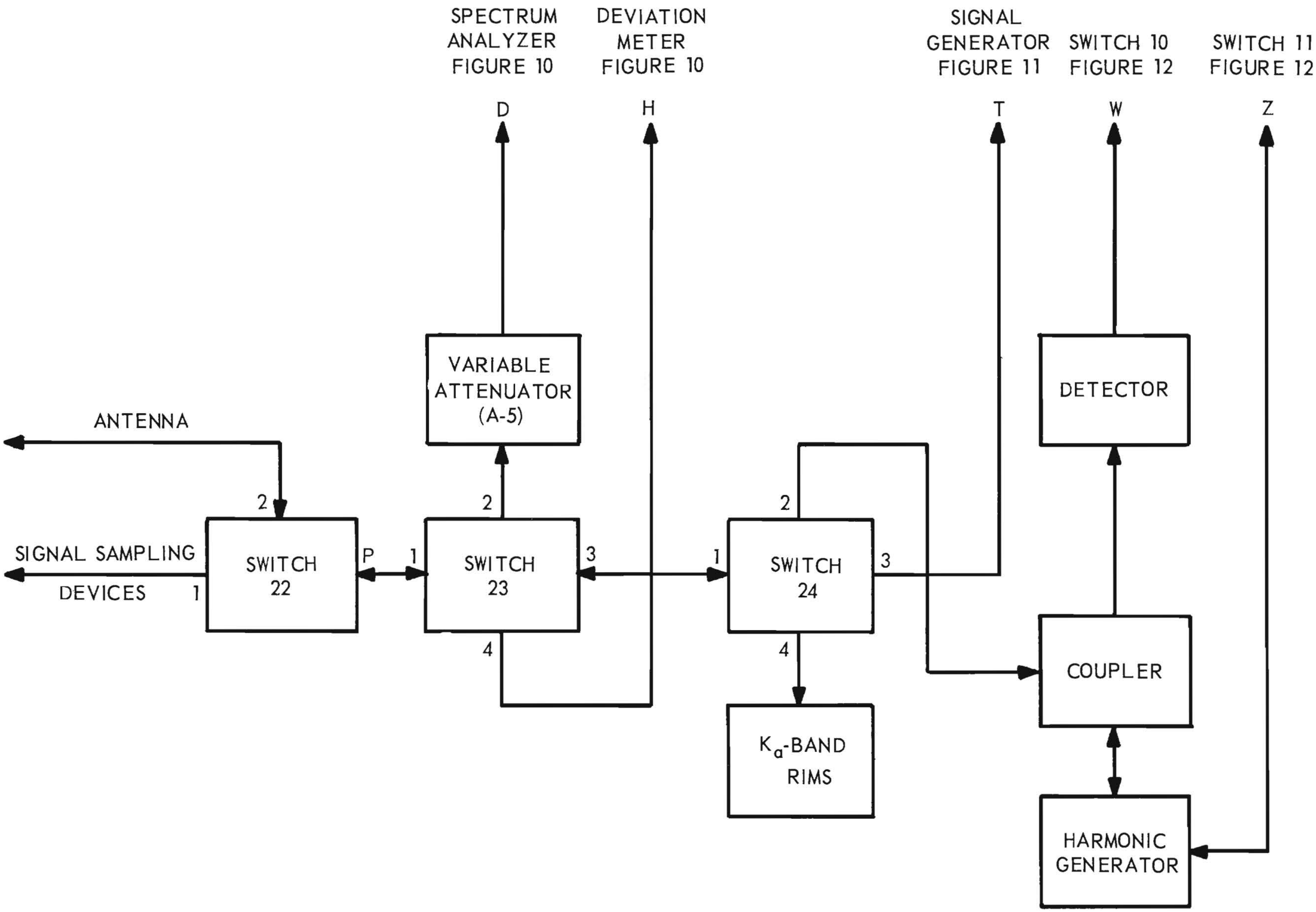

Figure 15. K_a- band subsystem.

RIMS, the input line, or the frequency measuring system. Switch No. 7 (figure 11) selects the desired frequency range to be supplied to the rest of the measuring system.

Switches no. 14, 18, 21, and 24 (figures 12, 13, 14, and 15) perform a similar function as switch no. 5. Switches of the four port, three position configuration are available in the waveguide bands. For clarity, figure 16 shows the configuration of this switch. As can be seen by this drawing, any port can be connected to any of the other three. A coaxial version of this switch has not been found in the literature, but present construction techniques appear to be adequate to produce a coaxial model.

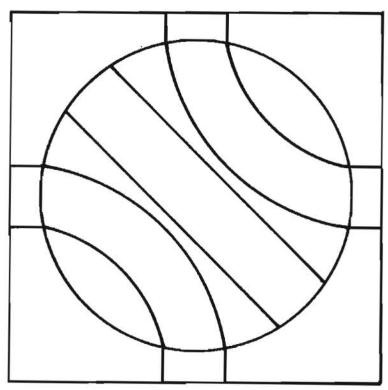

Figure 16. Diagram of four port, three position switch.

The signal generators covering the 7 to 15 Gc frequency range are the signal sources for the X-band subsystem. Switch no. 8 (figure 11) allows the 7 to 11 Gc signal generator to feed into the coaxial or X-band waveguide subsystems. The 10 to 15.5 Gc signal generator would have a waveguide output connector. Switch no. 15 (figure 12) performs the function of selecting one of these signal generators. Figure 17 shows an alternate waveguide distribution system to obtain signal generator outputs in all waveguide sizes in

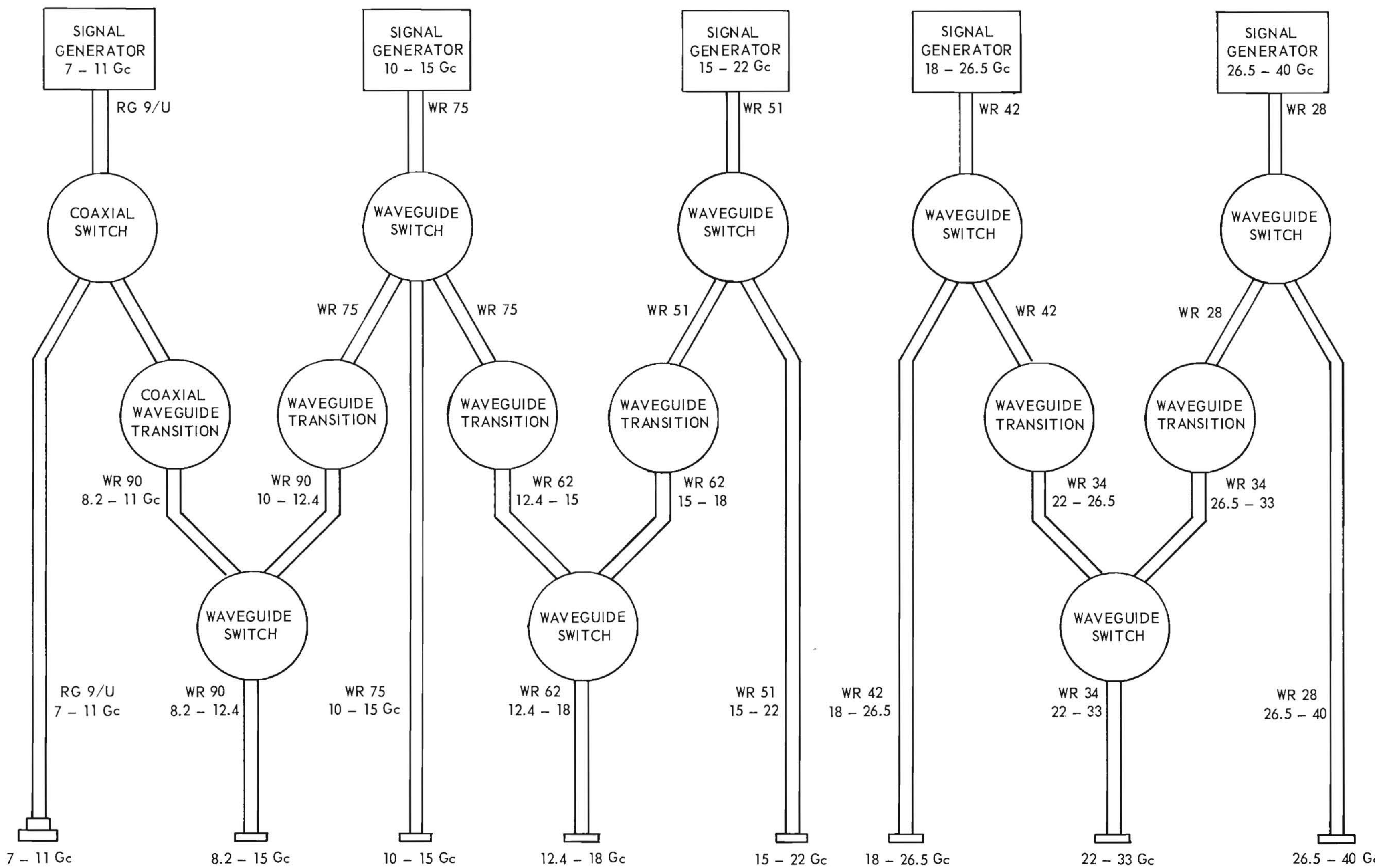

Figure 17. Diagram of a possible waveguide distribution system for signal generators from 8.2 to 40 Gc.

the 8.2 to 40 Gc frequency range. This system adds little to the system shown in figures 9 through 15 as between-series adapters are available for going to the intermediate waveguide sizes; it does provide a fixed installation of these adapters in a switch selectable configuration if desired.

The standard response indicator is attached through the video connector to the output of the receiver under test. Since the functions of this instrument will vary according to the receiver being tested, these are not permanent connections but are performed with interconnecting cables. This same video connector may be used to connect a modulation signal to a transmitter under test.

The variable attenuators are for the purpose of preventing the overloading of the input of the spectrum analyzer. Rotary vane attenuators should be used here to obtain wide frequency characteristics in the waveguide bands.

Figure 18 gives the block diagrams of the equipment arrangement necessary to conduct the power line tests. Also, the sampling and coupling networks are shown for the receiver and transmitter. These items of equipment are located near the equipment being tested and are outside the shielded room.

Line conducted interference and emissions tests are to be conducted to 100 Mc. At this frequency coaxial losses are negligible; therefore, signal path lengths are not critical. Switch no. 27 selects the particular power lead to be tested. The operation of switches no. 25 and 26 are illustrated by figure 19.

For these tests, runs of RG-55/U to the signal source, frequency measuring system, and RIMS will not introduce excessive error into the measurements.

Since a large percentage of tests will be made on coaxial systems, and in order to reduce the number of connections to be made by the operator, a system

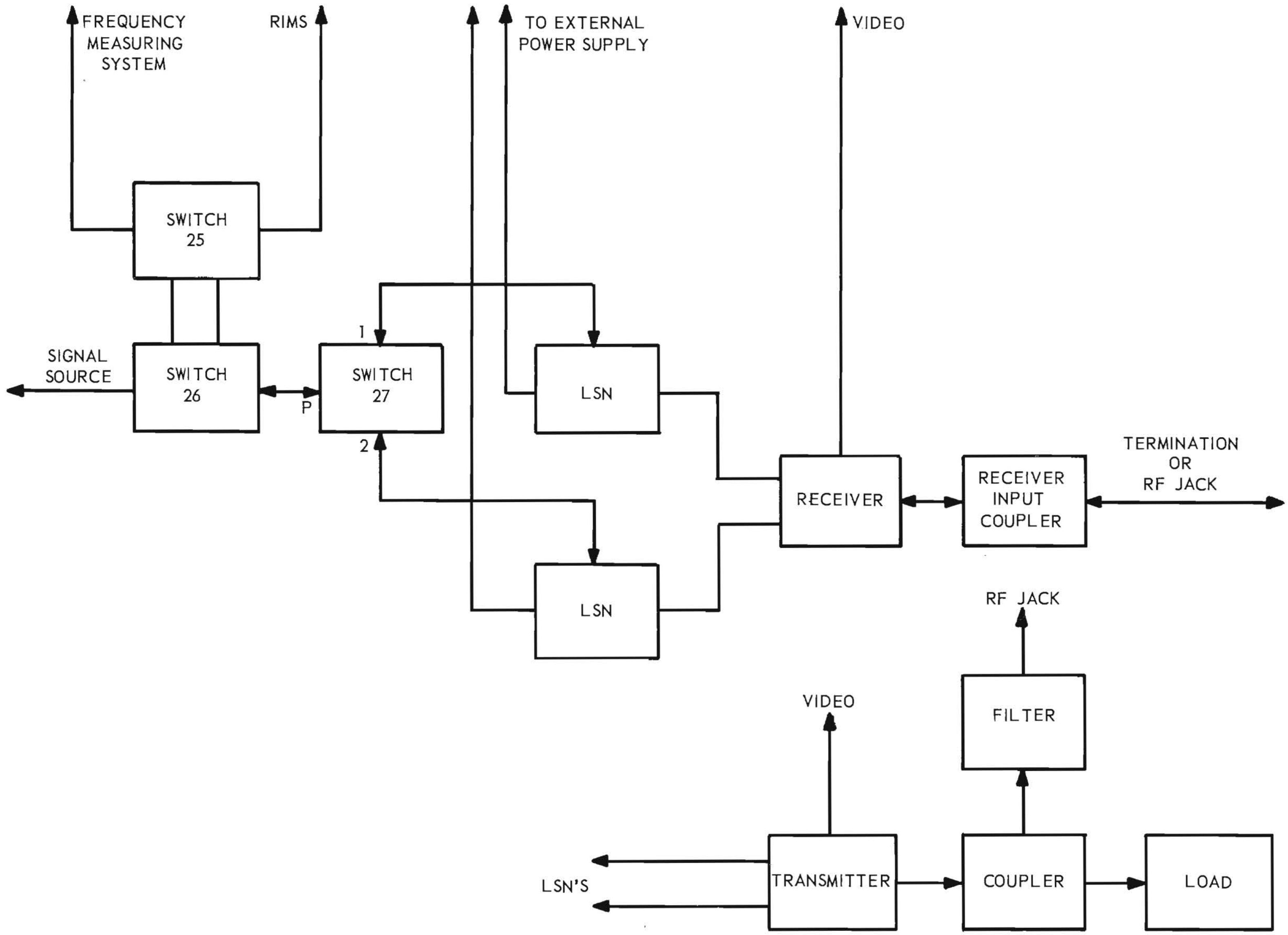

Figure 18. Line conducted interference test setup.

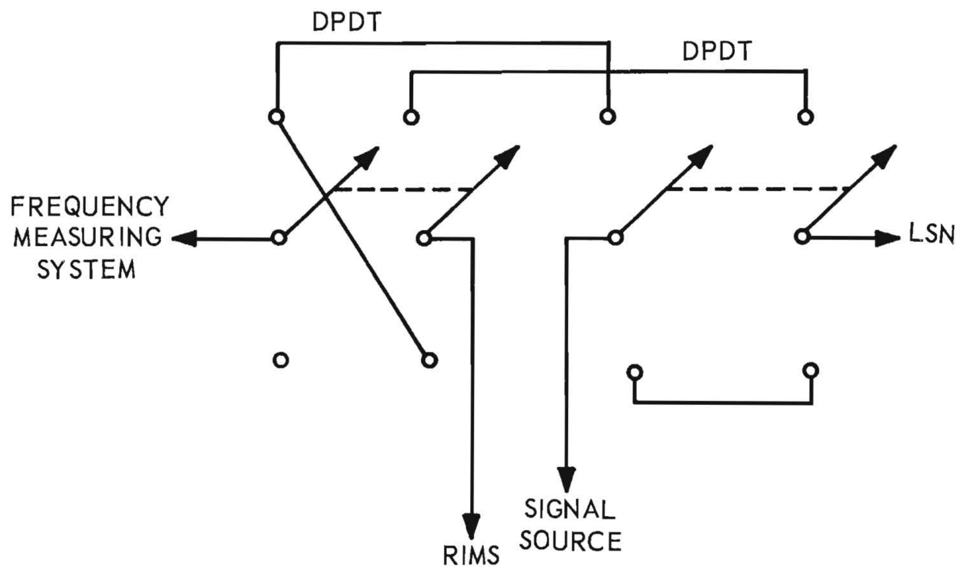

Figure 19. Operational diagram of switch no. 25 and switch no. 26.

of cascaded directional couplers as shown in figure 20 is suggested. This type of arrangement of directional couplers has been evaluated[5] and found to cause very little disturbance to the operation of the transmission system. This set-up allows measurements to be conducted from 14 kc to 12 Gc without interruption to change sampling devices.

Switch no. 32 selects the proper frequency range to feed into the measuring system. Switches no. 28, 29, 30, and 31 either terminate the signal sample or direct it to switch no. 32. The switch combination should be set up such that when switch no. 32 is at a particular port, the corresponding switch at the coupler should be at port 2.

The tapped load is a high powered attenuator. At present a single high powered attenuator capable of covering this frequency range is not available. Further work needs to be done in the development of high powered attenuators that would provide a good termination in the frequency range from dc to 12 Gc. It is also possible that frequency sensitive attenuators (having losses that increase with frequency) could be inserted ahead of a low frequency load and accomplish the desired wide band termination.

Figure 21 is a scaled floor plan of a possible truck-mounted test van. The overall length of the truck bed is only 23 feet. If required, this length could be extended without going to a trailer configuration.

The layout of the equipment is based on equalization of losses among the systems. The higher frequency components are placed so that the signal paths are shortest.

The plan is drawn on the basis of rack mounting the equipment in standard 19-inch racks. Allowance is made for the rack itself. A survey of the items of equipment that would be included indicated that a depth of 24 inches is

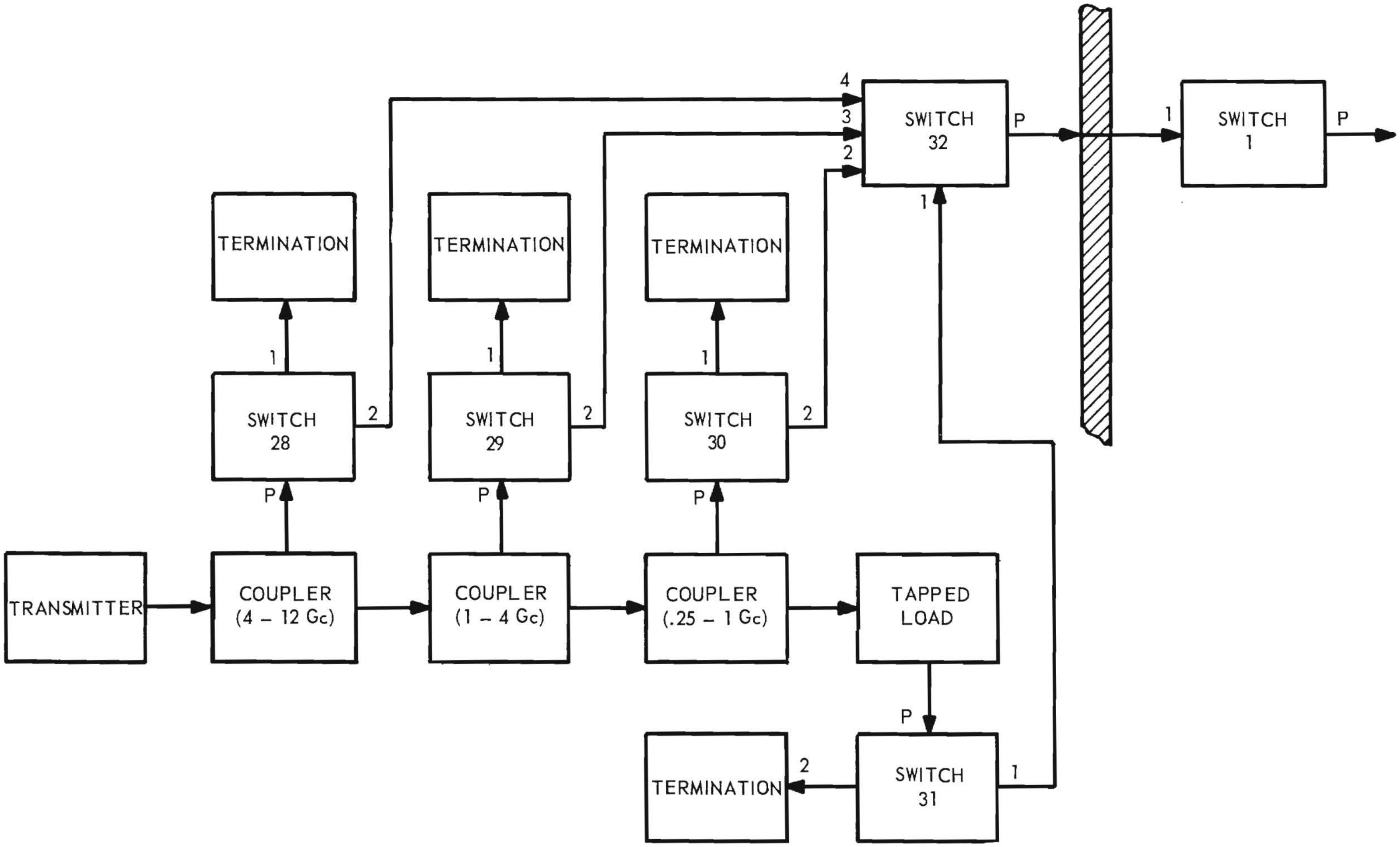

Figure 20. Signal sampling device arrangement for dc to 12.4 Gc.

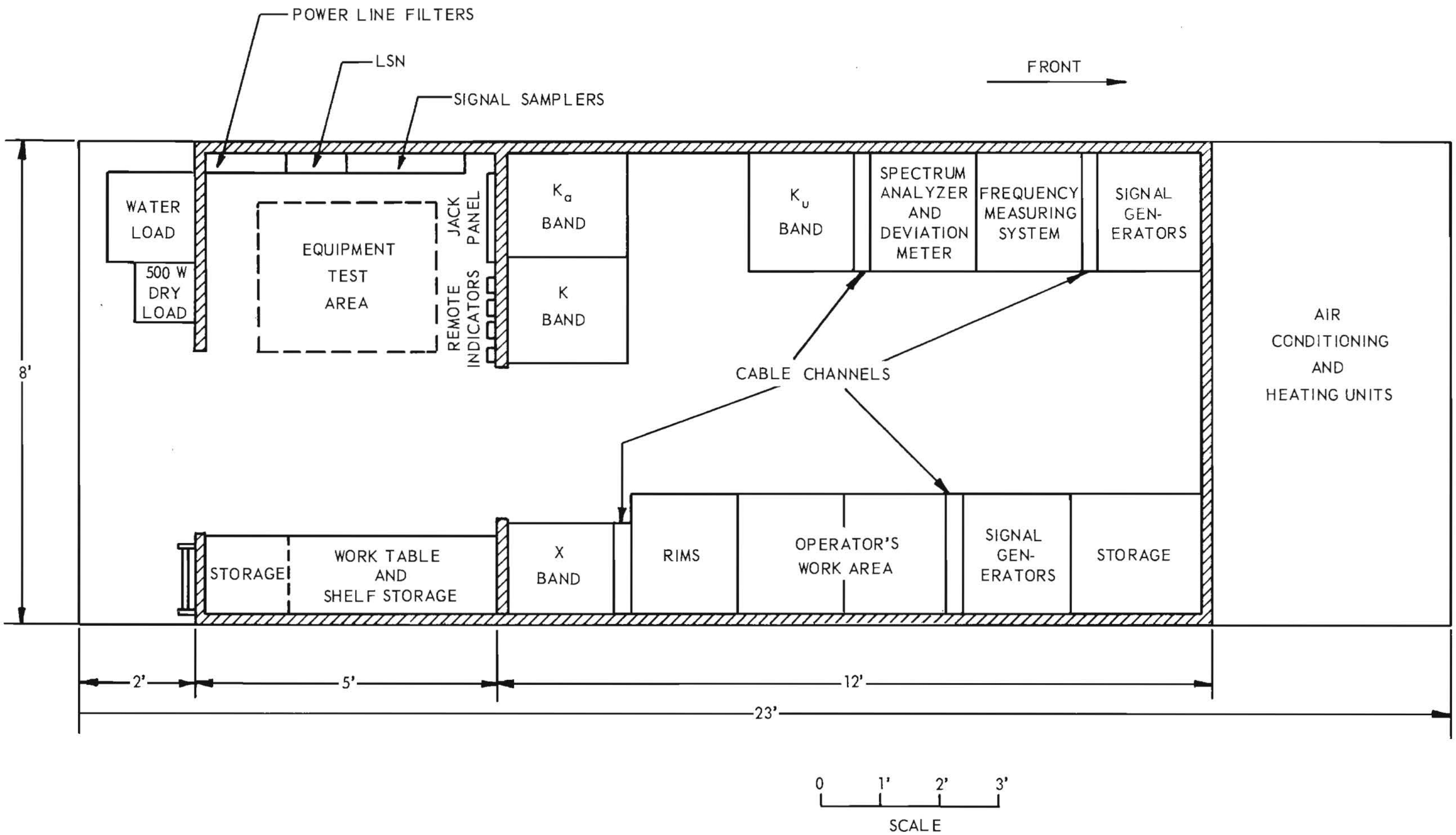

Figure 21. Floor plan of van for interference test set.

adequate. Cable channels are provided to furnish a convenient mounting channel for coaxial lines and waveguide runs to the equipment. This reduces the necessity of mounting signal lines down the face of instruments. Cable channels are to be provided in the ceiling for interconnecting wiring.

Space is indicated in front of the van for locating air conditioning and heating facilities. Air ducts will be provided with wave-guide-below-cutoff vents to keep external interference from affecting the measurements.

Terminations in the form of a water load and a dry load are placed exterior to the van enclosure on a floor extension. These terminations are placed in this position to facilitate heat removal.

The power lines must be filtered to eliminate another possibility of unwanted external interference. These filters are placed in the power line on the supply side before the line impedance stabilization networks.

Figures 22, 23, and 24 are the equipment layouts in the van interior. The final equipment arrangement will be affected by the models chosen. The scaled layout drawing is on the basis of presently available typical units which meet the needs of the test setups.

The operator's desk is centrally located in the van and close to the RIMS. It is also in a position where the operator can turn around and be near the spectrum analyzer, deviation meters, and frequency measuring system.

Several of the switches were chosen to be electrically operated depending upon their frequency of use and accessibility. The switch control panel is located near the operator since he will have to use it often.

Space for a number of storage drawers is available for storing such items as isolators, filters, attenuators, etc., which are not specifically included in the test setups but which are needed at various times.

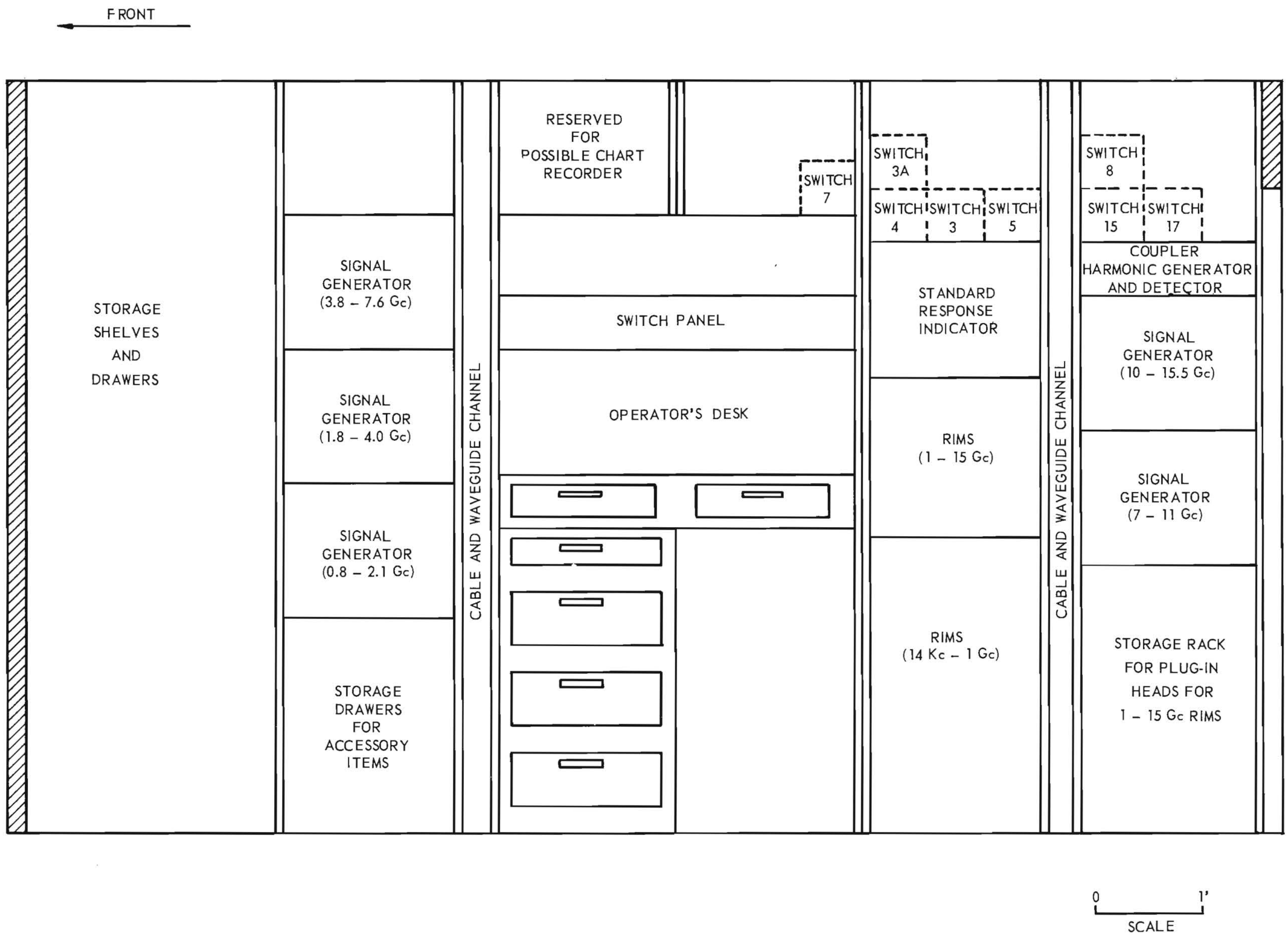

Figure 22. Layout of equipment racks on right side of van interior.

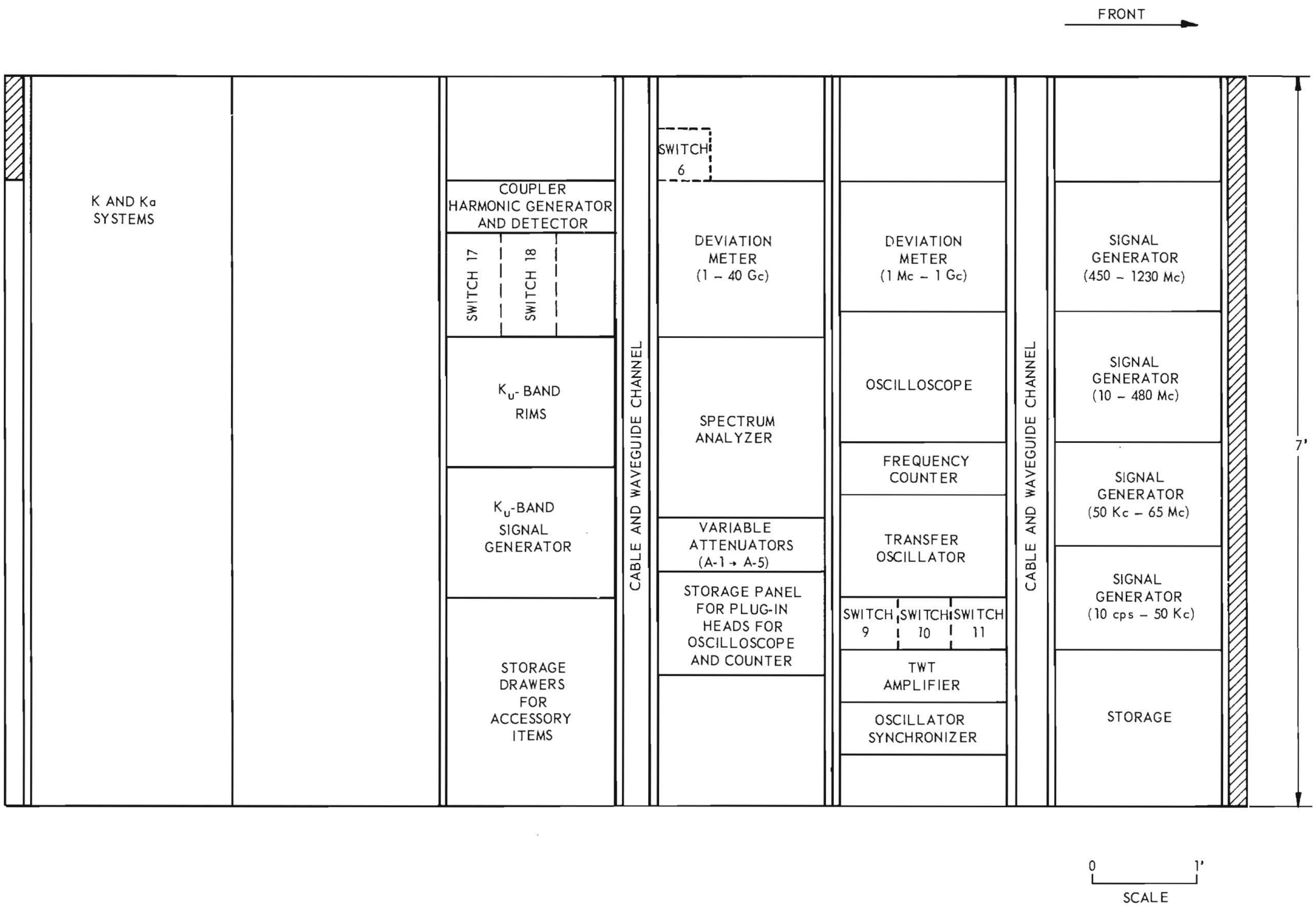

Figure 23. Layout of equipment racks on left side of van interior.

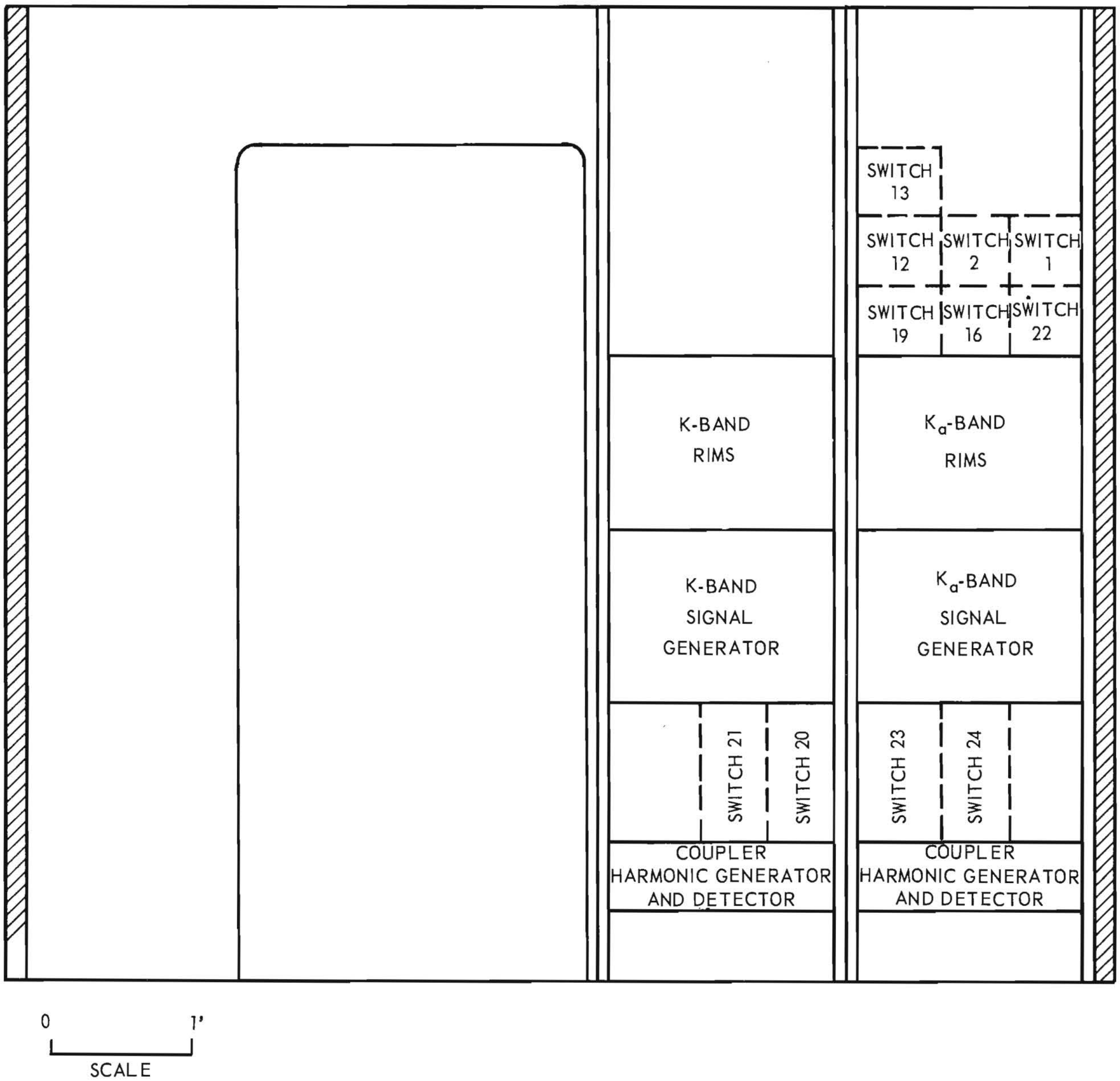

Figure 24. Layout of equipment racks in the rear of van interior.

2. Operation

In section B the individual test setups were presented in block diagram form. Part 1 of this section combined all of these individual setups into an integrated system which allowed practically all of the tests to be performed with the various equipment arrangements accomplished with switches. This section is included to demonstrate the use of the integrated system in performing the individual tests.

Figure 25 shows the setup of the power line conducted emissions test (see figure 1a) as it would be performed with the test set. For this particular test, there appears to be several unnecessary switches in the signal path. These switches are required for other tests as will be evident later in the discussion. Switch no. 1 is shown located inside the measurements room. Consideration should be given to placing this switch in the testing room, which would require one less rf cable feed through the dividing wall. The receiver input coupler may be an isolator, attenuator, or impedance matching device, such as a minimum-loss pad, depending on the function it is expected to perform. Accessibility to systems of other than 50 ohms impedance level could be obtained by the use of the proper minimum-loss pad in this position.

For the power line tests, only one line stabilization network (LSN) is shown in the block diagrams. Certain situations require two or more—one in each power lead (see figure 18). Between the actual power source and the equipment under test there should be line filters to minimize outside interference that may be present on the power leads. In tests where LSN's are used the power line filters should be between the power source and the LSN.

In figure 25 the signal appearing at the LSN is routed to the RIMS and frequency meter through the video jack via an auxiliary cable. It is deemed

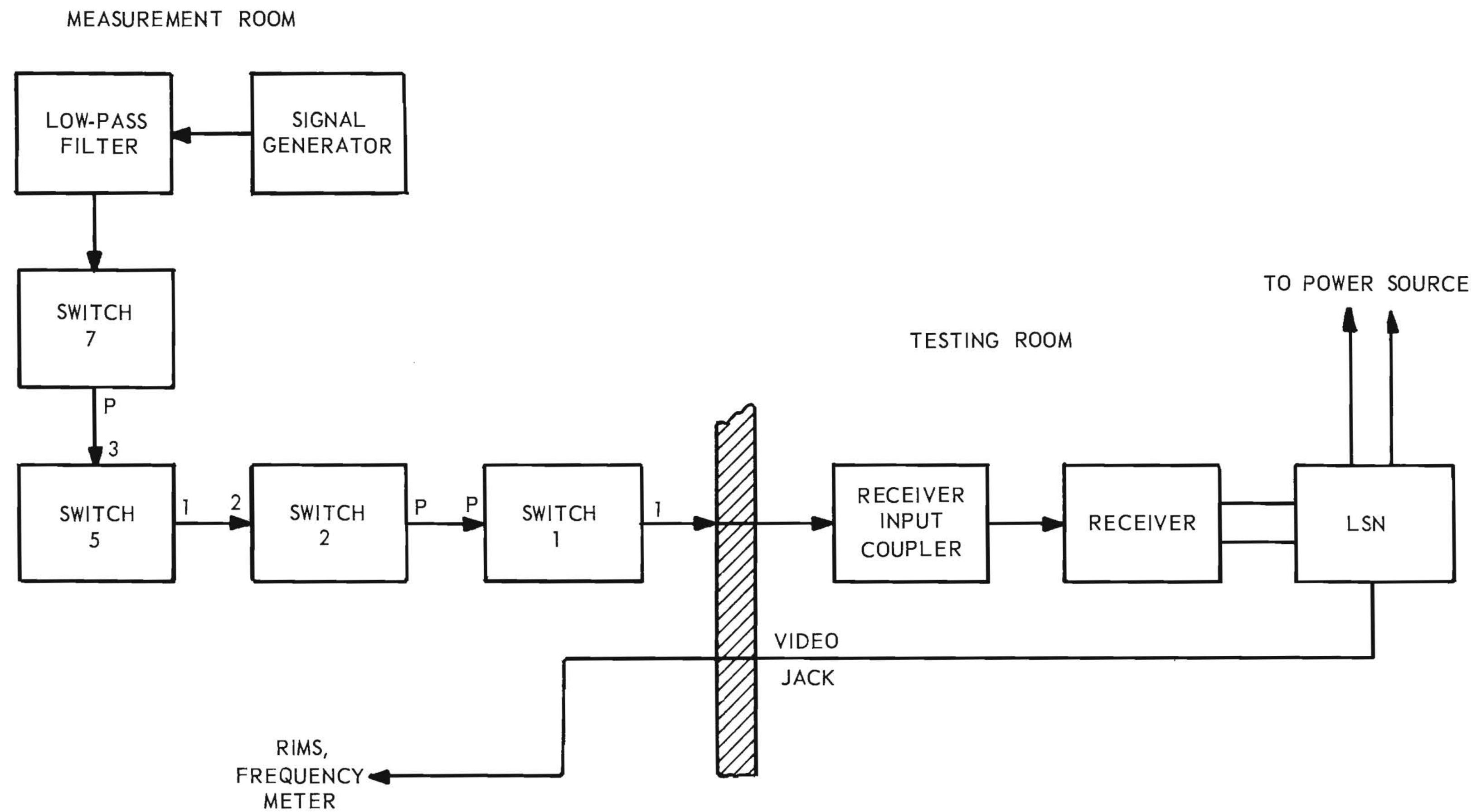

Figure 25. Test set arrangement of equipment for receiver line conducted emissions test.

impractical to attempt to provide permanent cable paths for every conceivable testing situation. For those cases that arise infrequently, auxiliary cables should be used. Also certain cable interconnections will have to be performed by operating personnel. Largely these interconnections have been restricted to the low frequency (<100 Mc) cases where small mismatches are not so detrimental.

In this and in the following diagrams, signal paths through the switches have been designated with a numbering system. The common (or pole) terminal on the switches is designated with a "P". The numbers on the switch blocks show the proper signal paths for the particular test under consideration. Switch no. 7 is a multiple position switch that selects the appropriate signal generator for the frequency desired. No signal path is indicated for this switch as any signal generator may be used.

Figure 26 shows the equipment arrangement which will perform the power line conducted emissions test on transmitters. The output monitor indicated in figure 1b is shown as the deviation meter. Either the deviation meter, spectrum analyzer, or RIMS may be used as an output monitor depending upon the information desired.

Switch no. 6 selects the appropriate deviation meter for the frequency of the signal under observation.

The audio signal generator is supplied through the video jack to the audio or video input to the transmitter modulator, as some test procedures specify that the rf signal be modulated a prescribed amount during the test. The signal appearing at the signal jack of the LSN is routed to the RIMS as discussed for receivers.

The rejection filter is for the purpose of attenuating any fundamental

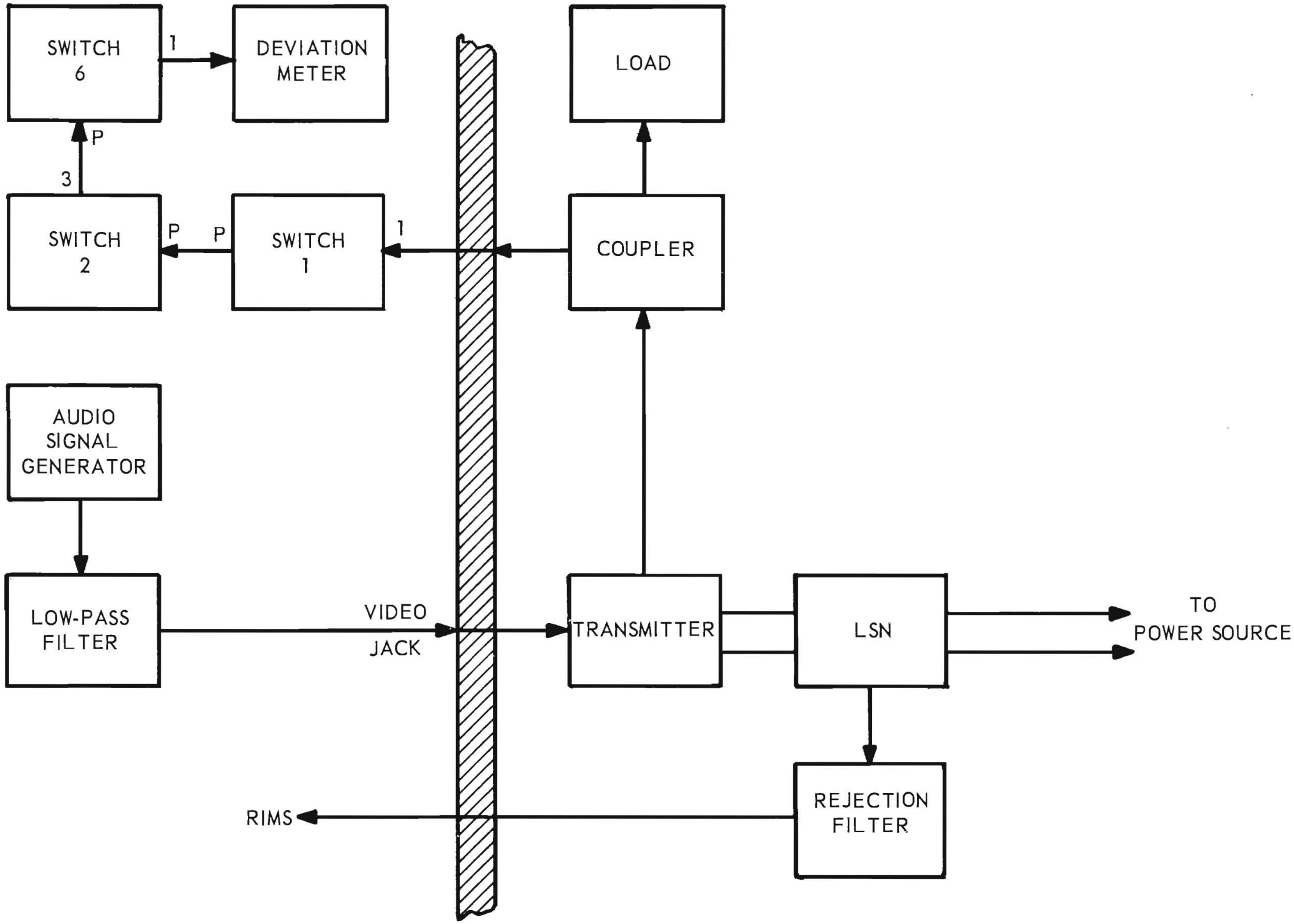

Figure 26. Test set arrangement of equipment for transmitter line conducted emissions test.

frequency signal that may be present when trying to measure other smaller signals. A device that may be useful and should be examined further is a ferrite limiter. These devices are frequency selective in their limiting. This means that if two signals of different amplitudes but close in frequency are applied to the limiter, only the one which exceeds the limiting threshold will be attenuated.

The power line and nonsignal line conducted susceptibility test for receivers (figure 2a) is shown in figure 27. The standard response indicator reveals when a predetermined response is present in the receiver. This means that the operator can scan the required frequency range with the signal generators and not have to continually observe the receiver for responses.

Switch no. 5 serves an added function in this diagram, that of routing the test signal to the LSN. It also allows the test signal to be routed to the frequency measuring system to determine its exact frequency to at least $1:10^6$ accuracy (see figure 16).

Figure 28 is the system arrangement necessary to perform the power line and nonsignal line conducted susceptibility test on transmitters. Since the signal to be applied to the LSN is below 100 Mc, an auxiliary cable would be used to connect the appropriate signal generator to the LSN.

The output monitor for this test is shown as a spectrum analyzer. If desired, a deviation meter could be used as shown in figure 26 or a RIMS as shown in figure 30.

The audio susceptibility setup of figure 3 is not shown in this series as it is not necessary to attempt to connect it into the system. The audio amplifier and isolation transformer are specialized items of equipment and are not used in other tests. The test signals are in the audio range and

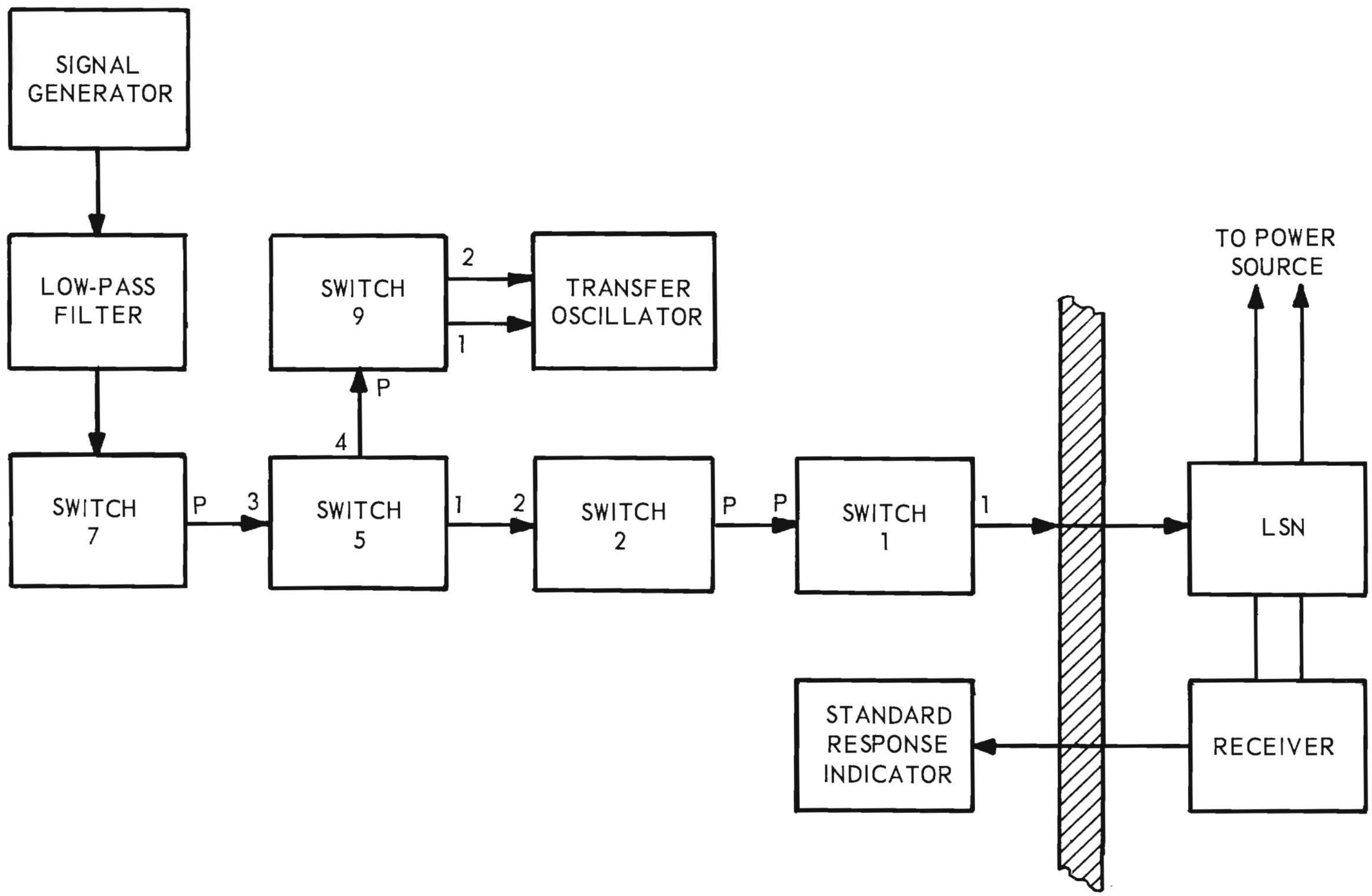

Figure 27. Test set arrangement of equipment for line conducted susceptibility test of receivers.

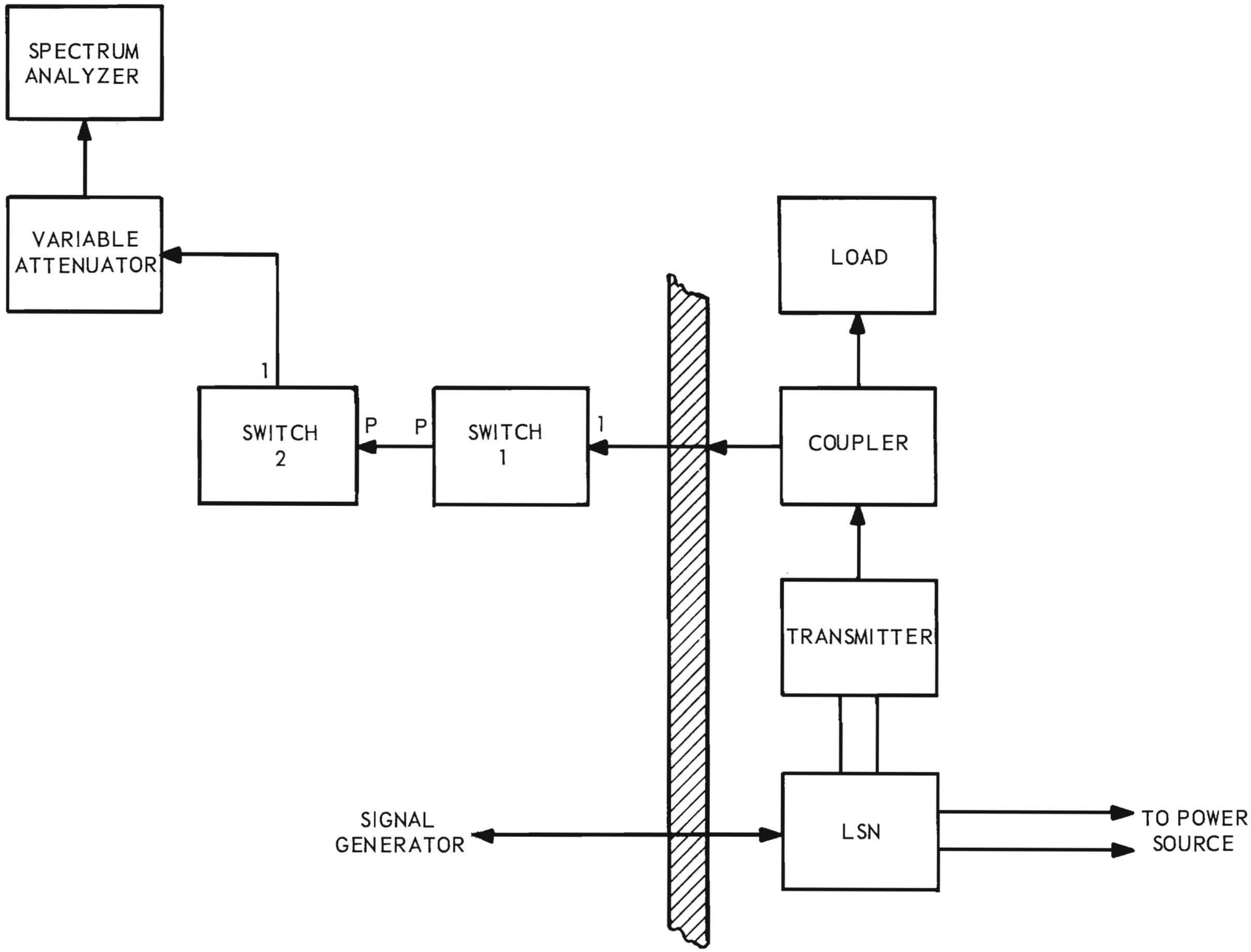

Figure 28. Test set arrangement of equipment for line conducted susceptibility test of transmitters.

present no problem requiring switches. The setup should be performed in the test room as needed. Detection of a standard response at the receiver or transmitter output would be accomplished as indicated in figures 27 and 28.

Figure 29 shows the antenna and signal line conducted susceptibility test (figure 4) as it would be done with the test set. The operation of the frequency measuring system and standard response indicators are as explained earlier. The conducted susceptibility test in the waveguide regions can be made by adapting from the waveguide system to the receiver where adapters exist. These are not presently available above 18 Gc. A need exists in this test to develop some system which provides a solution to the multimode problem which can be used in the field.

The receiver antenna conducted emissions test (figure 5a) is shown in figure 30. In this test the full potential of the four port, three position switch, no. 5, is utilized. The signal appearing at the antenna terminals of the receiver is detected by the RIMS. This signal path is completed by connecting ports 1 and 2 together. To measure the amplitude of the emissions, the signal generator is applied to the RIMS by ports 2 and 3. Next the frequency of the emission is determined by measuring the frequency of the signal generator output by connecting port 3 to port 4, which goes to the frequency measuring system.

The spurious and harmonic emissions test of a transmitter (figure 5b) is shown in figure 31. The pad or attenuator is illustrated in case additional attenuation is desired following the coupler. The actual measurement setup is identical to that for receivers as shown in figure 30. For spurious emissions in the waveguide bands, coupling to the coaxial systems by the use of dominant mode waveguides to coaxial adapters in the region of usefulness of

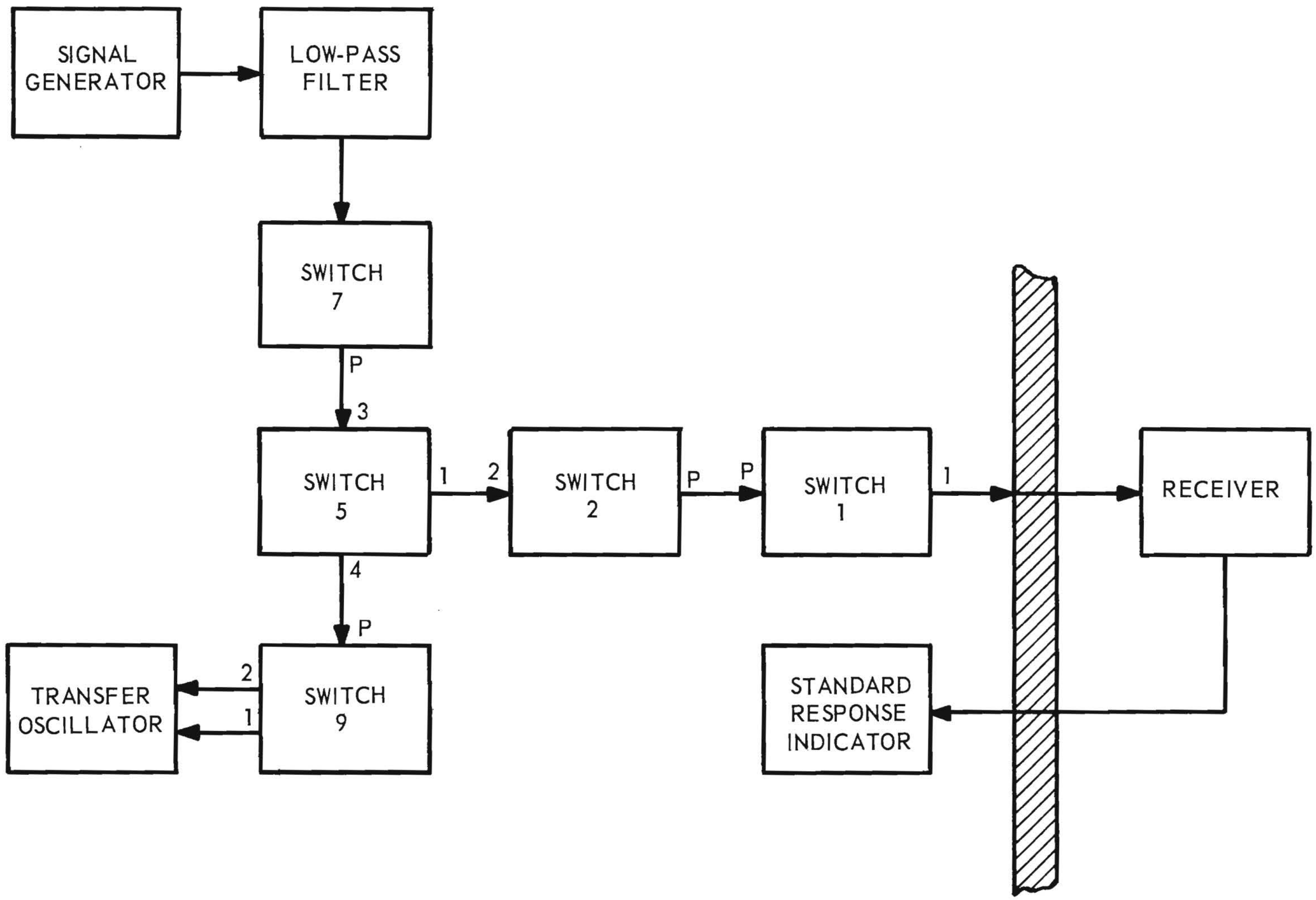

Figure 29. Equipment arrangement for antenna conducted susceptibility test of receivers.

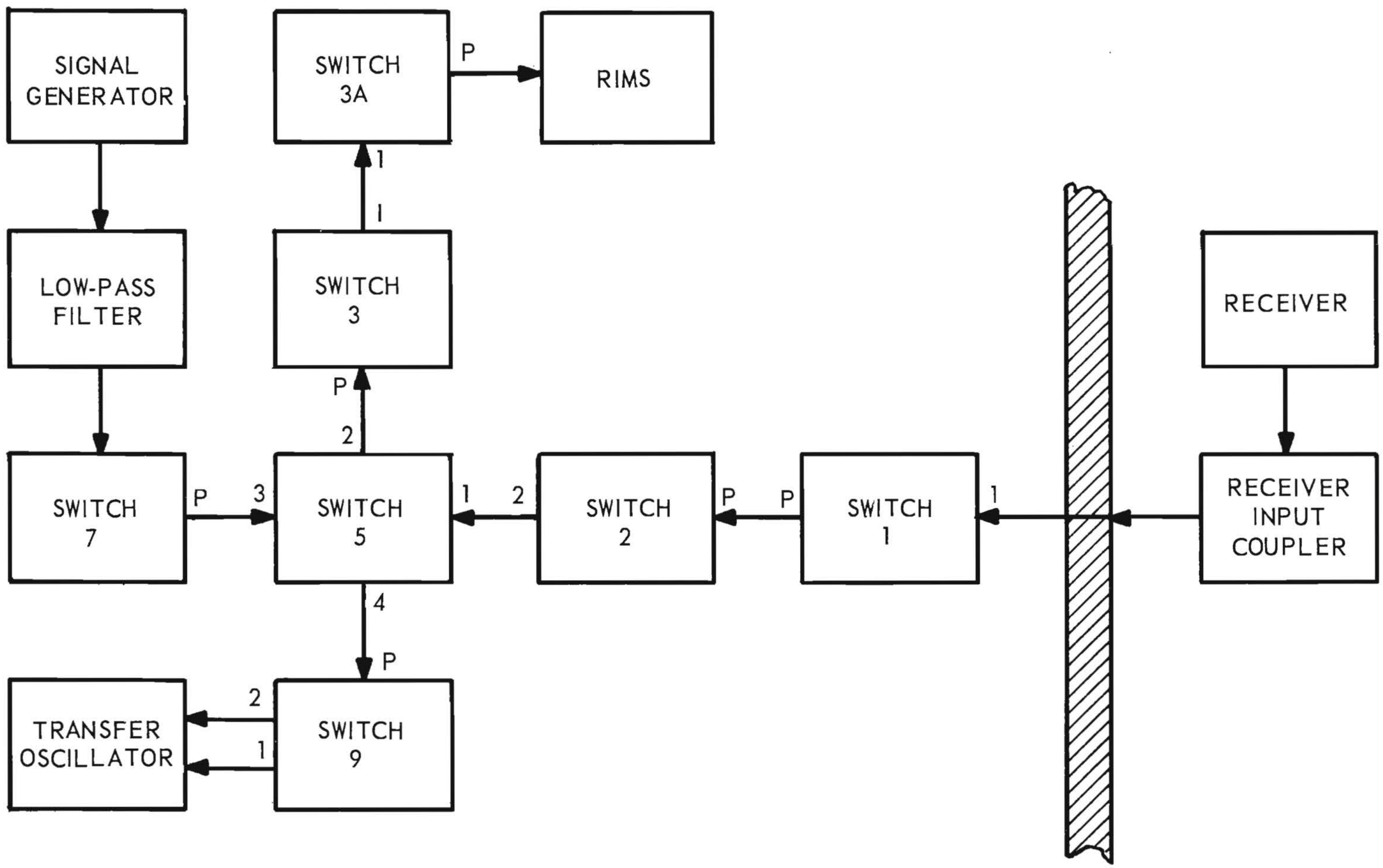

Figure 30. Equipment arrangement for antenna conducted emissions test of receivers.

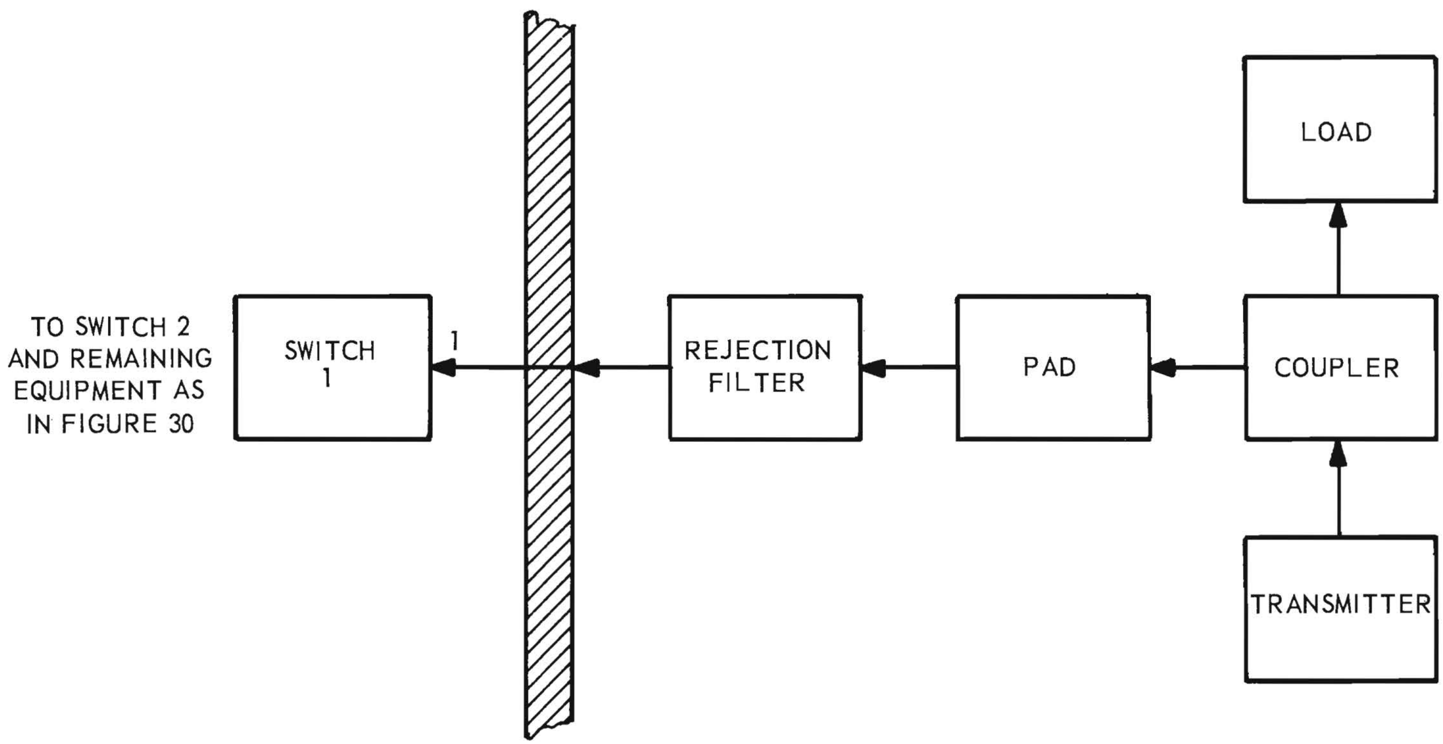

Figure 31. Equipment arrangement for the transmitter antenna conducted emissions test.

the coaxial system, or into the waveguide systems at the higher frequencies, presents a standard way of performing the test but does not assure accurate results because of the multimode problem. Further work needs to be done in this area.

The receiver intermodulation test setup (figure 6a) is as shown in figure 32. Isolators are indicated in each of the signal paths to minimize intermodulation that may occur in the signal generators themseleves. Various filters or hybrids may also be used for this purpose. Where they may be used, isolators are broadband and are more useful from this standpoint.

The additional signal generator will generally be of the same frequency range as the one already a component of the test set. This one test, which requires two signal generators at the same frequency, does not justify providing two signal generator complexes because of economics and space limitations in the van. When the receiver intermodulation test is performed, another signal generator that is compatible with the receiver being tested must be obtained elsewhere.

Figure 33 shows the intermodulation test setup for transmitters (figure 6b). The features of this equipment arrangement have been discussed previously. If the power outputs of the transmitters are too high to be handled by the reverse coupling arm of the couplers, coupling with antennas must be done. The coupler that is shown coupling the two transmitters together would be removed. The loads would be replaced with antennas and coupling would be accomplished by appropriate spacing and/or orientation of the antennas.

The case and cable radiation test setup (figure 7) is not detailed. However, the equipment arrangement is essentially the same as shown in figure 30, the antenna conducted emissions test. Switch no. 1 is switched to the antenna port,

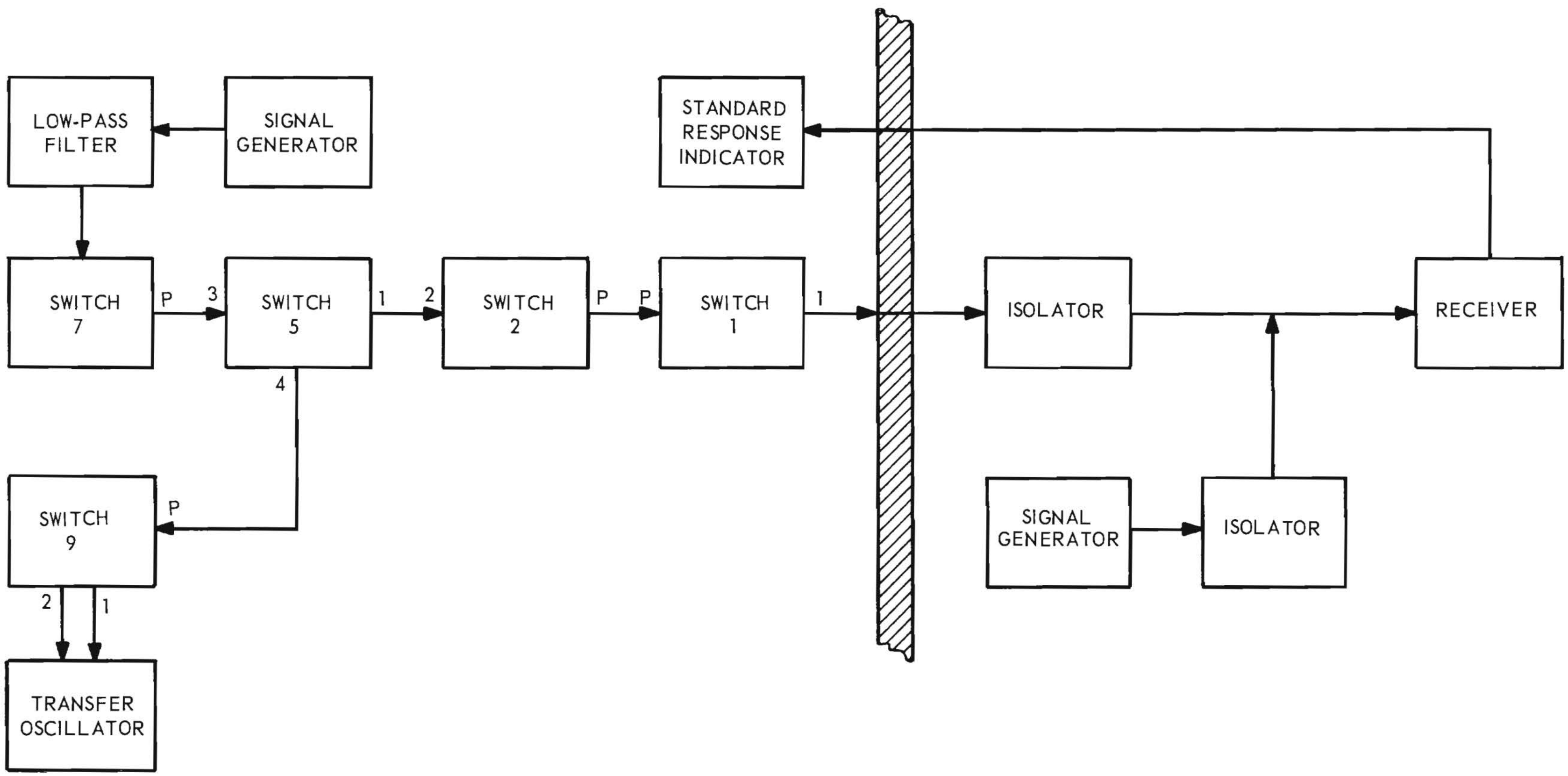

Figure 32. Equipment arrangement for the receiver intermodulation test.

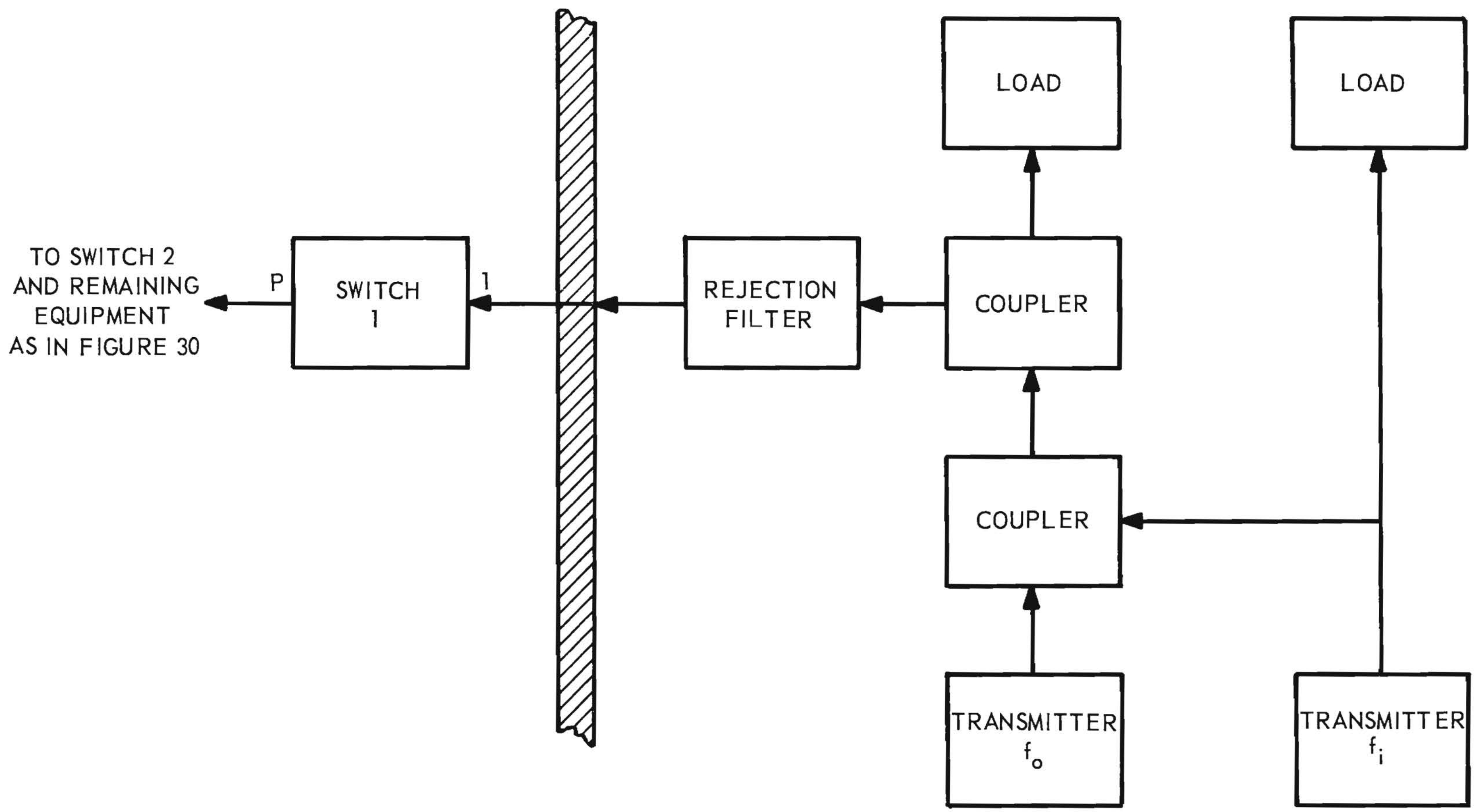

Figure 33. Equipment arrangement for the transmitter intermodulation test.

which is port number 2.

The radiated susceptibility test (figure 8) is conducted with the arrangement shown in figure 29 except that again switch no. 1 connects to the antenna port. Provision must be made to observe any disturbances that occur in the receiver or transmitter outputs either by observing the video output or providing an auxiliary cable to the spectrum analyzer or deviation meter.

3. Human factors considerations

In so far as practical, the accessory set should be designed with certain human factors being considered which will enable the operator to perform at maximum efficiency. The equipment arrangement inside the van is based on the joint consideration of minimizing the signal path attenuation and providing for as convenient an operation as possible. Since it is expected that the RIMS's will be the most used items, they are placed near the operator's desk. The height of the meters on the equipment in their indicated locations may not be optimum but weight considerations and the related problem of accessibility enter into the mounting of the larger pieces of equipment above floor level. The other primary measuring instruments such as deviation meter, spectrum analyzer, and frequency measuring instruments are placed directly in front of the operator's desk area.

The desk height is shown as approximately 40 inches, which is a practical compromise for both sitting and standing. This allows the operator to move around and return to a sitting position at the desk with ease.

As indicated in several of the figures, remote indicators are located in the test room. These are not only for the convenience of the operator to save him unnecessary steps, but also as a practical necessity for detecting responses and tuning in a particular signal. A swivel mounted, large scale meter should be centrally located inside the measurements room to allow the operator to observe the operation of the measuring equipment from any point in the room.

The ambient noise level inside the van is not expected to be severe. Insulation for the purpose of heat flow retardation will aid in reducing the noise level from external sources. The major source of noise in the accessory items is that due to cooling fans which should not be excessive.

Temperature control presents a larger and more difficult problem. The power consumed by the test equipment may exceed 5 kw, most of which will be dissipated as heat into the van enclosure. This means that substantial cooling must be provided by the air conditioning system. The cooling system—its size and distribution—must be integrally planned from early stages of construction.

IV. CONCLUSIONS AND RECOMMENDATIONS

A Design Plan for a Radio Frequency Compatibility (RFC) accessory set has been prepared, and specifications for various accessory items have been stated. In some areas refinements of existing equipment will be needed or new equipment will have to be developed to fill the needs of the accessory set. Some areas requiring refinement are the VSWR specifications of broadband attenuators or dummy loads, if the VSWR requirements of the Design Plan are to be met, and sampling device characteristics. Areas of equipment development include the microwave deviation detector, the standard response indicator, and broadband high power loads. Some work has been done on this project with thin film materials for high power dummy loads. Thin film resistive elements consisting of alloys having a small temperature coefficient of resistance have been investigated. These thin film loads would be useful because of their high power capabilities and extended frequency range resulting from their small size. Multimode problems which affect measurements in waveguide systems out of the dominant mode frequency range, and coaxial systems in the higher frequency ranges, are at present not solved in that no system provides the capability of making these measurements in a simplified manner useful for an operational measurement system.

No attempt has been made to specify the detailed characteristics of the accessory set when it is assembled in the final equipment configuration. Characteristics such as VSWR, and attenuation losses in the various transmission systems should be measured and corrective measures taken to prevent unreasonable specifications being applied to accessory components individually. A discussion of the VSWR problem from worst case consideration has been presented in Quarterly Report No. 2.

The configuration of the system is such that once its characteristics are measured and their value known, they should remain within tolerance for long periods of time requiring only periodic checking. The accessory set should reduce the variation of measurement data caused by changes in the configuration of the measurement system. Changes in the measurement system configuration present a problem when the various accessory components are assembled in a typical test setup each time a measurement is to be made.

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VI. APPENDIX

A. Additional accessory items

1. Frequency measuring system

MIL-I-11748 does not require an extremely precise determination of frequency; however, in the interest of providing a test set that will be of maximum usefulness it is desirable to supply frequency measuring capabilities that will meet the requirements of MIL-STD-449B as far as possible. MIL-STD-449B requires the determination of frequency to an accuracy of one part in 10^6.

Using a transfer oscillator, accuracies of this degree can be obtained to 12 Gc. In the waveguide bands above 12 Gc, frequency meters are generally accurate to one part in 10^3. Hewlett-Packard, in one of their application notes,[6] describes a frequency measuring system that provides much better accuracy in the waveguide bands and is useful from dc to 40 Gc. This system uses a standard transfer oscillator to produce harmonics to 12.4 Gc which affords direct measurement to this frequency. An auxiliary output from the transfer oscillator is amplified and subsequently applied to other mixers to produce harmonics from 12.4 to 40 Gc. A beat signal between one of the generated harmonics and the signal to be measured is used to adjust the frequency of the transfer oscillator to a subharmonic of the unknown signal. The frequency of the transfer oscillator signal is measured which consequently establishes the frequency of the unknown signal. A minor problem exists in the use of the system in that the determination of the harmonic number of the signal supplying the beat note may be difficult for inexperienced personnel.

2. Receiver input coupler

It is desirable that a receiver be properly terminated when making measurements of its interference properties or when utilizing it to perform measurements. To reduce the mismatch to less than 1.3:1 requires either stub tuners, an attenuator, or an isolator. Stub tuners are frequency sensitive and thus are eliminated on this basis.

A 10 db pad will reduce an infinite VSWR to less than 1.3:1. Since infinite VSWR's would not normally be encountered in a test situation, less attenuation could be used and thus reduce this unnecessary power loss. An attenuator for matching purposes should have a low residual VSWR. Units are commercially available* that exhibit a VSWR of 1.05:1.

An isolator with at least 20 db of isolation makes an excellent matching device with low insertion loss. They are not readily available below 500 Mc.

At the lower frequencies (less than 20 Mc) many systems are 300 ohm balanced systems. Three hundred ohm attenuators are not readily available, and in addition, most test equipment is designed for 50 ohm impedances.

An investigation of the requirements for a coupler to feed into a 300 ohm receiver from a 50 ohm system (or vice versa) led to the construction of a minimum-loss resistive pad. Because the receiver input coupler must operate from 14 kc to 400 Mc, the possibility of using reactive devices such as transformers is remote. The simplest approach is to use a resistive network that has uniform impedance characteristics throughout the frequency range of interest.

Precision resistors were placed in a specially constructed holder to achieve a flat response to 400 Mc. Experimental investigations revealed that the 274 ohm resistor in series with the 300 ohm line must be placed exterior to the metal body to flatten the insertion loss characteristic. This was accomplished by placing the resistor inside a plexiglas sleeve support that provides adequate mechanical rigidity to the 300 ohm terminals.

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*Model 372C precision attenuator, Hewlett-Packard Co., Palo Alto, California.

A drawing of the final model is shown in figure 34. The insertion loss and input impedance variations with frequency are shown in figure 35. Input impedance measurements at the 50 ohm terminal at 400 Mc indicated a VSWR of 1.11:1 with the 300 ohm terminals open and 1.07:1 with the 300 ohm terminals shorted.

3. Standard response indicator

In order to perform the majority of the receiver spectrum signature measurements described in MIL-I-11748 and MIL-STD-449B, it is necessary that a monitoring device or standard response indicator be connected to the output video or audio terminals of a unit under test to determine the presence or absence of a desired signal-to-noise ratio under various interference conditions. A distortion analyzer may be used to determine the signal-to-noise ratio on CW systems. The utilization of this instrument is time consuming and requires a great deal of operational adjustments on the part of the user. A standard response indicator for pulse systems is described in the literature.[7] The basic features of both of these methods may be combined in a single instrument.

It may be desirable to provide a Go/NoGo output signal in addition to the front panel meter reading. This feature would be necessary for radiated receiver measurements and, in some cases, for conducted measurements where the operator is required to be located at a point remote from the receiver-under-test. Providing two separate channels and an AGC loop in the CW portion of the circuitry makes it possible to obtain a continuous, direct reading of S+N/N ratio without the inconvenience of switching from "notch in" to "notch out" positions, adjusting the input level, and determining the difference between two meter readings as required for the distortion analyzer. For more

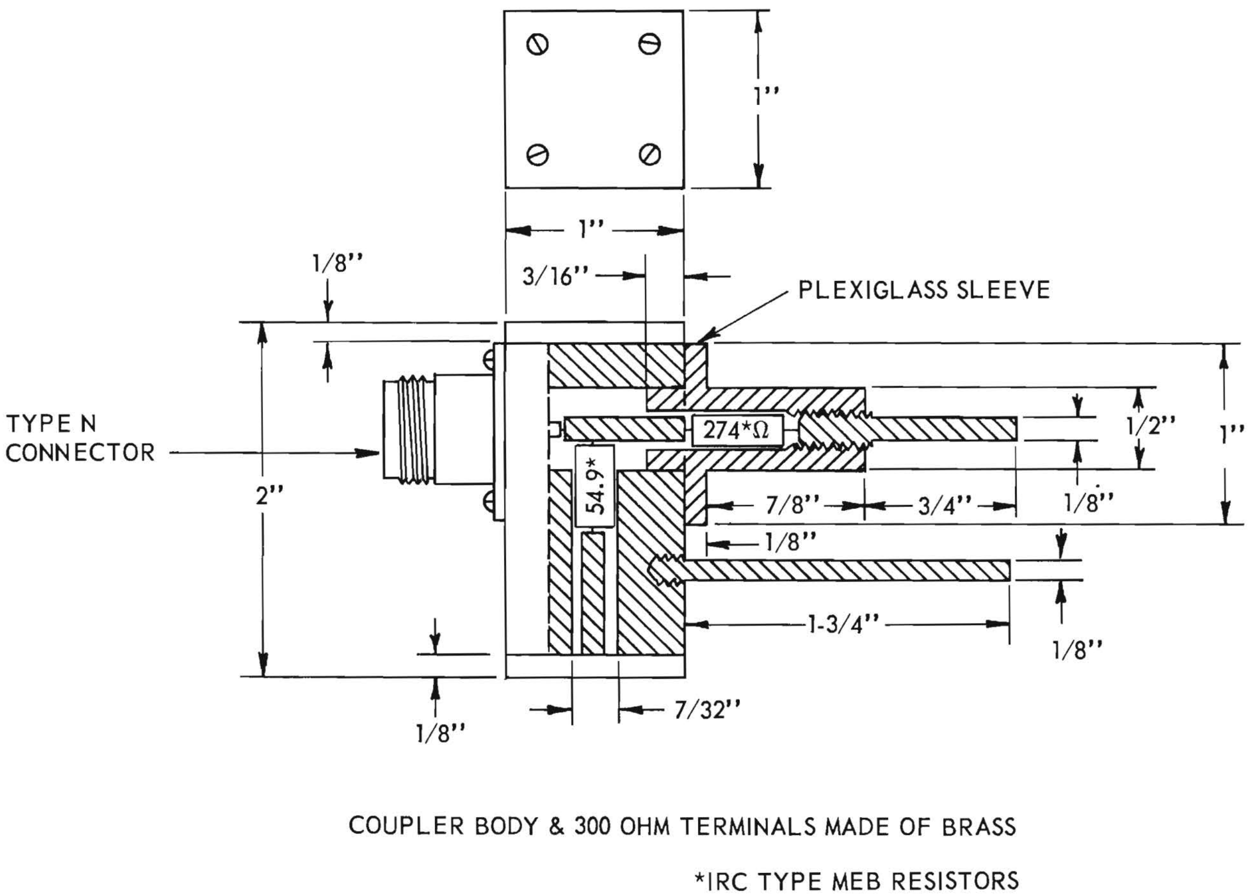


Figure 34. Partial cutaway drawing of receiver input coupler.

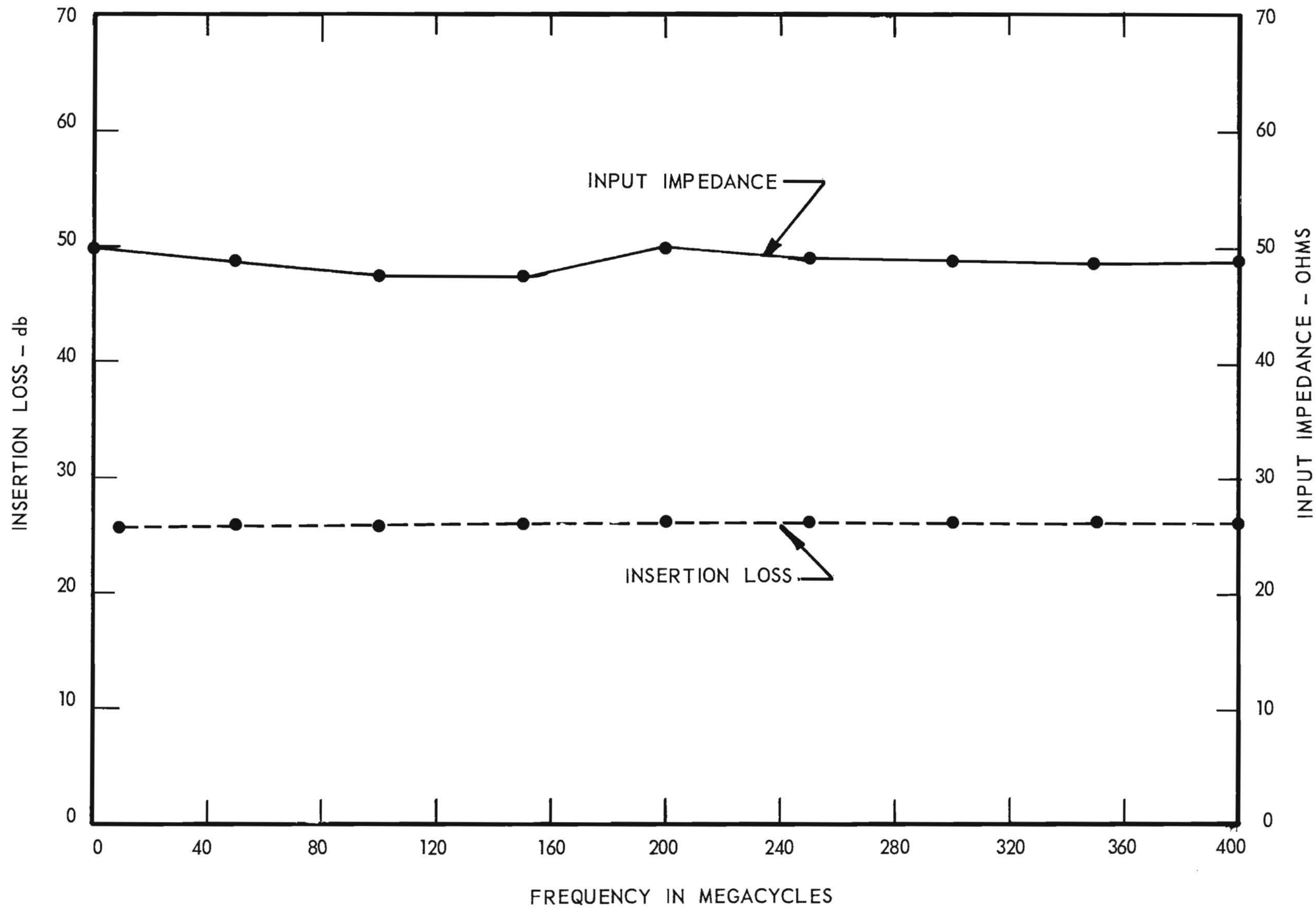


Figure 35. Input impedance and insertion loss characteristics of receiver input coupler.

details, reference should be made to a previous report[4] prepared under this contract.

This instrument provides a means of measuring the prescribed standard response in terms of a signal-to-noise ratio for pulse, AM, and FM systems. Addition of a synchronized signal for turning on and off the signal generator by use of a diode switch could provide the capability of making standard response measurements on an FM system using the quieting criterion.

4. Microwave frequency deviation meter

Frequency modulation monitors are available for monitoring transmitter outputs up through the vhf regions, but at microwave frequencies, this type modulation monitor is not readily available. These monitors are required because many of the tests required by MIL-I-11748 specify that the output of a transmitter be monitored to detect any disturbances in its operation due to interfering signals. In addition, other tests require that the output of a transmitter be deviated a specified amount and be monitored.

Above the frequency region where modulation monitors are available, the "zero count" technique using a spectrum analyzer is normally employed. This method is inaccurate because of the resolution capabilities of most spectrum analyzers, and it is time consuming in that new computations must be made for each value of modulation produced or required, and for each different modulating frequency.

In an effort to improve the technique of measurement of frequency deviation and improve the accuracy of frequency deviation detection, a system that will perform this measurement quickly and accurately is outlined. The system uses the principle of frequency-compression demodulation which Ruthroff and Bodtmann[8] applied in the vhf range.

The block diagram of the detector is shown in figure 36. The system

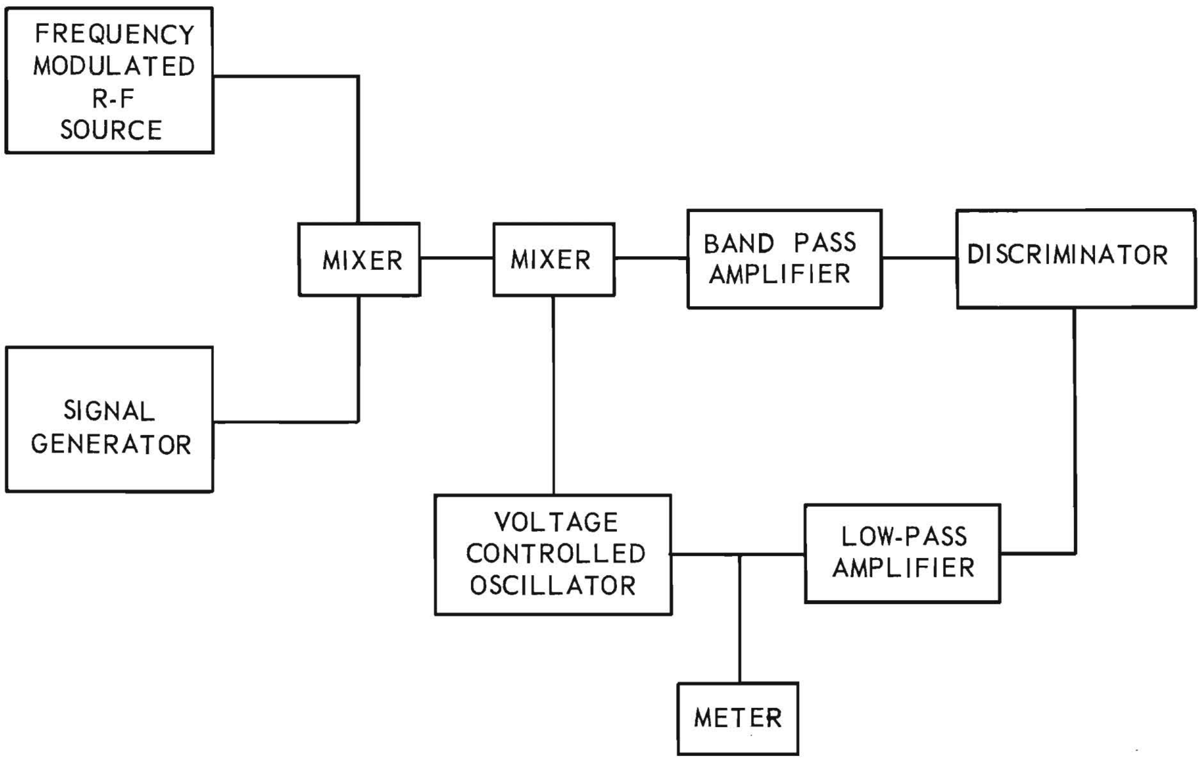


Figure 36. Block diagram of frequency deviation detector.

is designed with RFI testing in mind and assumes that signal generators near the frequency of the transmitter are available for use.

The oscillator is designed to operate at a convenient frequency. The difference frequency between the first mixer output and the oscillator output signal produces the intermediate frequency in the second mixer. The output of the discriminator is amplified by the low-pass amplifier and changes the oscillator frequency to produce a minimum output at the discriminator. The meter reading is proportional to the rectified output of the low-pass amplifier. The amplitude of this signal is proportional to the deviation of the transmitter output signal. The bandwidths required by the intermediate frequency and low-pass amplifiers are determined by the modulating frequency of the transmitter.

5. Audio susceptibility tester

A design has been prepared on the contract for an audio susceptibility tester, which consists of a coupling transformer and an audio amplifier. This susceptibility tester is to provide 3 volts rms open circuit voltage for series injection into the power line of the equipment being tested, with harmonic distortion less than 5 per cent and is to have an output impedance of less than 0.3 ohm. Design goals were set at 50 amperes of line current as a maximum value from dc to 400 cps with no more than 5 per cent of the supply voltage drop across the susceptibility tester transformer winding coupling into the power line of the equipment under test.

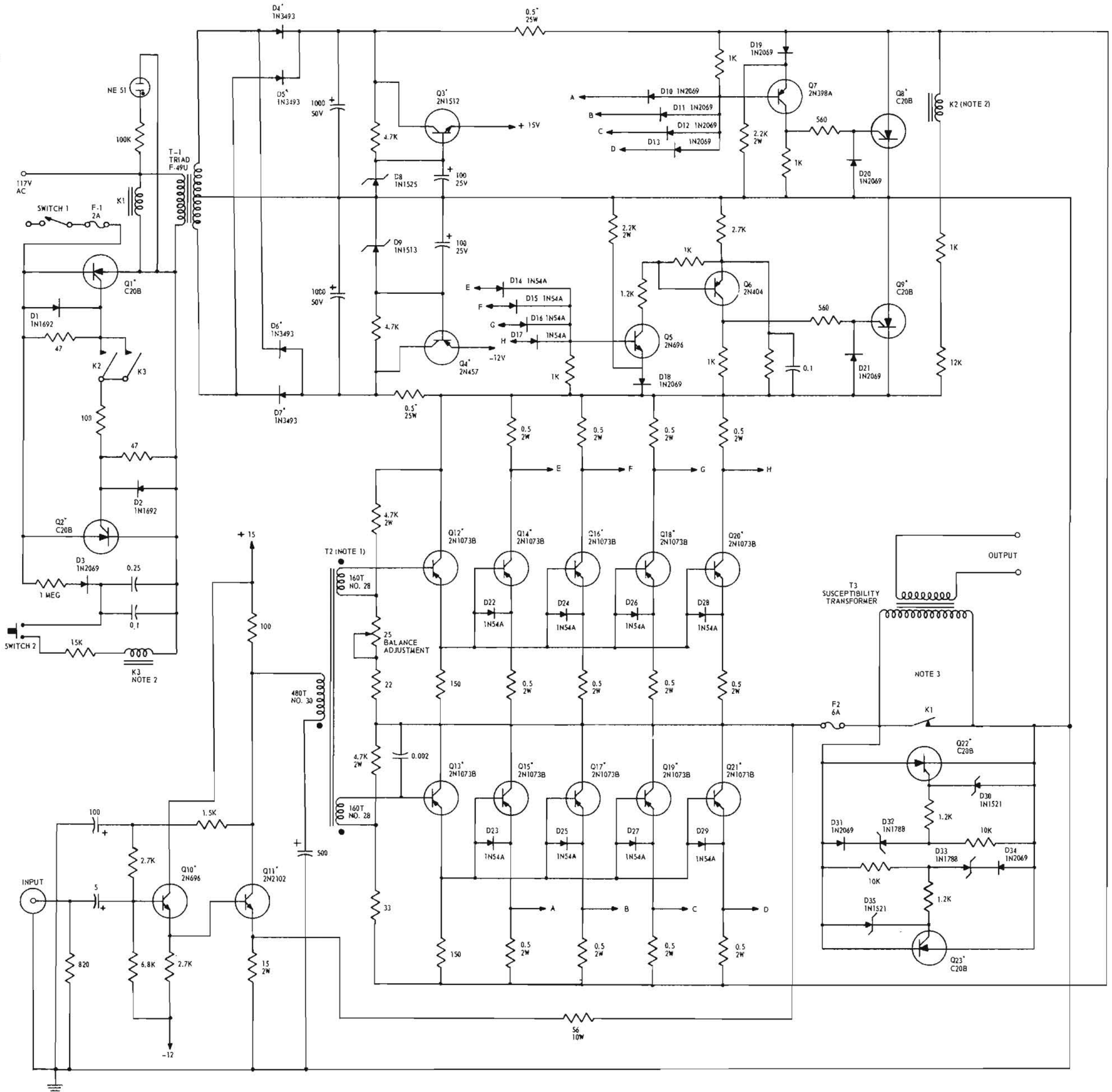
The design approach followed was to construct an amplifier having a low output impedance and to transform this low output impedance into the transformer winding in series with the equipment under test by use of a step-down transformer.

The susceptibility amplifier and transformer designs are interdependent. It was decided to construct a transistorized audio amplifier having a low output impedance. A susceptibility transformer with a turns ratio of 8:1 was selected as a compromise taking into account such factors as maximum back voltage on the power transistors, impedance present in the power line at the coupling transformer secondary, and power signal current feedback into the amplifier.

A schematic of the audio susceptibility amplifier is shown in figure 37. The power output stage uses the power transistors in a conventional bridge configuration: one half of which consists of power transistors; the other half consisting of the positive and negative power supplies. Feedback is used to obtain a low output impedance. Fairly elaborate protection devices are included in the amplifier to protect against overcurrent in the power transistors and overvoltage across these transistors. A more detailed discussion of the amplifier and transformer is presented in the final report[2] on this contract.

The susceptibility transformer uses bifilar winding techniques. The turns ratio of this transformer is 8:1, the dc resistance of the secondary winding is 0.0058 ohm, the leakage inductance referred to the secondary is approximately 0.15 μh, and the primary open circuit inductance is 130 mh. A diagram of the construction details of this transformer is shown in figure 38.

The frequency response and harmonic distortion characteristics of the amplifier are shown in figure 39. These tests were made with the amplifier loaded in a 0.5 ohm resistor on the secondary of the coupling transformer and include the response of the coupling transformer. The output voltage for these tests was the required 3 volts rms at the transformer secondary. Output



*MUST BE OPERATED WITH A HEAT SINK.

NOTES:

1. CORE 3/4 IN. STACK OF 0.0185 IN. THICK EI-75 SILICON STEEL LAMINATIONS 100% INTERLEAVED.
2. RELAYS K-2 AND K-3 MAGNECRAFT RELAY, SPST NO, CAT. NO. W102PCX4.
3. RELAY K-1, SPST NC, COIL 115V, CONTACTS 15 AMPS.
4. ALL CAPACITORS IN μf AND ALL RESISTORS IN OHMS UNLESS OTHERWISE SPECIFIED. ALL RESISTORS 1/2 WATT UNLESS NOTED.

Figure 37. Schematic diagram of audio susceptibility tester amplifier.

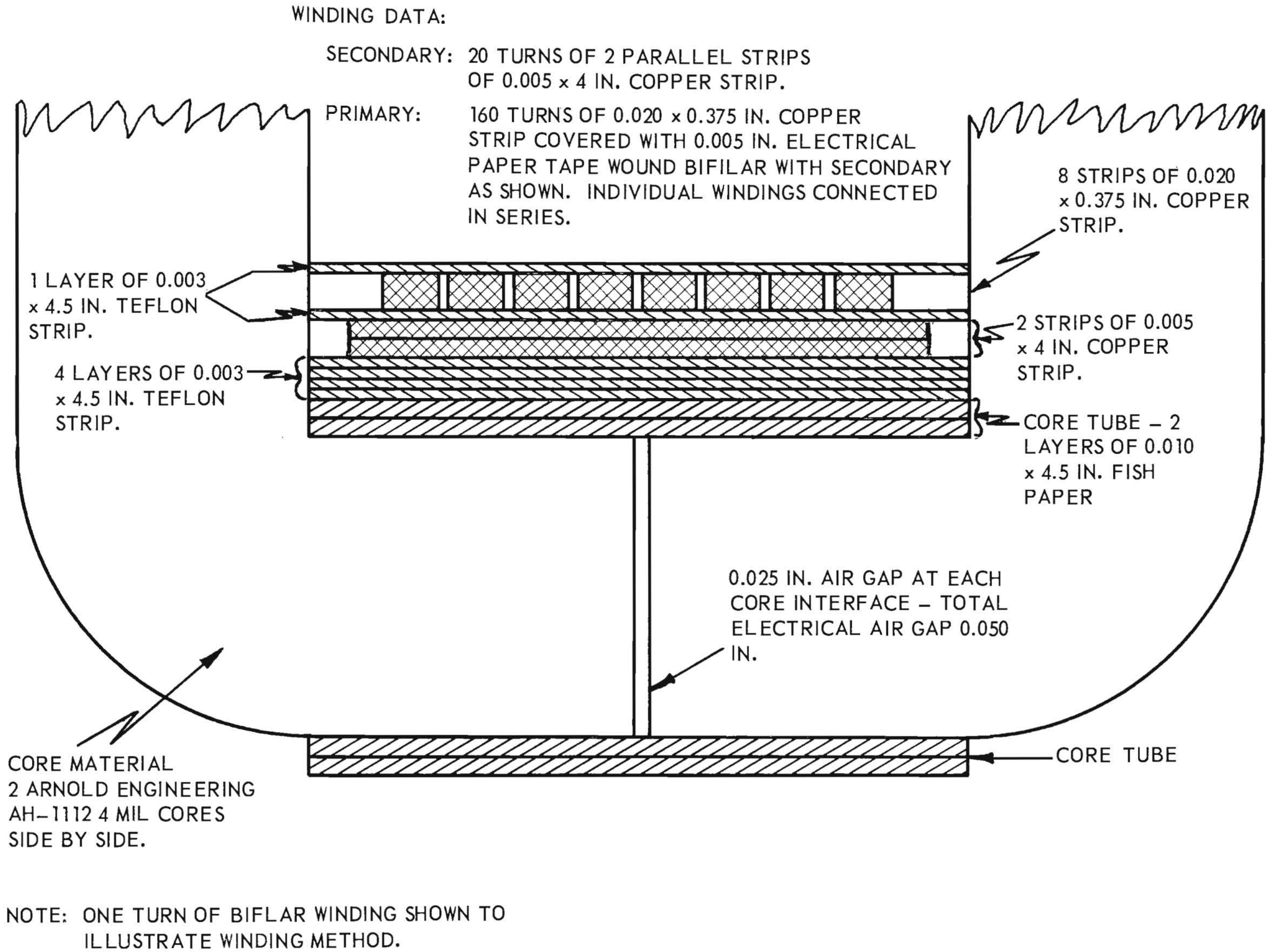


Figure 38. Winding configuration of coupling transformer.

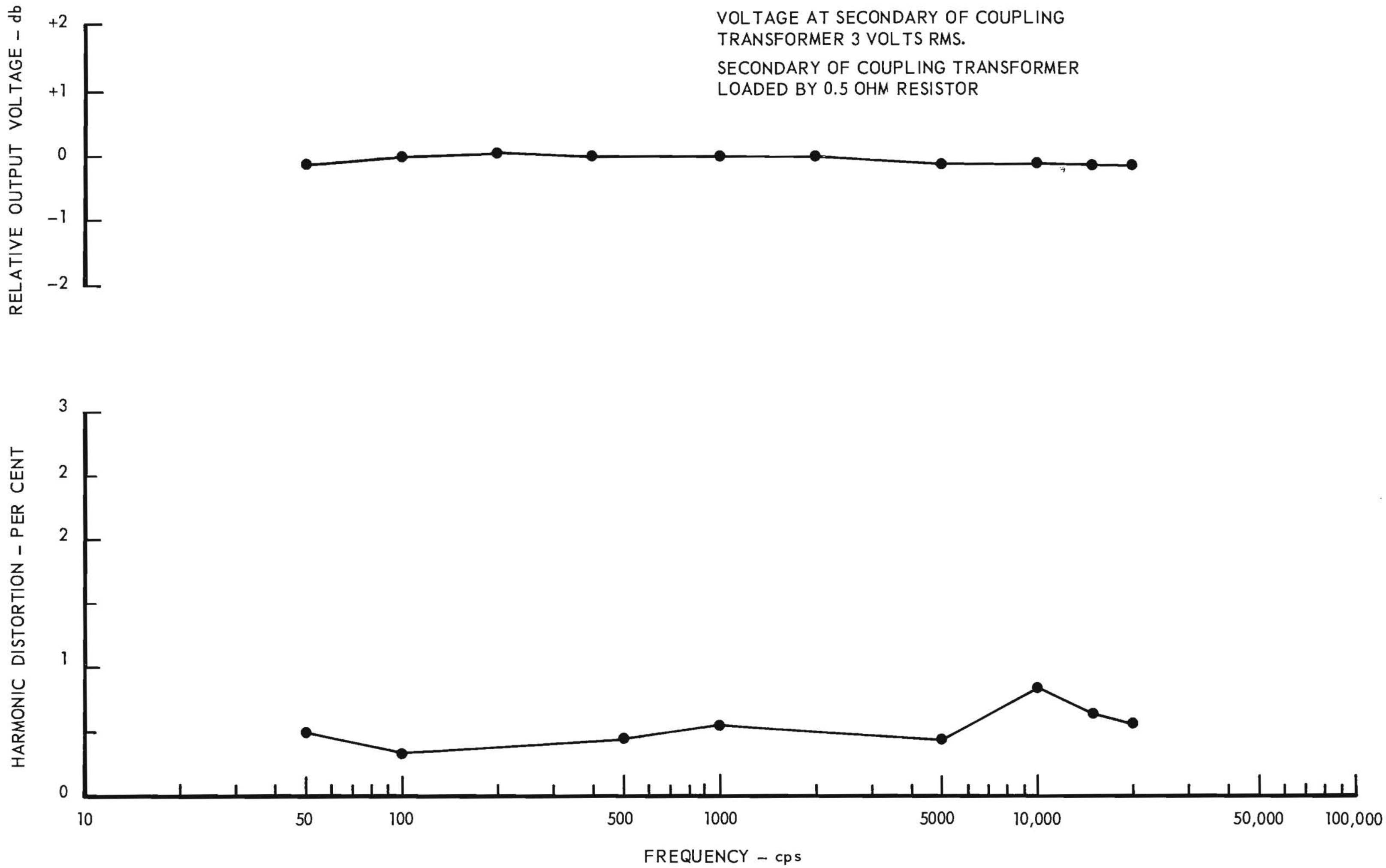


Figure 39. Frequency response and harmonic distortion of susceptibility coupling transformer and amplifier.

impedance of the audio susceptibility tester is shown in figure 40 at the output terminals of the coupling transformer. This test was performed with a current of 0.43 ampere rms into the secondary of the transformer.

Tests have been performed on the susceptibility tester with line currents of 35 amperes of 60 cps power current in the coupling transformer secondary and 50 amperes dc. During these tests the audio susceptibility testing voltage at the secondary of the coupling transformer was 3 volts rms and the audio power supplied was approximately 18 watts. Operation of the amplifier at ac line currents higher than 20 amperes requires the use of forced air cooling for the output power transistors.

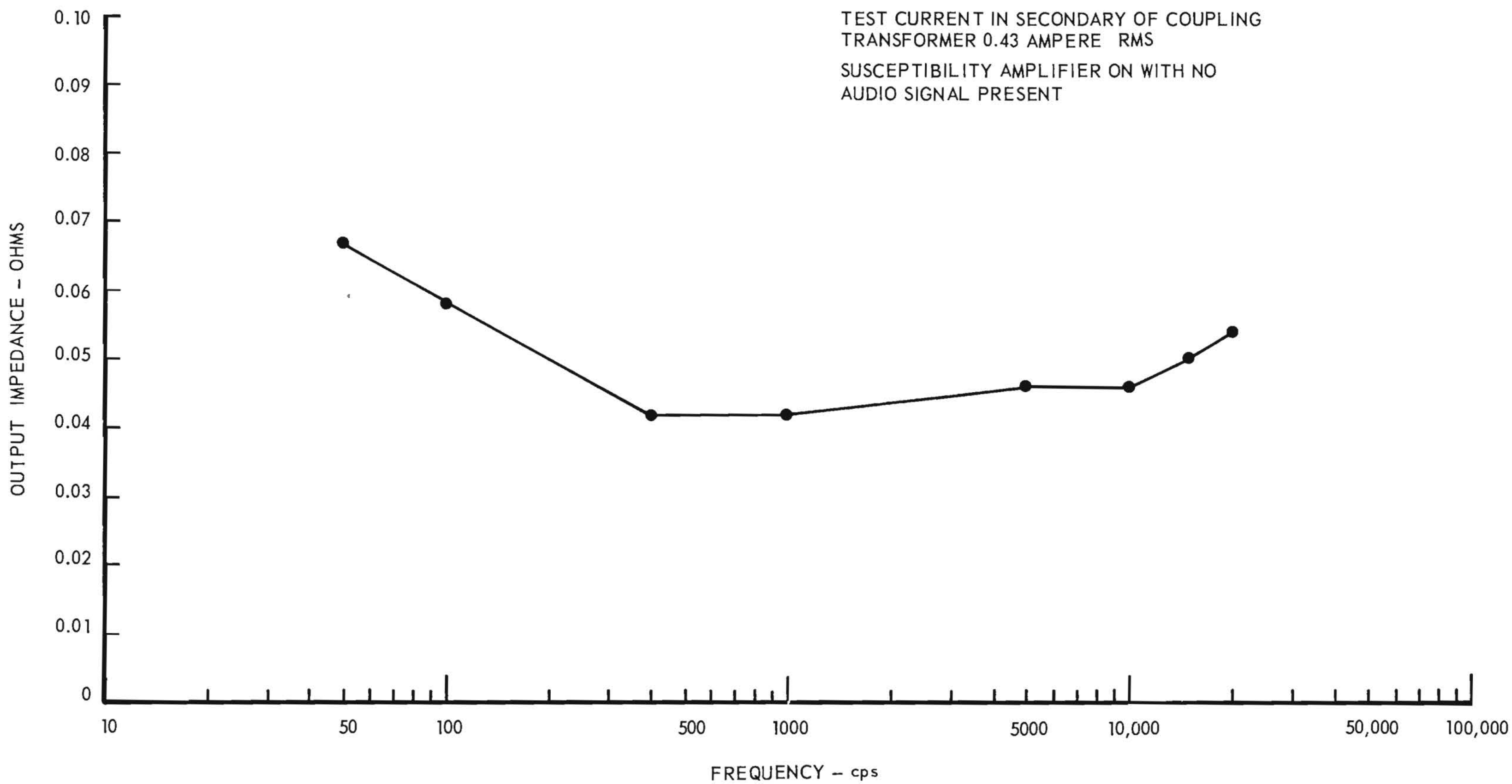


Figure 40. Output impedance of audio susceptibility tester at output terminals of coupling transformer.

B. Switch list

Following is a list of switches in the accessory set by number as they appear in the accessory set. Switches with as much isolation as possible are desirable—about 60 db seems to be state-of-the-art at present.

Switch no.	Connections	Type	Operational Mode
SW-1	Coaxial	SPDT	Manual
SW-2	Coaxial	Four port, three position	Electrical
SW-3	Coaxial	SPDT	Manual
SW-3A	Coaxial	SPDT	Manual
SW-4	Coaxial	SP5T	Manual
SW-5	Coaxial	Four port, three position	Electrical
SW-6	Coaxial	SPDT	Manual
SW-7	Coaxial	SP8T	Electrical
SW-8	Coaxial	SPDT	Manual
SW-9	Coaxial	SPDT	Manual
SW-10	Coaxial	SP4T	Electrical
SW-11	Coaxial	SP4T	Electrical
SW-12	WR-90	SPDT	Manual
SW-13	WR-90	SP3T	Electrical
SW-14	WR-90	Four port, three position	Electrical
SW-15	WR-90	SPDT	Manual
SW-16	WR-62	SPDT	Manual
SW-17	WR-62	SP3T	Electrical
SW-18	WR-62	Four port, three position	Electrical

SW-19	WR-42	SPDT	Manual
SW-20	WR-42	SP3T	Electrical
SW-21	WR-42	Four port, three position	Electrical
SW-22	WR-28	SPDT	Manual
SW-23	WR-28	SP3T	Electrical
SW-24	WR-28	Four port, three position	Electrical
SW-25	Coaxial	DPDT	Manual
SW-26	Coaxial	DPDT	Manual
SW-27	Coaxial	SPDT	Manual
SW-28	Coaxial	SPDT	Electrical
SW-29	Coaxial	SPDT	Electrical
SW-30	Coaxial	SPDT	Electrical
SW-31	Coaxial	SP4T	Electrical
SW-32	Coaxial	SP4T	Electrical

C. Specifications of accessory items

The following specifications are considered necessary for adequate, though not necessarily optimum, accessory items. They are not always available in present state-of-the-art.

1. Waveguide hardware

Element	VSWR
90° bends, E & H plane	1.05
45° bends, E & H plane	1.05
Twists	1.05
Transistions	1.10
Waveguide to coax adapters	1.25

2. Directional couplers

a. Coaxial

Bandwidth: Octave
Power rating: 1000 watts
Coupling: 40 db
Directivity: 30 db (nominal)
Main line VSWR: 1.3:1
Secondard line VSWR: 1.3:1
Insertion loss: 0.5 db

b. Waveguide

Bandwidth: Standard waveguide band
Power rating: Rating of waveguide
Coupling: 40 db ± 3 db
Type: Narrow wall
Directivity: 20 db
Main line VSWR: 1.1:1
Secondary line VSWR: 1.3:1
Insertion loss: 0.2 db

3. Isolators

a. Coaxial

Bandwidth: Octave (minimum)
Insertion loss: 1 db
VSWR: 1.25:1
Power (avg.): 10 watts
Isolation: 10 db

b. Waveguide

Bandwidth: Standard waveguide band
Insertion loss: 1 db
VSWR: 1.15:1
Power (avg.): 10 watts
Isolation: 20 db (minimum)

4. Attenuators

a. Coaxial

Frequency range: 0 to 11 Gc
VSWR: 1.2:1
Attenuation: 3, 6, and 10 db ± 0.5 db
Power (avg.): 1 watt
Impedance: 50 Ω

b. Waveguide

Frequency range: Standard waveguide band
VSWR: 1.15:1 (Hewlett-Packard produces a precision attenuator in different values with a VSWR of 1.05)
Power (avg.): 1 watt

5. Dummy loads

Type: Unspecified
Frequency range: As wide as the state-of-the-art permits
VSWR: 1.1:1
Power: 1000 watts

6. Switches

a. Coaxial

Frequency range: 0 to 11 Gc
Power rating: 10 watts
Isolation: 60 db
Insertion loss: 0.3 db
VSWR: 1.3:1
Characteristic impedance: 50 Ω

b. Waveguide

Frequency range: Standard waveguide band
Power rating: 10 watts
Isolation: 60 db
Insertion loss: 0.2 db
VSWR: 1.1:1

7. Filters

a. Low-pass

Passband attenuation: 1 db (maximum)
Stopband attenuation: 60 db
Skirt attenuation: 60 db within 10% of f_c
Range of stopband: 6 f_c
Spurious responses: None within stopband
Power rating: 2 watts
VSWR: 1.2:1 (see note)

b. High-pass

All specifications identical to those for low-pass filters except the passband should extend to at least 2 f_c.

c. Band-pass

Type: Tunable
Range: Octave or standard waveguide band
Bandwidth: 1% of the tuned frequency
Out-of-band attenuation: 60 db within 1 % of f_c
Spurious responses: 60 db down to 3.5 times the tuned frequency
Power rating: 2 watts
VSWR: 1.2:1 (see note)

d. Band-reject

Type: Tunable
Range: Octave or standard waveguide band
Bandwidth: 1% of the tuned frequency
Skirt attenuation: Maximum of 6 db 1% from f_c
Power rating: 2 watts
VSWR: 1.2:1 (see note)

NOTE: Most filter specifications give the passband or tuned frequency characteristic impedance or maximum VSWR. For testing purposes it is desirable to know the out-of-band impedance or mismatch. A constant impedance filter would provide the most reliability in that its effect on out-of-band signals would be of a more predictable nature.

D. Multimode sampling techniques

In attempting to measure signals other than the fundamental in a waveguide, one encounters the problem of energy propagating in more than one mode. The problem occurs to a lesser degree in coaxial systems. Most interference measurement techniques have more or less ignored the problem of power being in other than the fundamental mode.

At the fundamental frequency of a transmitter, the output stages are generally designed to launch a specific mode in the transmission system. This mode is usually the dominant TE_{10} mode in rectangular guides, the TE_{01} mode in circular guides, and the TEM mode in coaxial systems. Above some frequencies, energy can propagate in various modes. The number of modes depends upon the size of the guide and the frequency of the signal.

The primary obstacle in attempting to measure the power in a multimode signal lies in the field sampling device or technique. Most sample probes and sampling devices are sensitive to one mode primarily. This means that a single fixed probe may not respond accurately to the power that is contained in more than one mode.

A number of techniques have been developed for sampling a multimode field and determining the power contained herein. Edson[9] has made a comparative analysis of these methods. The most promising technique from the point of view of the Design Plan was developed at Airborne Instruments Laboratory.[10] The method is reported to be accurate to ± 1 db or better. High-power breakdown does not present a problem and no computer services are necessary for reduction of data. A test run of a particular frequency can be completed in minutes.

For more details the reader is referred to reference 10. This technique seems to be the most desirable for a piece of versatile test equipment. The accuracy is adequate and the time requirement is not excessive. The receiver used in the equipment setup is a RIMS and would be available for use. The greatest objection is that the signal line components become cumbersome and require a lot of space at the larger waveguide sizes.

E. Attenuation and mismatch considerations

1. Attenuation calculations

Sample calculations were made of some representative signal paths to determine if excessive losses were present and to determine the degree of equalization of losses between systems.

Average values of attenuation in db per 100 feet were used in computation of the losses. Table I gives the manufacturers' data on currently available low-loss coaxial transmission lines. Table II is a listing of the values of theoretical attenuation for waveguide sizes from X-band through K_a-band.

The values of attenuation are computed by estimating path lengths and then multiplying by the per unit attenuation. The attenuation due to the various accessory items such as switches and the like were obtained from the maximum specified values by manufacturers. Where this information was not available, the attenuation was estimated. Using this procedure, attenuation calculations were made for a coaxial system at 10 Gc and at the low ends (highest attenuation) of X- and K_a- bands.

The calculations for X-band are shown in table III to illustrate the procedure. Path losses are computed on the basis of 5.5 db/100 feet which is the highest theoretical attenuation over the frequency range of X-band.

A summary of selected path losses is presented in table IV for the coaxial, X-band, and K_a-band systems.

The maximum VSWR at the input port is not to exceed 1.2:1. This specification is going to be difficult to realize because two components with a VSWR of 1.1:1 (a fairly precise unit) can have a maximum VSWR of 1.21:1. Three or more units will have a much higher probability of exceeding the specification at least at one point over a practical operating band. Attenuators or isolators

TABLE I

DATA ON LOW-LOSS COAXIAL TRANSMISSION LINE AT A FREQUENCY OF 10 kMc

Name	Manufacturer	Cutoff frequency	Avg. power rating (watts)	Nominal Attenuation (db/100 ft)	Size
Heliax flexible	Andrew	10.8 Gc	50	18	3/8"
Foam flex	Phelps Dodge Electronic Products	12.5 Gc	160	21	3/8"
Styroflex	Phelps Dodge Electronic Products	14.3 Gc	100	15	3/8"
Helical membrane	Phelps Dodge Electronic Products	10.8 Gc	170	8.5	1/2"
Spirafil	Phelps Dodge Electronic Products	14.4 Gc	85	15	3/8"

TABLE II

WAVEGUIDE ATTENUATION CHARACTERISTICS

EIA Designation	Band	Frequency	Theoretical attenuation lowest to highest frequency (db/100 ft)
WR-90	X	8.2-12.4 Gc	8.64-6.02 (B)* 5.49-3.83 (Al)
WR-62	K_u	12.4-18.0 Gc	12.76-11.15 (B) 8.13-7.10 (Al)
WR-42	K	18.0-26.5 Gc	17.6-12.6 (Al) 13.3-9.5 (Ag)
WR-28	K_a	26.5-40.0 Gc	21.9-15.0 (Ag)

*B - Brass, Al - Aluminum, Ag - Silver.

TABLE III

SAMPLE CALCULATIONS OF SIGNAL PATH ATTENUATION

Item	Path	Distance (ft)	Attenuation (db)
1	Test location to switch no. 12	4	0.22
2	Switch no. 12		0.20
3	No. 12 to no. 13	0.5	0.03
4	No. 13		0.20
5	No. 13 to attenuator, A-2	15	0.83
6	A-2		0.50
7	Coaxial to waveguide adapter		0.40
8	Adapter to spectrum analyzer	1	0.18*
9	No. 13 to deviation meter	14	0.77
10	No. 13 to no. 14	9	0.50
11	No. 14		0.20
12	No. 14 to frequency measurement system	1	0.06
13	Coaxial to waveguide adapter		0.40
14	Adapter to RIMS	5	0.90*
15	No. 14 to no. 15	1	0.06
16	No. 15		0.20
17	No. 15 to 10-15 Gc generator	3	0.16
18	No. 15 to coaxial to waveguide adapter	0.5	0.03
19	Coaxial to waveguide adapter		0.20
20	Adapter to no. 8	0.5	0.03
21	No. 8		0.30
22	No. 8 to signal generator	4	0.72*

*Attenuation for lengths of coaxial line is computed on the basis of 18 db/100 ft.

TABLE IV

COMPUTED ATTENUATION OF SELECTED SIGNAL PATHS

Item	System	Path	Attenuation
1	Coaxial	Test location to RIMS	4.98 db
2	Coaxial	Test location to spectrum analyzer	4.25 db
3	Coaxial	Signal generator to test location	7.09 db
4	Coaxial	Signal generator to RIMS	4.65 db
5	Coaxial	Test location to deviation meter	3.69 db
6	Coaxial	Signal generator to frequency measuring system	6.72 db
7	X-band	Test location to RIMS	2.65 db
8	X-band	Test location to spectrum analyzer	2.56 db
9	X-band	Signal generator to test location	2.86 db
10	X-band	Signal generator to RIMS	3.01 db
11	X-band	Test location to deviation meter	1.15 db
12	X-band	Signal generator to frequency measuring system	1.91 db
13	K_a-band	Test location to RIMS	3.79 db
14	K_a-band	Test location to spectrum analyzer	7.06 db
15	K_a-band	Test location to deviation meter	6.22 db
16	K_a-band	Signal generator to test location	3.44 db
17	K_a-band	Signal generator to RIMS	1.61 db
18	K_a-band	Signal generator to frequency measuring system	4.91 db

could be used to minimize the VSWR of several components but even this may be difficult. The residual VSWR of coaxial attenuators is in the neighborhood of 1.3:1 over at least an octave band. Coaxial isolators have a smaller specified maximum VSWR of 1.2:1 (1.25:1 at 11 Gc) over an octave band. The specification will be easier to realize in waveguide bands as isolators are characterized by a maximum residual VSWR of 1.15:1 and attenuators are available* that are specified as having a maximum VSWR of 1.05:1 over a waveguide band.

An easily obtainable estimate of the VSWR of a number of components does not say in reality how the system will perform. A pseudo-exact analysis would be laborious to perform. It would require information such as the residual VSWR of each component over the operating band and the attenuation due to each component and each section of transmission line. Even the VSWR of connectors, which varies each time a connection is changed, must be known. With all this information, which is seldom available, the procedure of computing the overall problem involving two or more components becomes complex. The effects of all other components must be considered when making calculations at any particular one. And once a calculation is completed, a change in frequency or components necessitates a new calculation. It is evident that the process becomes unreasonably cumbersome in addition to not being completely reliable.

Therefore, the recommended approach is to select components that have the minimum residual VSWR reasonably available in the state-of-the-art, then measure the VSWR at the ports mentioned earlier, and apply the corrective measures of appropriate use of attenuators and/or isolators.

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*Model 372C precision attenuator, Hewlett-Packard Co., Palo Alto, California.

FINAL TECHNICAL REPORT

PROJECT A-693

RADIO FREQUENCY COMPATIBILITY (RFC) ACCESSORY EQUIPMENT SET (U)

H. W. DENNY AND J. R. WALSH, JR.

CONTRACT DA 36-039 AMC-02223(E)
DEPARTMENT OF THE ARMY PROJECT: 1G620501D449

15 April 1963 to 14 June 1964
Issued 15 July 1964

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Fort Monmouth, New Jersey

1964

Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

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FINAL TECHNICAL REPORT

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DEPARTMENT OF THE ARMY PROJECT: 1G620501D449

SIGNAL CORPS TECHNICAL REQUIREMENT
SCL-7687, dtd. 28 Sept. 1962

The object of this research was to prepare a Design Plan for a Radio Frequency Compatibility Accessory Set.

15 APRIL 1963 to 14 JUNE 1964
Issued 15 July 1964

Performed for
U. S. ARMY
ELECTRONICS LABORATORIES
FORT MONMOUTH, NEW JERSEY

FOREWORD

This report was prepared at the Georgia Tech Engineering Experiment Station on Contract No. DA 36-039 AMC-02223(E). The report discusses the results of a study project leading to the establishment of a Design Plan for accessory equipment to be used with radio interference measuring sets, and for the development of a receiver input coupler and audio susceptibility tester. The work was conducted under the general supervision of D. W. Robertson, Head, Communications Branch. In addition to the authors, the principal participants in the performance of the effort were W. R. Free, Research Engineer; E. W. Wood, Assistant Research Engineer; N. T. Huddleston, Graduate Research Assistant; and D. C. Griffin, Technical Assistant.

Respectfully submitted:

J. R. Walsh, Jr.
Project Director

Approved:

M. W. Long, Chief
Electronics Division

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I. PURPOSE

The purpose of this project was to conduct a study leading to a Design Plan for accessory equipment to be used with radio interference measuring sets, signal generators, and other test equipment. The accessory equipment includes the complementary devices necessary to determine radio frequency interference characteristics of U. S. Army electrical and electronic equipment in accordance with military specification MIL-I-11748. The frequency range of interest is 0.014 to 40,000 Mc. It was also the purpose of the project to investigate two items of equipment. These were a receiver input coupler and an audio susceptibility tester.

The areas of investigation on this project were divided into three tasks as follows:

I. Evaluation of state-of-the-art items and techniques from the viewpoint of modifying or extending them to fill the Design Plan requirements.

II. Investigation of new techniques and materials where the Design Plan requirements cannot be met by state-of-the-art items or techniques.

III. Verification of findings and conclusions by experimental work as necessary.

II. ABSTRACT

A summary of a Design Plan prepared for a radio frequency compatibility accessory equipment set is presented. The accessory set is a combination of accessory items, which, when used in conjunction with signal generators, radio frequency interference measuring sets, and other test equipment, will provide for the selection of various test setups for making measurements in accordance with military specification MIL-I-11748. Class I equipment was primarily considered in formulating the Design Plan but the measurements for Class II and Class III equipments can be performed with little or no modification. The Design Plan is complete through the block diagram stage and a suggested equipment layout configuration is presented.

Accessory items such as dummy loads, signal samplers, filters, switches, and attenuators are discussed as they may be applied in the accessory set. Mismatch considerations involving the operation of several accessory items in tandem are discussed.

A brief review of work done on a resistive element for a thin film dummy load is presented, as well as the design details of a receiver input coupler.

A discussion is presented on line impedance stabilization networks, and the evaluation performed on a commercial rejection filter is summarized.

Design details of an audio susceptibility tester, including a coupling transformer and transistorized audio amplifier, are presented.

III. PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

On May 22, 1963, Mr. D. W. Robertson and Mr. J. R. Walsh, Jr., visited USAEL, Fort Monmouth, New Jersey, to discuss technical matters concerning the project.

Mr. J. R. Walsh, Jr. attended the Fifth National Symposium on Radio Frequency Interference held June 4-5, 1963, in Philadelphia, Pennsylvania.

Discussions of project technical and contractual details were held at Georgia Tech on July 16-18, 1963, with Mr. Sideny Weitz and Mr. R. L. McKenzie of USAEL.

A visit was made to Georgia Tech on July 30, 1963, by Mr. Warren Kesselman of USAEL and Mr. I. N. Mindel, Jr., J. T. Ludwig, and Mr. Martin Sherman of IIT Research Institute, and a discussion of nonlinear effects in dummy loads was held.

The Ninth TRI-SERVICE Conference on Electromagnetic Compatibility held in Chicago, Illinois, on October 15-17, 1963, was attended by Mr. J. R. Walsh, Jr.

Mr. H. W. Denny, Mr. W. R. Free, and Mr. J. R. Walsh, Jr. attended a conference held at USAEL, Fort Monmouth, New Jersey, on November 26, 1963, to discuss details of the Design Plan and possible areas of needed developmental work.

Mr. Sidney Weitz and Mr. Guy Johnson visited Georgia Tech on December 16, 1963, to discuss project technical matters.

IV. FACTUAL DATA

A. Accessory set

1. Approach

The principal effort of the project has been the development of a Design Plan for a RFC accessory set. The effort was conducted in three phases. The first phase consisted of an analysis of MIL-I-11748 to determine the tests, test setups, and equipment requirements. The next step was involved with an investigation of the various accessory items needed to meet the power and frequency requirements. The final phase was the combination of the accessory items into a compatible arrangement for an accessory set.

2. Design

a. General discussion. In attempting to conduct interference measurements over a very wide frequency range as required of this accessory set, there are certain limitations that should be recognized in the present state-of-the-art of equipment. The development of test equipment has not in all cases been able to keep abreast of the expanding boundaries of testing requirements.

Inherent characteristics of presently used transmission media tend to classify equipment into discrete frequency blocks. Three-eights inch coaxial cable is usable through X-band. The attenuation of the more common types such as RG-9/U begins to be appreciable in the gigacycle region. Modifications in the dielectric, such as foaming or spiraling, decrease the losses at the higher frequencies. Near the higher frequency end of X-band, conventional coaxial cable is capable of supporting modes other than the TEM mode. This frequency can be extended by decreasing the size of the coaxial line but this results in an increase in the losses for similar types. Conversely, larger diameter coaxial cable has less attenuation but the frequency at which modes other than the TEM mode can propagate is lower.

The characteristics of wave propagation in waveguides also set a practical upper and lower limit on the frequency range of usefulness of waveguides. The inherent high-pass properties of waveguides set a lower bound on the frequency range. The propagation of higher ordered modes imposes an upper bound on the frequency range for which a given size waveguide is normally used.

A problem in attempting to measure signals that may be much higher in frequency than the operating range of the transmission system employed by the equipment is encountered in the antenna conducted emissions test for both transmitters and receivers. In attempting to measure spurious signals in a waveguide above the dominant mode frequency range, the problem of energy propagating in more than one mode is encountered. Most interference measurement techniques have more or less ignored this problem. Efforts have been undertaken to remedy the situation, but further steps are necessary to produce a measurement system for field use.

At the fundamental frequency of a transmitter, the output stages are generally designed to launch a specific mode in the transmission system. This mode is usually the dominant TE_{10} mode in rectangular guides, the TE_{01} mode in circular guides, and the TEM mode in coaxial lines.

The primary obstacle in attempting to measure the power in a multimode signal lies in the field sampling device or technique. Most simple probes and sampling devices are not sensitive to all modes. Consequently a single fixed probe will not provide an accurate measurement of the total power.

A number of techniques have been developed for sampling a multimode field and determining the power contained therein. Edson[1] has made a comparative analysis of these methods. The most promising technique at present was developed at the Airborne Instruments Laboratory.[2] The method is reported to be accurate to ±1 db or better. High power breakdown does not present a problem and no computer services are necessary for reduction of data. A test run at a particular frequency can be completed in minutes. This technique seems to be the most desirable for a piece of versatile test equipment. The accuracy is adequate and the time requirement is not excessive. The receiver used in the equipment setups is a radio interference measuring set (RIMS) and would already be included in the test set for other uses. The greatest objection is that the signal line components become cumbersome and require excessive space at the larger waveguide sizes.

Another test that presents problems is the intermodulation test. When performing this test on receivers, the signal generators supplying the test signals have a tendency to generate intermodulation products in their output stages. These products obscure those which may be developed in the receiver and produce errors in the measurements. Various combinations of filters may be used to prevent the output from one signal generator from reaching the output of the other. The spacing of the frequencies used in this test places stringent requirements on filters which are difficult to meet in the present state-of-the-art. The optimum type of filter for this application is a variable (tunable) filter with a steep attenuation characteristic. In the absence of ideal filters, isolators may be used to accomplish the same purpose. Isolators are currently available in octave and standard waveguide bandwidths. They are generally capable of handling 10 or more watts of average power with isolations of above 10 db. Isolators have another advantage over filters in that, due to their broadband nature, tuning is not required. Because they are ferrite devices, isolators may act as a product generator themselves. No information which substantiates or negates this possibility has been found. This property should be investigated thoroughly before isolators are finally selected for use in the intermodulation test.

Difficulties are encountered in the transmitter intermodulation test because of the required coupling between the two transmitters. The amount of power than can be handled by the secondary line of a directional coupler is generally much less than the capacity of the main line. Coupling of high powered transmitters must therefore be done by radiation between antennas.

An additional problem exists in that the two relatively strong signals present at the input of the RIMS have a tendency to generate intermodulation products in the input stage. In testing low powered transmitters, the judicious placement of filters in the signal paths may reduce this problem. This method may be difficult to apply in the case of high powered signals, in which case the application of special testing procedures is the only recourse.

Coaxial to waveguide adapters have a residual VSWR in the neighborhood of 1.25:1 over a waveguide band. Additional work needs to be done on this item to reduce the VSWR as this is high in comparison to most other test items. Adapters are presently available through the K_u-band; a need exists to cover the remainder of the frequency range to 40 Gc. Without some form of adapter the testing of transmitters and receivers for emissions throughout the range required by MIL-I-11748 is difficult.

The probability that an imperfect impedance match will be obtained when two separate pieces of equipment are mated gives rise to sources of error which must be taken into account.

b. Design plan summary. Early in the study, an analysis was made of MIL-I-11748 to determine the tests required and the parameters, with their magnitudes, that needed to be measured. On the basis of this analysis, test setups were diagrammed in block form and the equipment requirements enumerated. Next, classification and integration of the tests were performed to permit maximum utilization of equipment without duplication and to require a minimum of operator time. Then an investigation was made of the feasibility of an equipment configuration which would allow the equipment to be used in a mobile van test setup.

To achieve a feasible van mounted facility, the test setups were divided into two parts. One part is the measurement portion which includes switches, measurement instruments, and signal sources. This portion is included inside a shielded room in the van. For a static, laboratory type setup, this part of the measurement system would be located inside a conventional screen room. The other part of the test setups contains the signal sampling elements such as antennas and coupling devices, and the terminations. A smaller, less critically shielded room provides a space for the pickup devices as well as medium sized pieces of equipment that are to be tested. Antennas and dummy loads should be mounted exterior to the van.

Figure 1 is a simplified flow diagram of the measurement portion of the test setups. These elements are located inside the shielded room.

Figure 2 gives the breakdown of the coaxial subsystem with connections to some of the measurement instruments of the waveguide systems indicated. The range from 14 kc to 15.5 Gc is shown as being covered by two RIMS's.

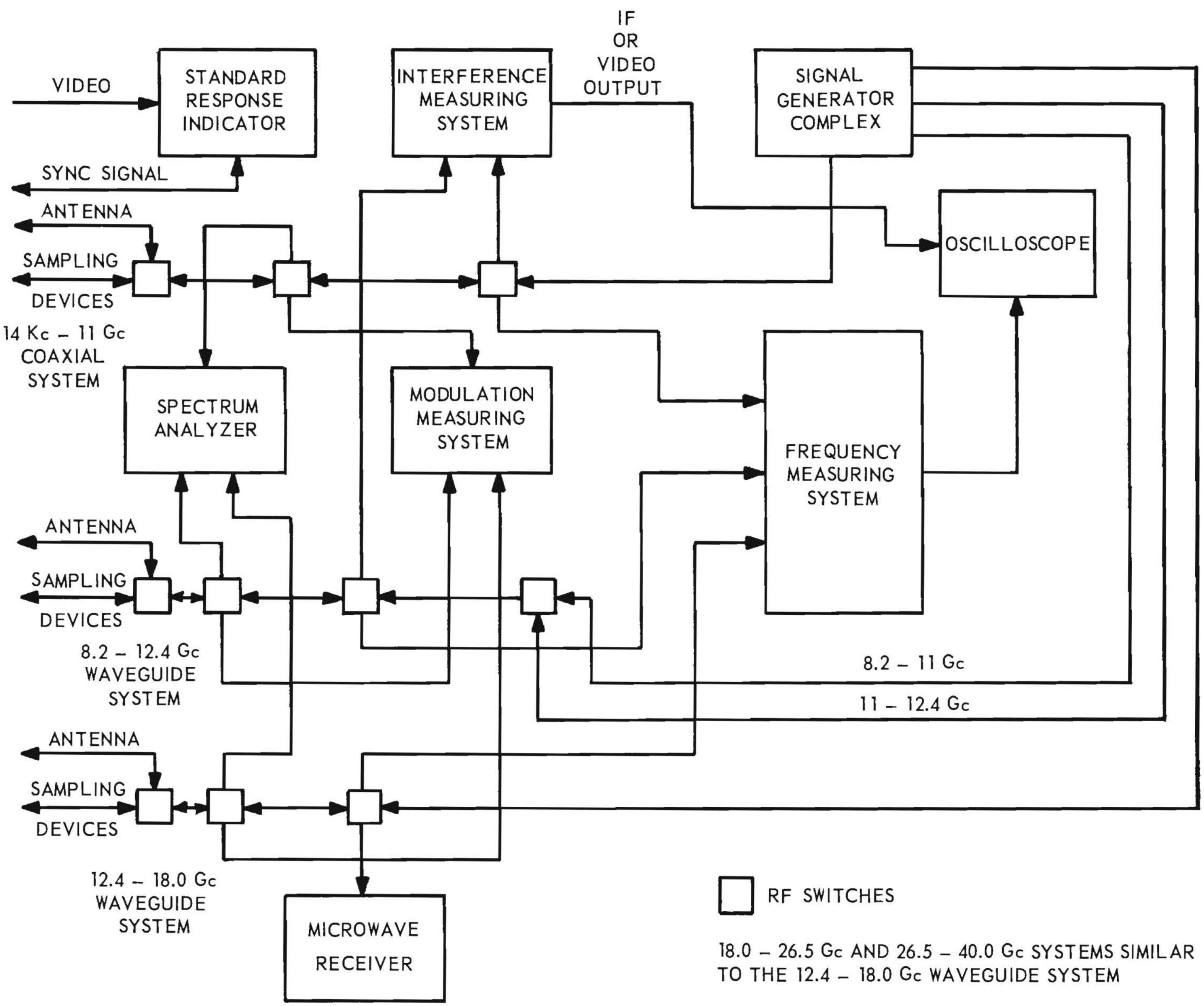

Figure 1. Simplified flow diagram of interference measurement system.

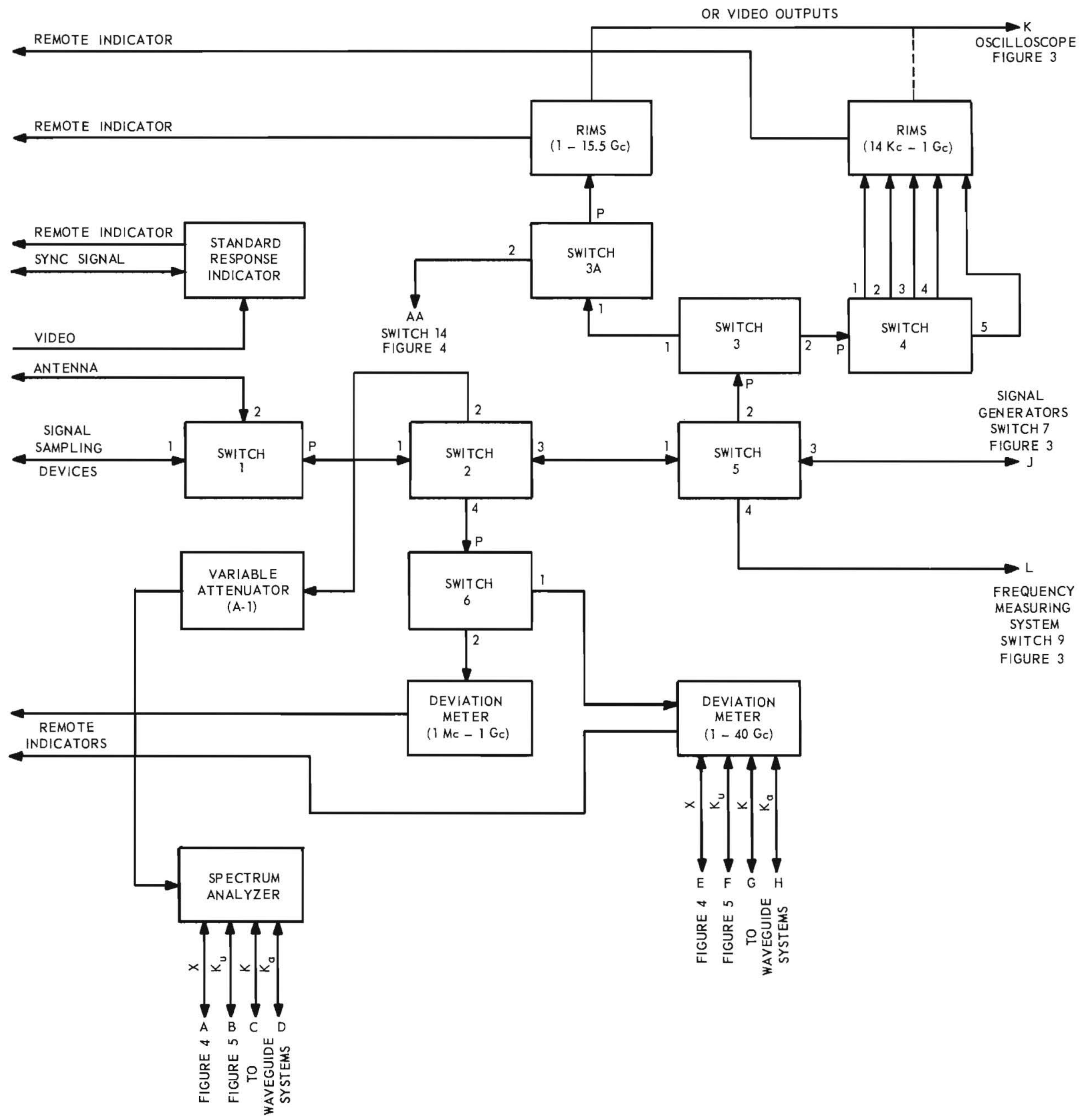

Figure 2. Interconnection diagram of measurement instruments and a portion of the coaxial subsystem.

Commercial units* are available from 14 kc to 10 Gc with built-in radio frequency heads that may be selected with appropriate rf switches. At present, extension to higher frequencies (15.5 Gc) is possible only with plug-in heads.** To avoid a separate unit to cover X-band, the unit with the plug-in heads is considered in this design.

The deviation meters are shown as two units because commercial instruments*** provide measurement capability to 1 Gc, while further development is required to provide coverage to 40 Gc. A summary of a possible approach was included in the Design Plan.

Spectrum analyzers are available to cover from 10 Mc to 40 Gc without modification. Since most spectrum analyzers provide only a coaxial input to 12 Gc, an additional switch may be required to accomodate the two inputs at X-band—one from the coaxial system and one from the waveguide system.

A possible approach to the standard response indicator was presented in Quarterly Report No. 3. A distortion analyzer and a standard response indicator for pulsed systems† may perform the required functions in the absence of the described unit.

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*Noise and Field Intensity Meter, Model NF-105-F, The Singer Company, Metrics Division, Bridgeport, Conn., and Model NM-62A, Stoddart Aircraft Radio Company, 6644 Santa Monica Blvd., Hollywood 38, California.

**Noise and Field Intensity Meter, Model NF-112, The Singer Company, Metrics Division, Bridgeport, Conn.

***FM Deviation Meter System, Model 1102, Advanced Measurement Instruments, Inc., Sommerville, Mass., and Carrier Deviation Meter, Model TF-791D, Marconi Instruments, Englewood, N. J.

†Standard Response Indicator, Model C2A1, Sperry Microwave Electronics, Co., Clearwater, Florida.

Remote indicators are shown located in the test area for tuning purposes and for the power line tests. Some measuring instruments have facilities for remote indicators while others may have to be modified to provide this capability.

Figure 3 is a block diagram of the signal generator complex and a portion of the frequency measurement system. The signal generators are shown having frequency ranges which are characteristic of the type in use at the present time. More efficient coverage of the frequency range with fewer equipment combinations may be possible with newer signal generators which exhibit wider frequency ranges than those shown. Low-pass filters are shown at the outputs of the signal generators for the purpose of attenuating the harmonics of the desired signal as required. Practically, the permanent location of filters here may be difficult as most generators cover more than an octave band of frequencies. This means that variable (tunable) filters would be required or that the fixed cutoff frequency filters must be changed during operation. Facilities for switching the filters in and out become complex—requiring a great number of switches. Therefore, although switched low-pass filters would be desirable at the generator outputs, the complexity involved may well defeat the purpose.

The oscilloscope is useful for pulse system frequency measurements and as a general purpose indicator. An internal oscilloscope is provided in the transfer oscillator for CW frequency measurements. A recently announced plug-in head* allows the oscilloscope to be used as an IF centered spectrum analyzer. This type unit could be used to observe spectrums below 10 Gc or at any other frequency desired, when used in conjunction with the RIMS, by observing the IF spectrum.

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*Pentrix Corporation, 860 Sheperd Avenue, Brooklyn, N. Y.

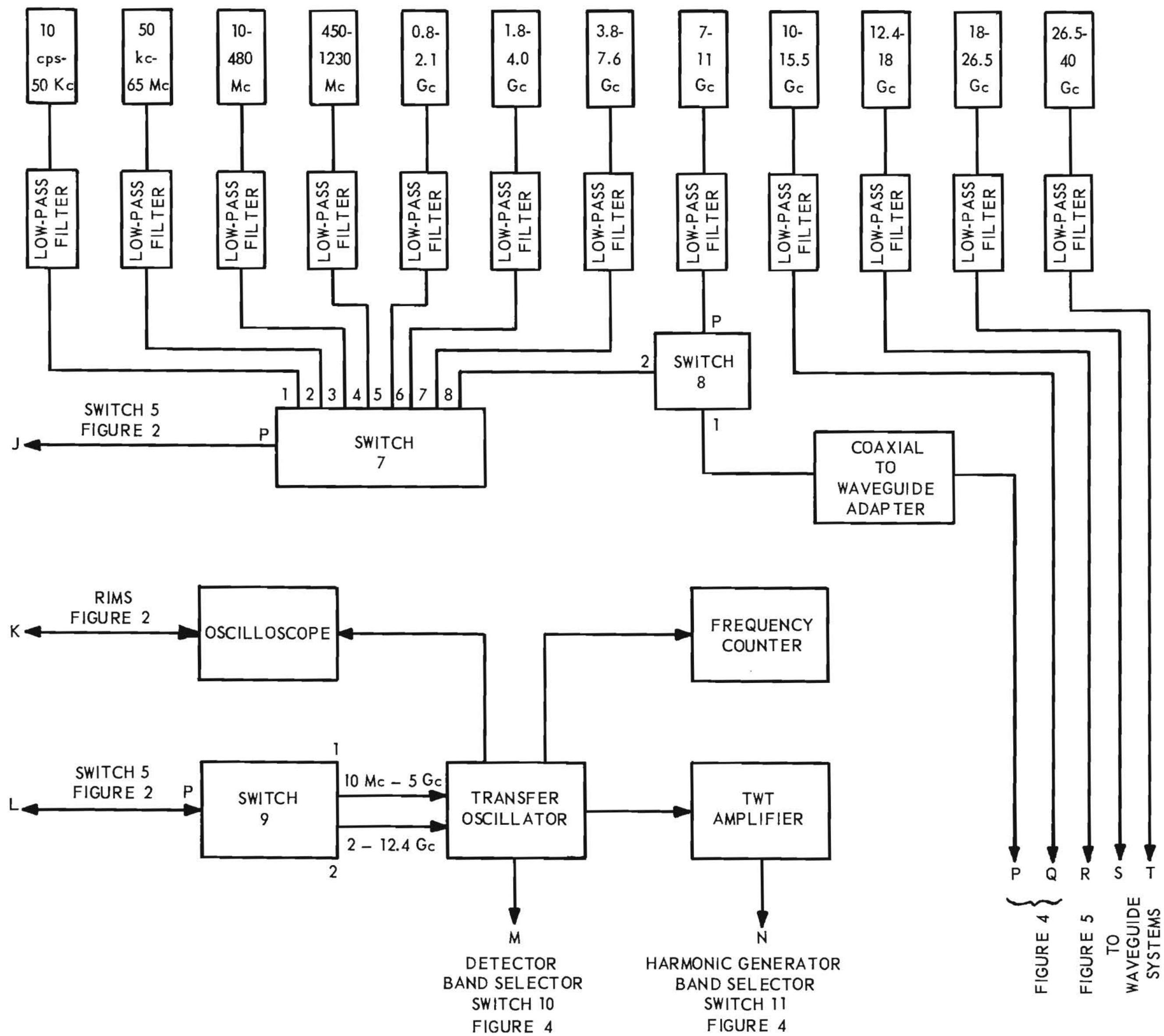

Figure 3. Signal generator complex and a portion of the frequency measurement system.

Figure 4 gives a breakdown of the X-band waveguide subsystem. Although coaxial components are generally usable through X-band, the waveguide system was included for two reasons: (1) the preponderance of X-band waveguide equipment now in common use, and (2) the high attenuation of coaxial line in this frequency range. The system is a hybrid one of waveguides and coaxial lines. Coaxial cable lengths are to be kept short. All switches are waveguide components. The variable attenuator is also a waveguide type as it exhibits better characteristics than coaxial attenuators above 10 Gc.

Also shown in figure 4 is the switch combination that enables the selection of the different ranges when making frequency measurements. Switch no. 11 selects the desired system to which the mixing signal is applied to heterodyne with the signal to be measured. Switch no. 10 at the same time selects the associated detected beat note. The harmonic generator, coupler, and detector are frequency compatible with their associated subsystems.

Figure 5 gives the block diagram of the K_u-band (12.4 to 18 Gc) subsystems. This system is entirely composed of waveguide components. The RIMS is shown as an integral unit of this system to keep signal paths as short as possible.

Figure 6 is a scaled floor plan of a possible truck-mounted test van. The overall length of the truck bed is only 23 feet. If required, this length could be extended without going to a trailer configuration.

The layout of the equipment is based on equalization of losses among the systems. The higher frequency components are placed so that the signal paths are shortest.

The plan is drawn on the basis of rack mounting the equipment in standard 19 inch racks. Allowance is made for the rack itself. A survey of the items of equipment that would be included indicated that a 24 inch depth is adequate.

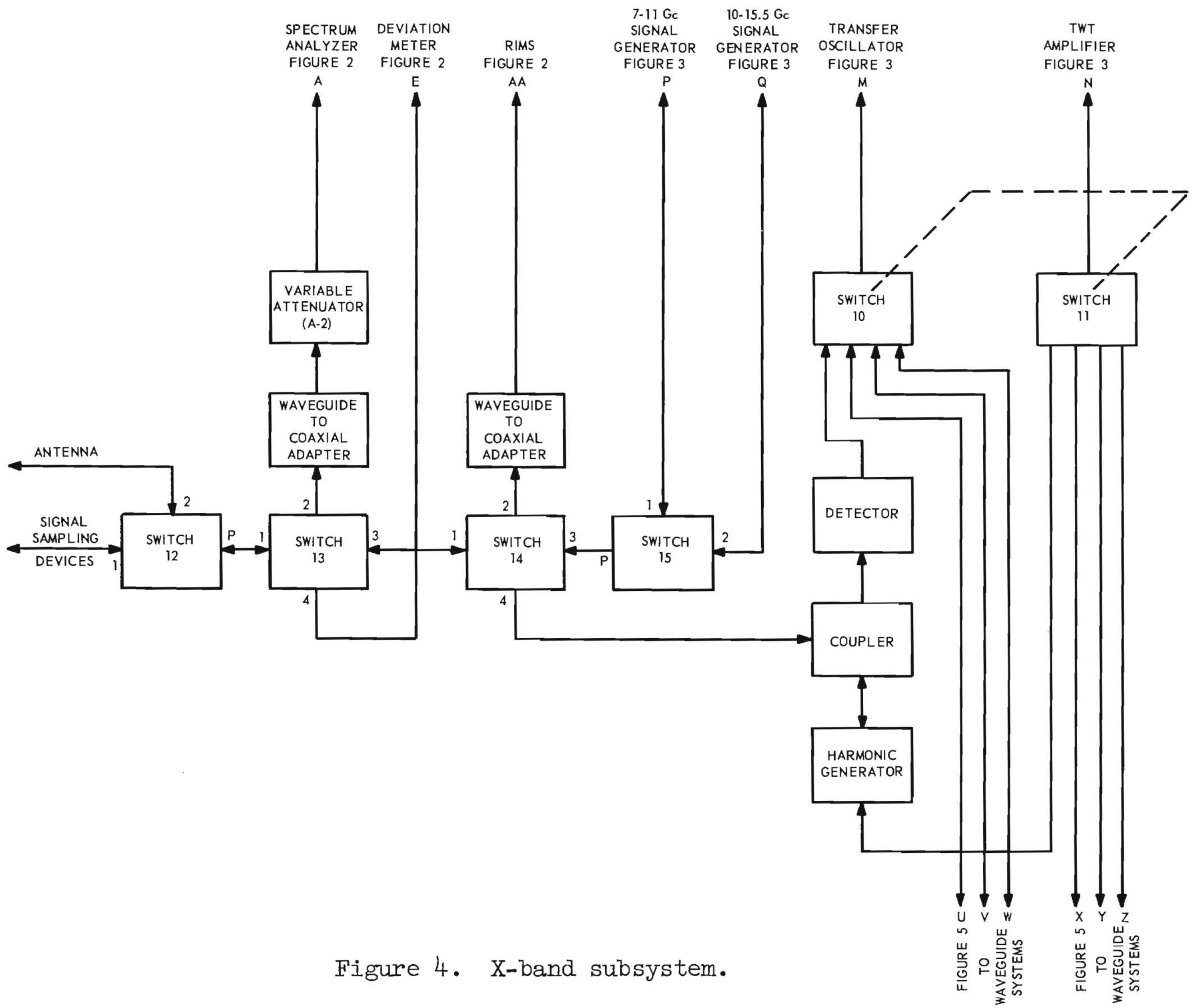

Figure 4. X-band subsystem.

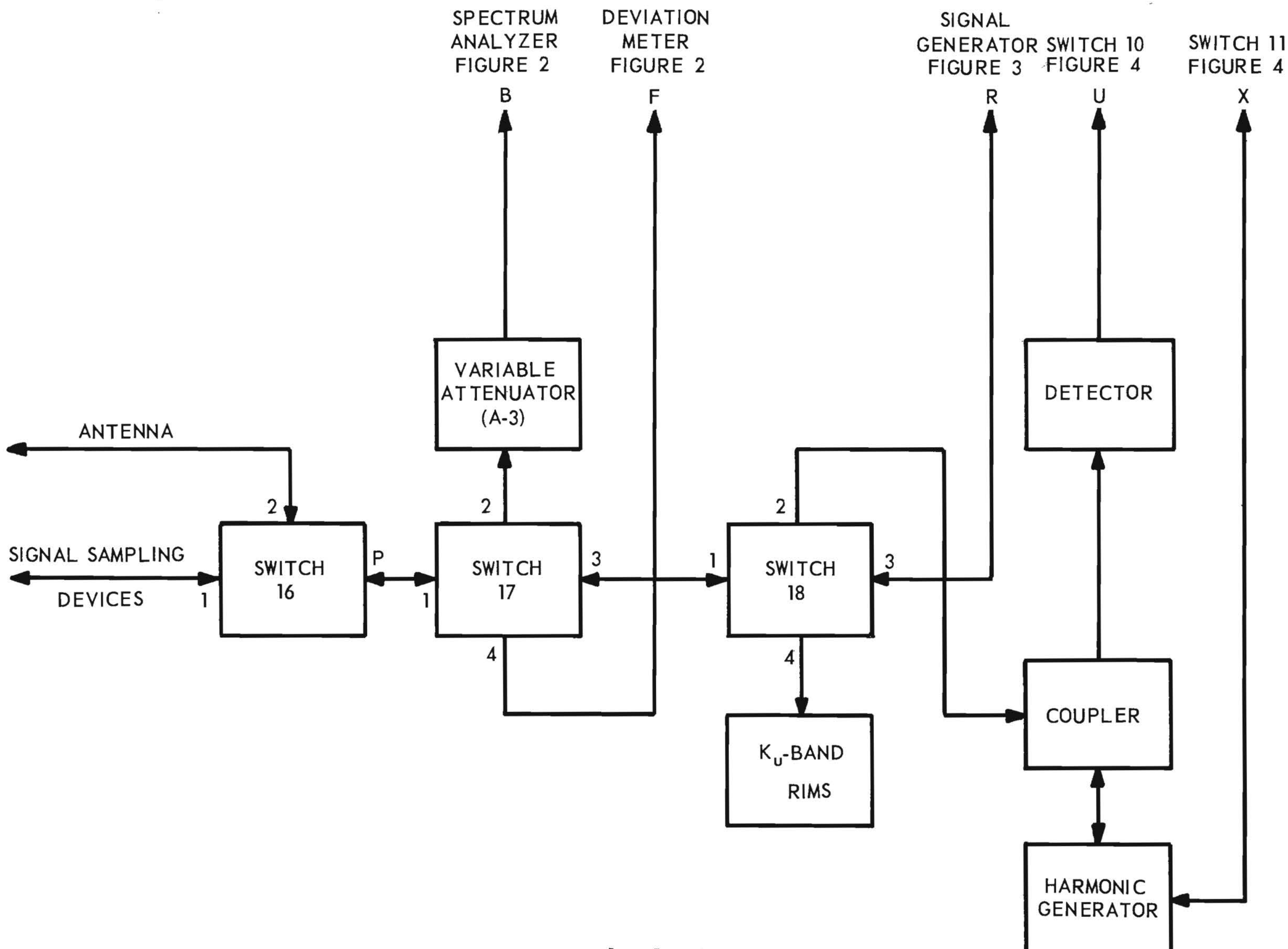

Figure 5. K_u-band subsystem.

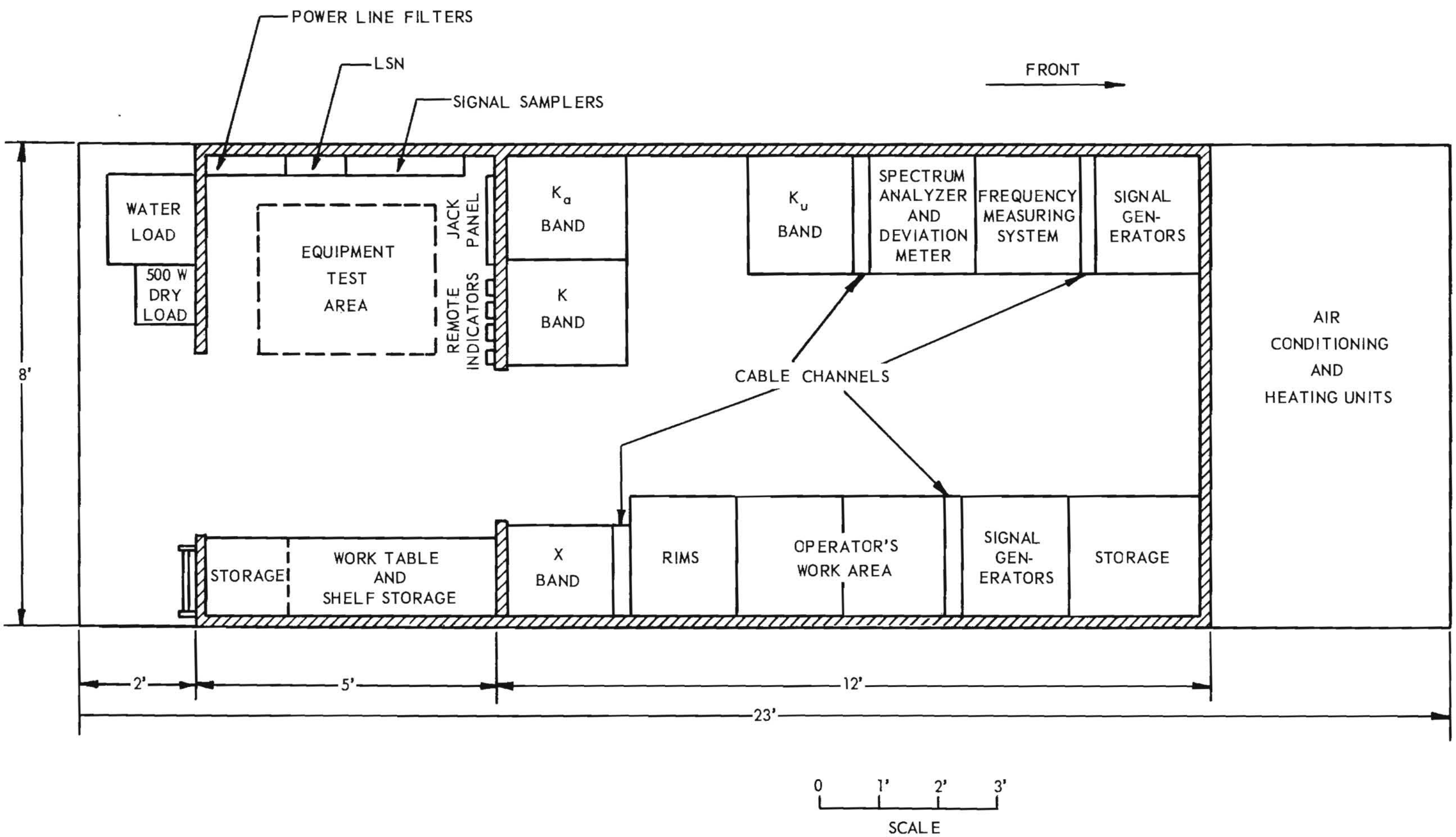

Figure 6. Floor plan of van for interference test set.

Cable channels are included to provide a convenient mounting channel for coaxial lines and waveguide runs to the equipment. This reduces the necessity of mounting signal lines down the face of instruments. Cable channels are to be provided in the ceiling for interconnecting wiring.

Space is indicated in front of the van for locating air-conditioning and heating facilities. Air ducts will be provided with waveguide-below-cutoff vents to keep external interference from affecting the measurements.

Terminations in the form of a water load and a dry load are placed exterior to the van enclosure on a floor extension. These terminations are placed in this position to facilitate heat removal.

The power lines must be filtered to eliminate another possibility of unwanted external interference. These filters are placed in the power line on the supply side before the line impedance stabilization networks.

The operator's desk is centrally located in the van and close to the RIMS. It is also in a position where the operator can turn around and be near the spectrum analyzer, deviation meters, and frequency measuring system.

Several of the switches were chosen to be electrically operated depending upon their frequency of use and accessibility. The switch control panel is located near the operator since he will have to use it often.

Space for a number of storage drawers is available for storing such items as isolators, filters, attenuators, etc., which are not specifically included in the test setups but which are needed at various times.

c. Discussion of accessory items. In searching the literature and manufacturers' catalogues, particular emphasis was placed on power handling capabilities and frequency coverage. Coaxial components are generally wideband in nature. For this reason, coaxial components are preferred to about 12 Gc. This frequency range can be covered with a minimum number of components. The power handling capability of coaxial components is less than waveguides. The large coaxial systems have increased power handling capabilities, but have the possibility of other modes of propagation being present.

The problem of handling the power requirements imposed upon this test set has been analyzed in view of commercially available components and recent developments in the state-of-the-art and in view of the test setups required to perform each of the required tests. A survey of all the test setups revealed that the high powered components could be limited to transmission lines, dummy loads, and sampling networks.

(1) Dummy loads. Many of the tests require that the equipment be properly terminated in an appropriate load. As the operating frequency and output power levels of transmitters increase, the problems of heat dissipation and matching become more severe than at the low frequencies.

Two primary problems are associated with loading. First, the loading material must be a good absorber of the incident wave. Its electrical properties must be such that there is little reflection. The reflection of the incident wave is affected by both the composition and configuration of the absorber.

The other major problem with loads is the difficulty in dissipating the heat that is absorbed by the load. Recent developments with high temperature materials give promise of increasing the power dissipating capabilities of solid loads. Water is often used effectively either as a coolant for solid loads or as an absorber itself.

From an investigation of the catalogues of several commercial producers of dummy loads it was observed that loads are available to dissipate 10 kw average power in the vhf, uhf, and low microwave frequency ranges. The typical power handling capability at 40 Gc is in the neighborhood of 100 watts.

The selection of a dummy load is influenced by a number of factors. Although a specification of the Design Plan is a 10 kw CW power handling capability, a termination of this capacity is not practical or necessary in most cases. The physical size alone would be incompatible with the rest of the accessory items.

A review of the testing setups reveals that limitations of other accessory items make extremely large terminations unnecessary. The main line and secondary line power rating of available coaxial directional couplers place an upper limit on power requirements for loads unless higher power couplers become available. For instance, a 1 kw main line rating on couplers would negate any higher power requirements on terminations. A higher powered transmitter would require that its output be radiated in order to perform spurious emissions tests and other tests involving the high power transmitter output.

A related problem is also encountered in transmitter intermodulation tests in that the amount of power that can be handled by the secondary line of a directional coupler is generally much less than the capacity of the main line. This is true for both coaxial and waveguide models. Coupling of higher powered transmitters must then be done by radiation, which removes the need for terminations. The power line tests and emissions tests on waveguide systems could be done as readily with the transmitter loaded with its associated antenna. The main line power limitation of couplers for waveguide systems does not seem to be a problem since narrow wall directional couplers are capable of handling the rated power of the guide.

Dry loads, either air cooled or liquid cooled, are generally limited in their frequency coverage from dc to 10 Gc (or less) or to a waveguide band. Above 1 kw capacity they become rather large. Water loads are smaller in size, allow the greatest dissipation of power in the microwave region, and provide a wider useful frequency range. An adequate water supply is required, which may not always be available in a field test setup. Water reservoirs and cooling units of a practical size limit the capacity of such loads in the absence of a large supply of water.

Thus, on the basis of the considerations of excessive physical size, limitations in state-of-the-art, and characteristics of the test setups, a termination capable of handling 10 kw is neither necessary nor practical. A 1 kw load should be adequate for the test set. At the higher waveguide bands, transitions could be used to adapt the guide to a lower band load if the frequency characteristics of the load are compatible with the frequency of the signal to be absorbed. Information from Chemalloy Electronics Corporation, Santee, California indicates that this company produces water loads and calorimeters with larger power handling capabilities that could be used in this manner over broad frequency ranges.

(2) Signal samplers. General considerations of the maximum power requirements and of the estimated system sensitivity required result in 40 db of coupling being the nominal value that would be most useful. If it is assumed that transmitters normally range from +30 dbm to +70 dbm (1 watt to 10 kw), 40 db of coupling would reduce the maximum power level down to +30 dbm or less. Most components such as attenuators, switches, filters and the like are rated at least at a 1 watt power level. Such items would not have to have high power ratings; therefore, the selection of items for the test set is simplified. The minimum signal level required to be measured by

MIL-I-11748 is -64 dbm. This is measured with the transmitter in the stand-by condition, which means the high powered fundamental does not present any problem. It may be necessary to perform this measurement with the sampling device removed. The lowest signal level to be measured with the transmitter operating is -50 dbm or 60 db below the fundamental, whichever is greater. These considerations show that the 1 watt maximum operating level after sampling is a reasonable level. Present state-of-the-art capabilities indicate that the sensitivity of RIMS's should be at least -90 to -100 dbm. The required system sensitivity should be retained after the addition of required components for filtering, matching, or other purposes.

Since couplers are needed to sample the transmitter output signal, their power handling capabilities are of prime importance. Ideally they should be capable of handling the rated power of the transmission system, which is the case for waveguide narrow wall couplers. Narrow wall couplers can also meet the 40 db coupling criterion and are available commercially to cover waveguide bands through 40 Gc.

Commercial coaxial couplers are generally rated at 1 kw or less, which is lower than the rating of the coaxial line. Octave bandwidths are available above 240 Mc.

A variable probe coupler such as the General Radio Model 874 GAL coupler could be used from 100 to 240 Mc. This coupler possesses a power handling capability which varies inversely with the square root of the frequency and is approximately 1 kw at 100 Mc.

A high powered attenuator would be useful as a sampling device from 14 kc to 100 Mc.

(3) Filters. There are many occassions in interference testing where selective passage or rejection of frequencies is desired. Every test utilizing a signal generator requires on occasion a low-pass filter to isolate the harmonics that the generator produces. The spurious emissions test and the intermodulation test require filters to prevent erroneous responses due to the measurements system.

Low-pass filters are readily available commercially for coaxial applications. They may be obtained with various cutoff frequencies and various degrees of sharpness at cutoff. A characteristic of a typical short line type low-pass filter is that the insertion loss is subject, depending on the filter design, to deterioration above some frequency in the stop band, typically 6 f_c. Recent experimentation[3] indicates that the insertion loss above cutoff can be maintained with the inclusion of certain lossy materials. Variable cutoff frequency filters are available up to about 4 Gc and may be useful due to their versatility.

High-pass filters are readily available commercially for coaxial applications. Waveguide is inherently a high-pass filter. High-pass filters generally are not as sharp in their cutoff characteristics as are low-pass filters. Coaxial types are characterized by degeneration of the passband at about 2 to 3 f_c. Variable high-pass filters are normally restricted to audio frequencies. Fixed high-pass filters to cover every situation would be impossible to predetermine, but appropriately chosen cutoff frequencies would be useful.

Although variable low-pass and high-pass filters are desirable, improved performance of fixed frequency filters would be the deciding factor in the final selection. Trade literature indicates a marked improvement in skirt characteristics as well as extended out-of-band performance. The number of fixed filters required for a given frequency range is, of course, larger than the number of variable filters needed to cover the same range. The consideration of fewer pieces of equipment is offset by the generally slower cutoff characteristics of the variable filters.

Throughout the coaxial range, low-pass and high-pass filters should be chosen with cutoff frequencies that will insure differentation between the fundamental and the second harmonic. If the cutoff frequency is chosen to be about 1.8 times the next lower cutoff frequency, sufficient overlap is provided. The skirt attenuation should rise rapidly enough to reach at least 60 db within 10 per cent of the cutoff frequency.

Fixed tuned band-pass filters for various frequencies and for varying bandwidths are readily obtainable. For testing purposes, band-pass and band-reject filters must be variable because of the impracticality of predetermining where the filters would be required. A search of product catalogues revealed one source* of tunable band-pass filters. Nine units are required to cover the range from 500 Mc to 40 Gc.

In some of the tests to be performed by the test set, it is particularly desirable to attenuate a specific frequency or a band of frequencies. By attenuating a specific frequency, the effective sensitivity of the system is increased to measure other interference producing signals that are nearby. Rejection filters are less plentiful than band-pass filters. A set of coaxial tunable rejection filters have been designed and built[4] to cover the range from 14 kc to 1 Gc. Seventeen of these filters are required since each one covers approximately an octave range. Another version** covers the same range with

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*Frequency Engineering Laboratories, Asbury Park, New Jersey.

**Electro-Mechanics Company, Austin, Texas.

three units with plug-in coils.

So called "waffle iron" filters have been designed[5] that have wide stop bands. The "waffle iron" filter is capable of high powered applications and can be used to attenuate transmitter harmonics and other spurious outputs above the fundamental frequency.

Ferrite devices such as YIG filters and frequency selective limiters offer advantages for filtering purposes. YIG filters are voltage tunable which is a desirable characteristic for the test set. The frequency selective limiters could be used in lieu of a rejection filter to attenuate a particular signal that exceeds the limiting threshold while allowing a smaller signal nearby to pass with no limiting.

(4) Switches. To facilitate rapid measurements, switches are necessary to minimize the time spent in connecting and disconnecting cables and test equipment. Current literature from manufacturers indicates that there should be no problem in obtaining adequate switches to perform most required functions. Coaxial switches are available that cover the frequency range from dc to about 12 Gc and waveguide switches are available that cover the individual waveguide bands. A four port, three position switch that is capable of connecting a particular port to any of the other three is available in a waveguide version. Present construction techniques appear to be adequate to produce a coaxial version. Mechanical, electrical, and electro-mechanical switching is available.

(5) Attenuators. Attenuators are useful in any measuring setup for extending the range of power measuring instruments. They may also be used to

provide a reference impedance for insertion loss measurements and to reduce reflections occurring in a mismatched system.

The power handling capabilities for a given size attenuator are generally determined by the temperature characteristics of the resistive material. Special construction techniques providing for better heat dissipation make possible higher powered attenuators. For the purpose of the test set, 1 watt attenuators will be adequate since they will be used following the coupler or other signal samplers.

The data from some manufacturers indicate that closely matched attenuators are available that exhibit small variation from their nominal attenuation over limited frequency ranges. The typical characteristic curves indicate that the specifications on the variation of attenuation and VSWR are relaxed to extend the frequency coverage.

The typical VSWR specification is in the neighborhood of 1.5:1. More closely matched units are necessary to avoid exceeding the 1.2:1 specified for the test set. If the attenuator is to be used to correct mismatches, its residual VSWR must be low enough to permit correction to within the desired limits.

d. Mismatch considerations. To obtain an idea of how closely the final design conforms to the maximum VSWR specification, it is necessary to make an estimate of the mismatch between the components of the set. The primary points of interest are (1) the rf input port into the system, (2) the output port to the RIMS, (3) the output port to the spectrum analyzer, and (4) the output ports to the signal generators. The input impedance is considered to be that at the rf input jack of the system. This port leads to the measuring instruments and signal generators. The impedance that the spectrum analyzer and the RIMS see should be closely matched as these instruments are used to measure signal levels and very high VSWR's would cause errors. The same is true for the signal generators if the associated power meters are used to measure differential or absolute power levels. If the outputs are not terminated in their characteristic impedance, the resulting readings will be incorrect.

A technique was derived[6] which enables a worst case analysis to be made of the VSWR of a system. This technique assumes that all VSWR's are equal to the largest, that there are no re-reflections of the reflected wave, and that the system is lossless.

The maximum VSWR at the output port is not to exceed 1.2:1. This specification is difficult to realize because two components with a VSWR of 1.1:1 (a fairly precise unit) can have a maximum VSWR of 1.21:1. Three or more units will have a much higher probability of exceeding the specification at lease at one point over a practical operating band. Attenuators or isolators could be used to minimize the VSWR of several components, but even this may be difficult. The residual VSWR of coaxial attenuators is in the neighborhood of 1.3:1 over at least an octave band. Coaxial isolators have a smaller specified maximum VSWR of 1.2:1 (1.25:1 at 11 Gc) over an octave band. The specification will be easier to realize in waveguide bands as isolators are characterized by a maximum residual VSWR of 1.15:1 and attenuators are available* that are specified as having a maximum VSWR of 1.05:1 over a waveguide band.

An easily obtainable estimate of the VSWR of a number of components does not say in reality how the system will perform. A pseudo-exact analysis would be laborious to perform. It would require information such as the residual

*Model 372C precision attenuator, Hewlett-Packard Co., Palo Alto, California.

VSWR of each component over the operating band, and the attenuation due to each component and each section of transmission line. Even the VSWR of connectors, which could vary slightly each time a connection is changed, must be known. With all this information, which is seldom available, the procedure of computing the overall VSWR for two or more components becomes complex. The effects of all other components in the transmission system must be considered when making calculations at the input terminals. Once a calculation is completed a change in frequency or components necessitates a new calculation. It is evident that the process becomes unreasonably cumbersome in addition to not being completely reliable.

Therefore, the recommended approach is to select components that have the minimum residual VSWR reasonably available in the state-of-the-art, then measure the VSWR at the ports mentioned earlier, and apply the corrective measures where necessary by use of appropriate attenuators and/or isolators.

B. Thin film load

Some experimental work was conducted on thin film techniques for constructing a high power dummy load. The major effort was directed toward the evaluation of deposition techniques. Firing, electroplating, evaporation, sputtering, and pyrolytic deposition are the better known ones. The processes of firing and evaporation were utilized to plate resistive materials on a substrate.

The firing process involves depositing the desired metal by applying a resinate solution to the substrate and then removing the carrier by heating. It is a simple process to use from an equipment requirements standpoint. Quality control is a matter of art in that it greatly depends upon the experience of the individual applying the film of resinate solution. Using this technique, investigations of the temperature coefficient of resistance (TCR) of several samples of metal combinations were performed with a minimum of time.

Platinum and gold resinate solutions were applied to alumina substrates in varying combinations and fired. Table I presents a summary of the results of nine samples. It is of interest to note that the alloys of metals exhibit a lower TCR than does the single metal sample. The lowest TCR's are produced by approximately volumetrically equal solutions of platinum and gold resinates.

Sample 9 was fired on a fused quartz substrate. The slightly higher TCR is characteristic of films applied to smooth substrates as opposed to rough surfaces.

TABLE I

ELECTRICAL RESISTANCE DATA ON THIN FILM RESISTORS

Sample no.	Composition +	Substrate	Resistance ++	TCR
1	1-0	Alumina +++	42.4	.00189
2	1-1	Alumina	5.9	.00035
3	1-1	Alumina	20.8	.00039
4	1-2	Alumina	301.5	.00031
5	2-1	Alumina	16.0	.00048
6	1-1.5	Alumina	18.1	.00042
7	1-3	Alumina	41.5	.00066
8	1-1	Alumina	40.4	.00037
9	1-1	Fused quartz	12.7	.00044

\+ This column gives the ratio of the volume of platinum resinate solution to gold resinate solution respectively. These resinate solutions are supplied by Engelhard Industries, Inc.

++ Resistance at room temperature after any annealing was done.

+++ American Lava Company, AlSiMag 614.

Figure 7 shows the resistance versus temperature behavior of five of the samples of Table I which demonstrate the typical behavior. The definitely greater temperature dependence of the single metal resistance is shown by sample 1. Figure 8 shows the per cent change in resistance versus temperature for selected samples. Room temperature (25° C) is taken as the reference temperature. These curves are from data that were taken after annealing of the film.

Platinum-rhenium alloys produce very low TCR's and attempts were made to fire rhenium resinate but difficulties were encountered due to the absence of a firing procedure. Rhenium oxidizes at about 250° C and above this temperature an inert atmosphere must be supplied.

Palladium has demonstrated a low TCR[7] for a pure metal. No reports of experiments with a platinum-palladium alloy were found. Palladium has a melting point near that of platinum. Palladium oxidizes as easily as rhenium and efforts to fire it were unsuccessful.

Power dissipation tests were conducted on samples 3 and 9 by applying 60 cps power to the sample. A hot spot developed near the center of sample 3 which resulted in a crack developing around the unit. It appeared as though the localized heating caused an increase in resistance and the two effects cascaded to failure. The power test was run on sample 9 to observe the differences in the quartz and alumina substrates. Film failure appeared to be in the nature of film agglomeration. This phenomena has been found[7] to occur at about half the melting temperature. In all probability agglomeration of the gold used in the film resulted in failure. This particular effect was the primary factor prompting the consideration of higher

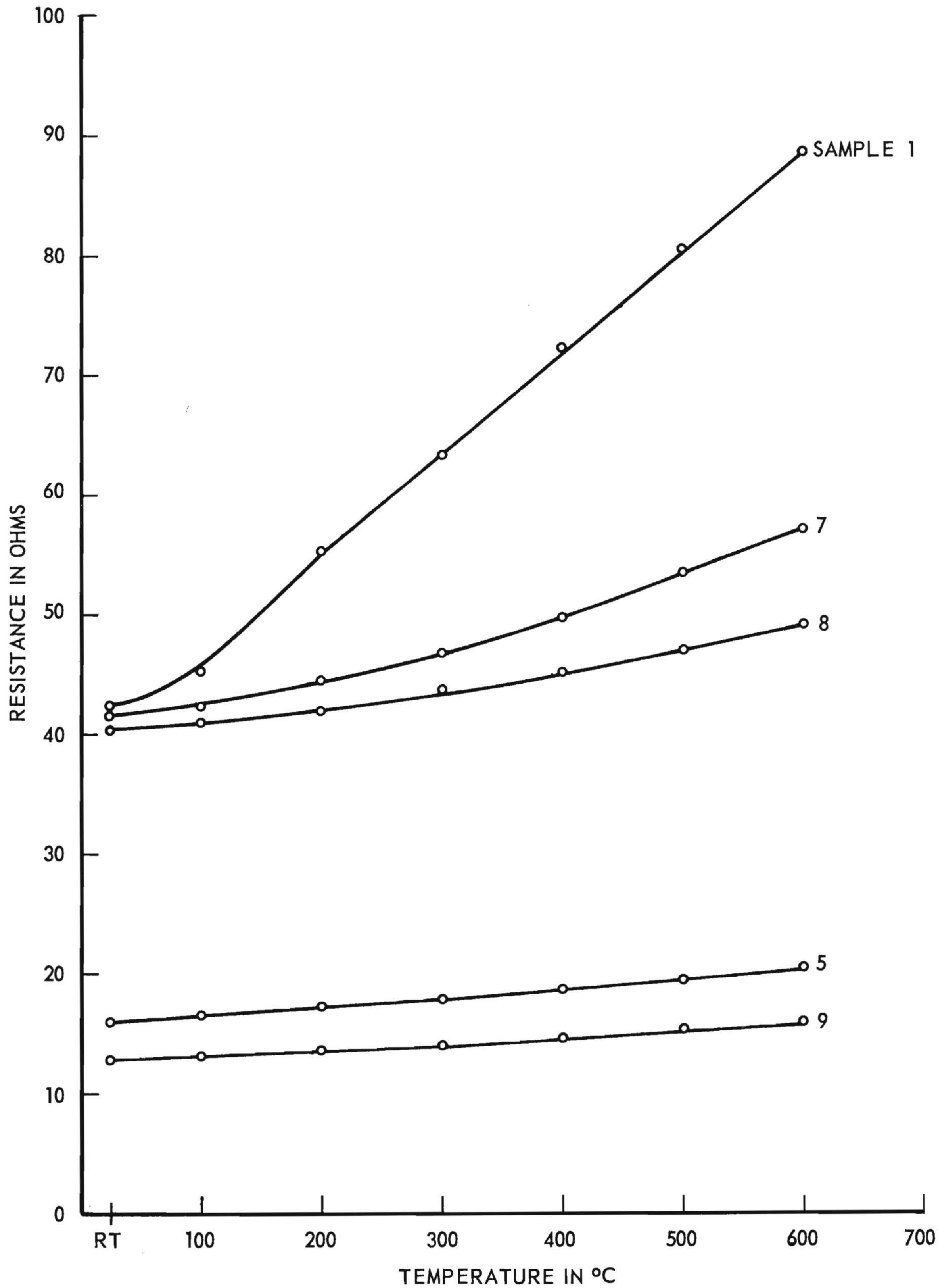

Figure 7. Resistance versus temperature behavior for five fired resistance samples.

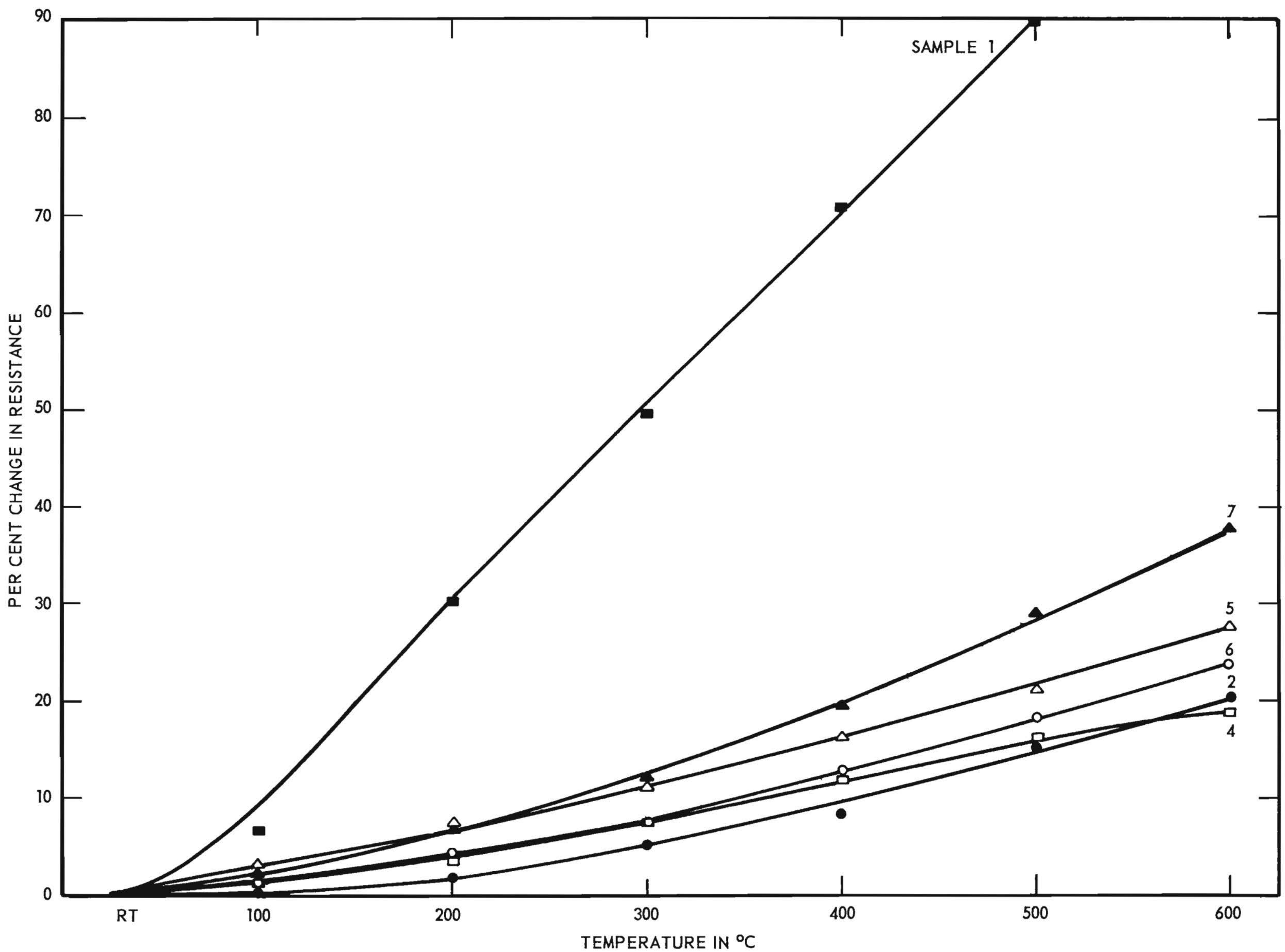

Figure 8. Per cent change in resistance versus temperature for six fired resistance samples.

melting point metals such as rhenium and palladium as the alloying material for platinum.

Lack of success in the firing of rhenium and palladium resinates led to the investigation of evaporation techniques using an electron beam vacuum system. A beam of electrons is focused on a source of ions. Metallic ions are evaporated from the source and coat the substrate. The particular equipment was limited in its flexibility in that no provision was made for lowering or raising the substrate or the source for overcoating. Some samples were made by evaporating tungsten onto a glass slide and then overcoating with fused quartz. The films exhibited a tendency to peel, apparently due to differences in the expansion coefficient of tungsten and fused quartz.

To produce a film on a length (6 inches) of 3/8 inch diameter substrate, there must be some method for uniformly heating the substrate. A substrate heater was constructed by coating the inside and outside of a fused quartz 1.5 inch O.D. cylinder with platinum resinate solution and then firing. A 1-1/4 inch by 4-7/8 inch window was cut in one side of the cylinder to allow the electron beam to reach the source. A band of fritted silver was fired on each end of the heater for the purpose of attaching power leads.

The heater worked well and uniformly heated the substrate but difficulties were still encountered in attempting to produce a uniform film. Inability to change the relative positions of the substrate and source was again the prime reason for the troubles encountered. The resistance of the films was too high to be useful. This resulted from the inability to produce a sufficiently thick film.

Recently acquired equipment has much more flexibility. Any future work on these lines should accomplish more in that additional control can be exercised over the process.

Other processes such as sputtering and the pyrolytic process should be examined further in any future work.

C. Line stabilization network

A minor effort was devoted to an investigation of line stabilization networks. Early in the project preliminary experimentation with possible coil configurations failed to provide useful results.

To produce a network that is useful below 150 kc it is necessary to obtain sufficient inductance to produce the required impedance. This is usually done with an inductor consisting of several turns of wire, which results in a certain minimum capacitance. The consequence is that resonances are associated with the coil within the frequency range of operation desired. The coil is normally expected to handle fairly large currents, up to 50 amperes, which means the size of the coil is rather large due to the required conductor size. Thus, two related problems are associated with stabilization networks: (1) to obtain appreciable input impedance at the lower frequencies, a coil with sufficient inductance must be used, and (2) self capacitance causes resonance effects before the desired higher operating frequency is reached.

Another approach to the problem is utilization of the techniques used in developing dissipative filters. RFI filters* are available which maintain their insertion loss characteristics to 45 Gc. There has been other work along these lines reported in the literature.[3] The approach would be to

*McMillan Industrial Corporation, Ipswich, Massachusetts.

precede a normal line impedance stabilization network, having an appreciable impedance at the lower frequencies, with a lossy filter element which could possibly remove the undesired resonance effects of the coil and provide a known input impedance at the higher frequencies.

Some experimental work was conducted on determining the insertion loss characteristics of various ferrite materials in an epoxy binder. Figures 9 and 10 are graphs of insertion loss versus frequency for a number of filters which were constructed under another contract.* These cores were machined to fit a 874 GR air line. None of these curves indicate a close approach to the characteristics desired for use in a line impedance stabilization network but do show the characteristics of the lossy elements. To be useful the insertion loss of these lossy elements would have to be appreciable in the 100 kc to 1 Mc region. An attempt was made to produce a lossy filter having a much lower cutoff frequency using a coil potted in a mixture of carbonyl iron in an epoxy binder. It was found that the attenuation in the frequency range of interest was insignificant.

D. Receiver input coupler

One of the additional items to be investigated under this contract was a receiver input coupler having an input impedance of 50 ohms (VSWR less than 1.3:1) when its output is terminated by a load with a VSWR no greater than 3:1. Its output impedance is to be 50 and 300 ohms unbalanced (VSWR less than 1.5:1). The 50 ohm unit must be good in the frequency range of usefulness of coaxial transmission systems and the 300 ohm unit must be good to 400 Mc.

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*Georgia Tech Engineering Experiment Station Project No. A-744, Contract No. AF 30(602)-3282.

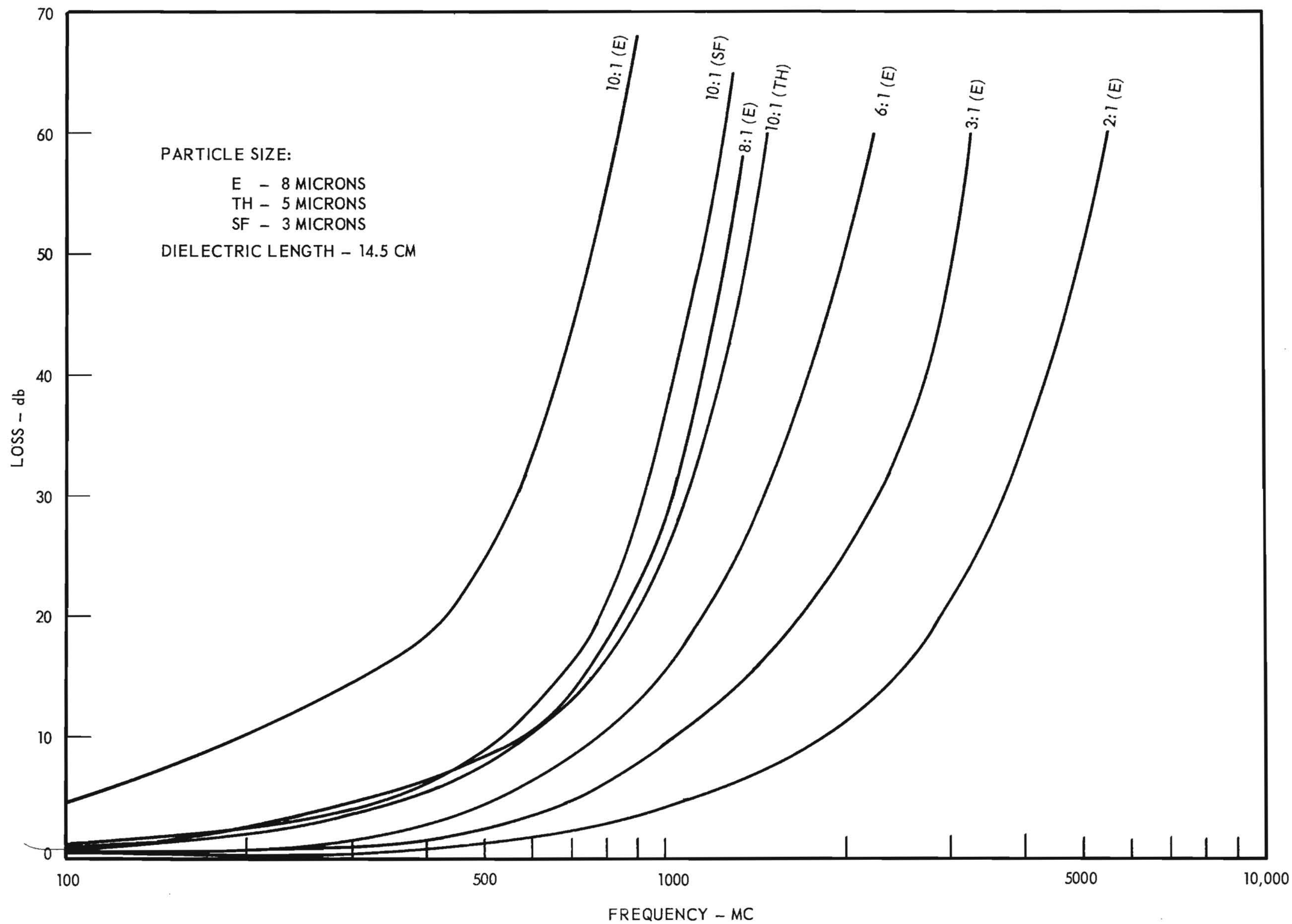


Figure 9. Attenuation versus frequency as a function of mix ratio of carbonyl iron and epoxy binder.

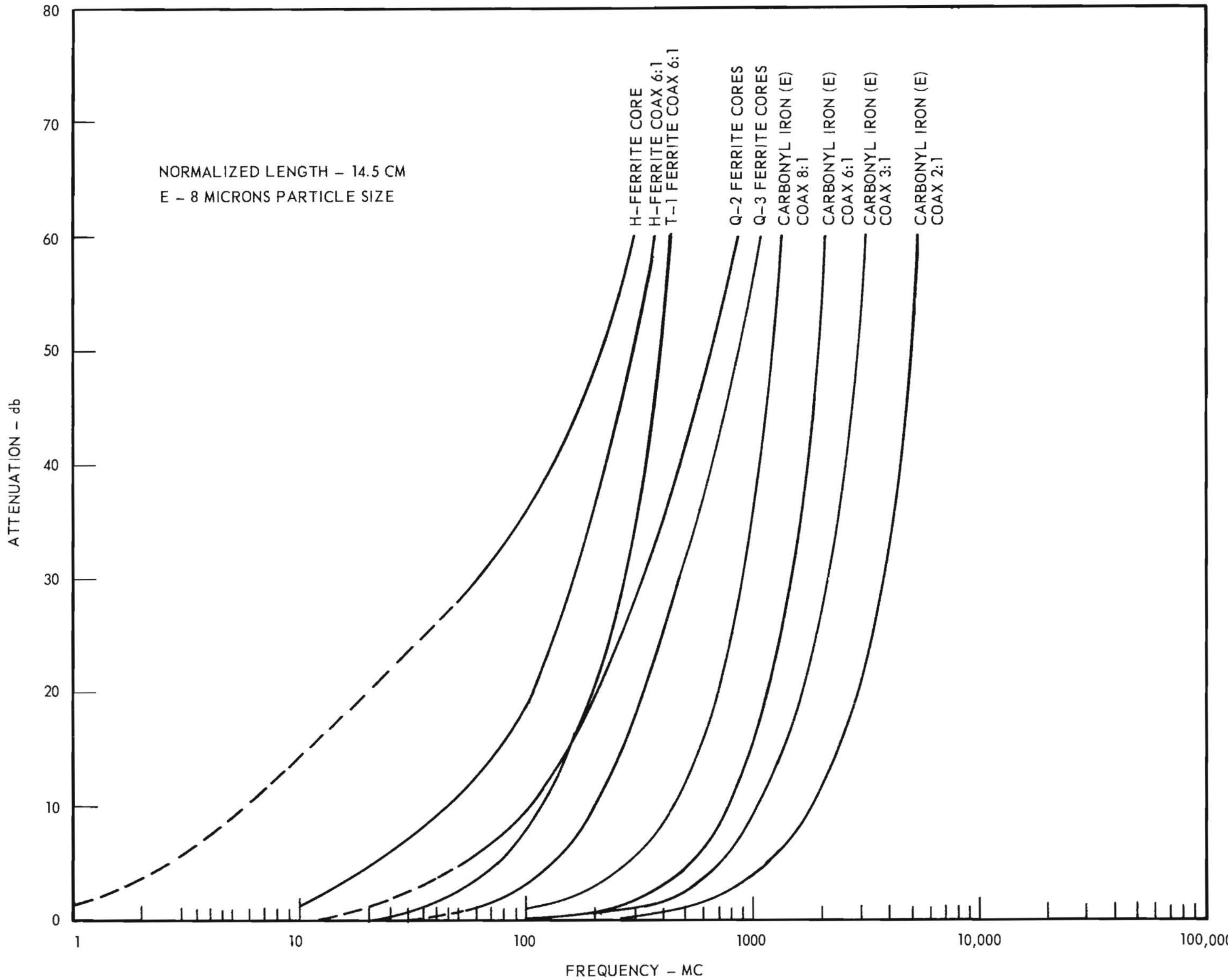


Figure 10. Attenuation versus frequency as a function of material and mix ratio.

The requirements of the 50 ohm unit required only in a 50 ohm coaxial transmission system, can be met by use of a 6 db pad. This item was considered to be available on the commercial market. Instead of the two different outputs, it is deemed more practical to use two units (which may be combined into one unit with a switch if desired). One of the units would have both a 50 ohm input and output impedance and would be the commercial 6 db pad.

At the lower frequencies (less than 20 Mc) many systems are 300 ohm unbalanced systems. Three hundred ohm attenuators are not readily available. In addition most test equipment is designed for 50 ohm input impedances.

An investigation of the requirements for a coupler to feed into a 300 ohm system (or vice versa) led to the construction of a minimum loss pad. Because the receiver input coupler must operate from 14 kc to 400 Mc, the possibility of using reactive devices such as transformers is remote. The simplest approach is to use a resistive network that maintains uniform impedance characteristics throughout the frequency range of interest.

The circuit shown in figure 11 presents a 50 ohm impedance at terminals 2,2 when a 300 ohm load is across terminals 1,1. Likewise, the impedance at terminals 1,1 is 300 ohms when a load of 50 ohms is between terminals 2,2.

This network was constructed using precision (IRC type MEB, 1 per cent tolerance) resistors in a specially designed holder which achieved a flat response to 400 Mc. The 273.9 ohms was approximated with 274 ohms and the 53.9 ohms with 54.9 ohms.

Experimental investigations revealed that the 274 ohm resistor in series with the 300 ohm line must be placed exterior to the metal body to flatten the insertion loss characteristic. This was accomplished by placing the resistor

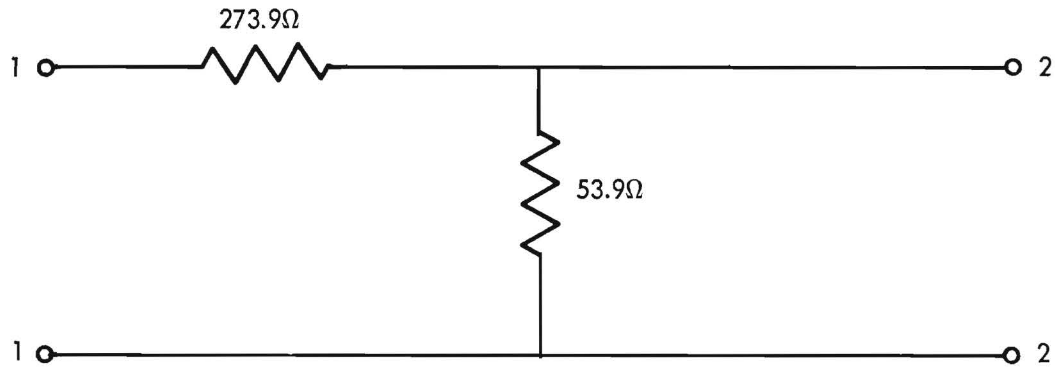


Figure 11. Resistance network for 50 to 300 ohm impedance matching.

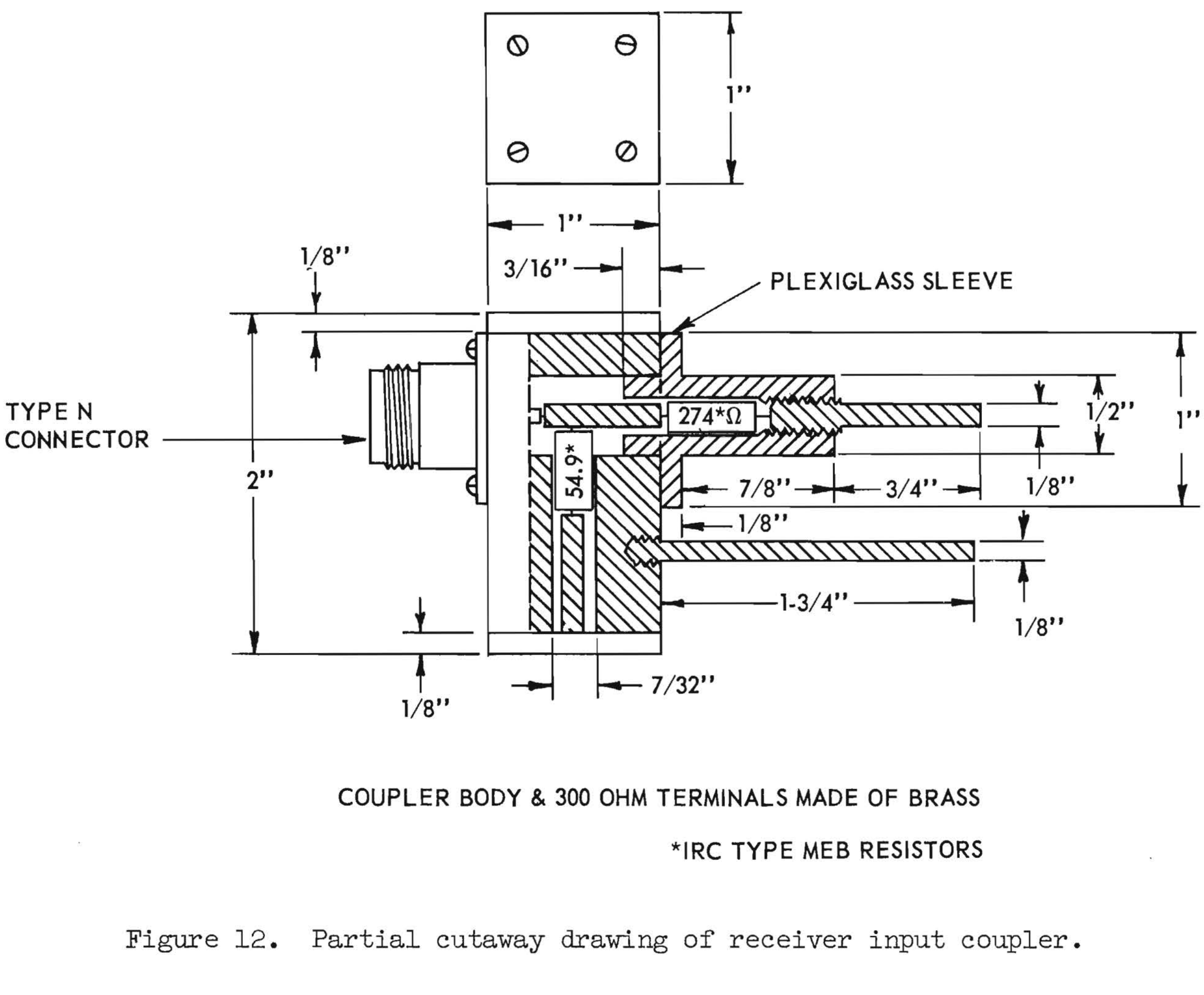


Figure 12. Partial cutaway drawing of receiver input coupler.

inside a plexiglass sleeve support that provides adequate mechanical rigidity to the 300 ohm terminals.

A drawing of the final model is shown in figure 12. The insertion loss and input impedance variations with frequency are shown in figure 13. Input impedance measurements at the 50 ohm terminals at 400 Mc indicated a computed VSWR of 1.11:1 with the 300 ohm terminals open, and 1.07:1 with the 300 ohm terminals short circuited.

E. Evaluation of EMCO rejection filter

In performing emissions tests on transmitters it is often necessary to attenuate the fundamental to allow measurements of adjacent signals which are much lower in amplitude. For this reason rejection filters are useful in extending the dynamic range of the measurement system and avoiding damage to sensitive measuring instruments. At the beginning of this contract two principal sources of rejection filter designs were available in the 14 kc to 1 Gc range. The Bureau of Standards developed a set of 17 different filters to cover this frequency range.[4] Filters developed by the Electro-Mechanics Company, Austin, Texas, cover this range with three filter units using plug-in coils. One of these units was purchased and evaluated for possible use in the accessory set.

The following are the published specifications:

Model: MF
Serial number: 1105
Tuning range: 100 to 400 Mc
Number of bands: 3
Characteristic impedance: 50 ohms

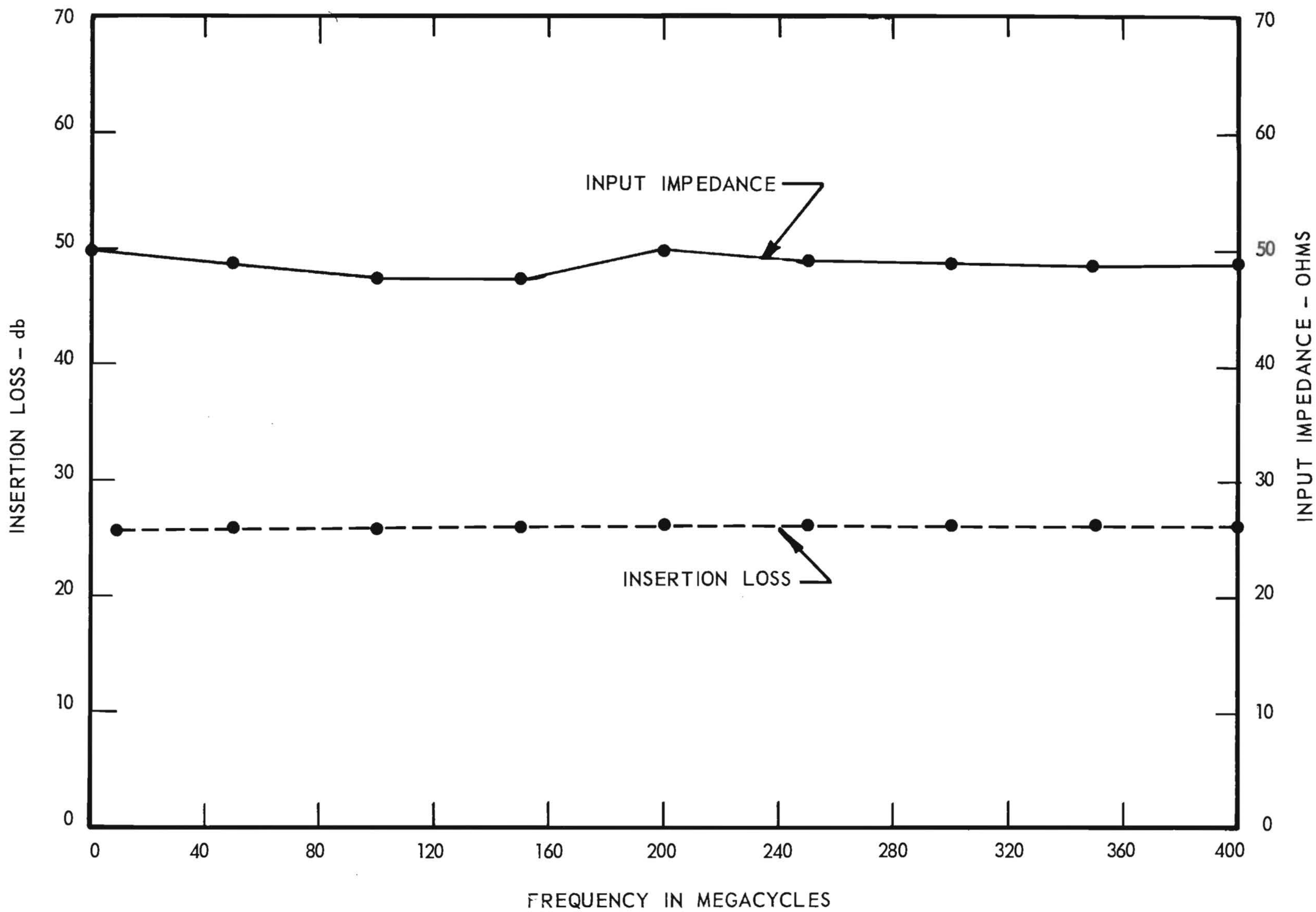


Figure 13. Input impedance and insertion loss characteristics of receiver input coupler.

Attenuation: 120 db or more at rejection frequency; 40 db or less at 10 per cent removed

Dimensions: 8-1/2" high
11-1/2" wide
11" deep

The insertion loss versus frequency characteristic for a tuned frequency at the center of each coil range was obtained and the results are shown in figure 14. Two important features are to be noted on these curves. One is that the maximum rejection obtainable by project personnel adjusting the filter was less than 100 db at best and only about 81 db at one point. In the opinion of project personnel, the primary problem in trying to obtain more rejection lies in the precise adjustment required on the potentiometer and capacitor controls of the filter, which was hard to obtain. The second important feature is that from 400 to 1000 Mc the attenuation begins to rise and develop peaks as high as 20 db in the neighborhood of 700 Mc. From the reoccurrence of these peaks with each coil they appear to be due to resonances in the filter enclosure.

A pseudo-sweep system was constructed by mechanically coupling a slow speed synchronous motor to the capacitor control. The motor was equipped with start-stop and reversing switches. Curve tracing was accomplished by recording the output of an Empire Devices noise and field intensity meter, Model NF105, while the filter was swept across its region of maximum rejection. In this manner the mechanical backlash in the controls was graphically displayed. From these graphs and recorded dial readings, figure 15, which demonstrates the backlash in the capacitor adjustment, was constructed.

In conclusion, it appears that this filter is not entirely satisfactory for this Design Plan because (1) extreme care is required to obtain a rejection

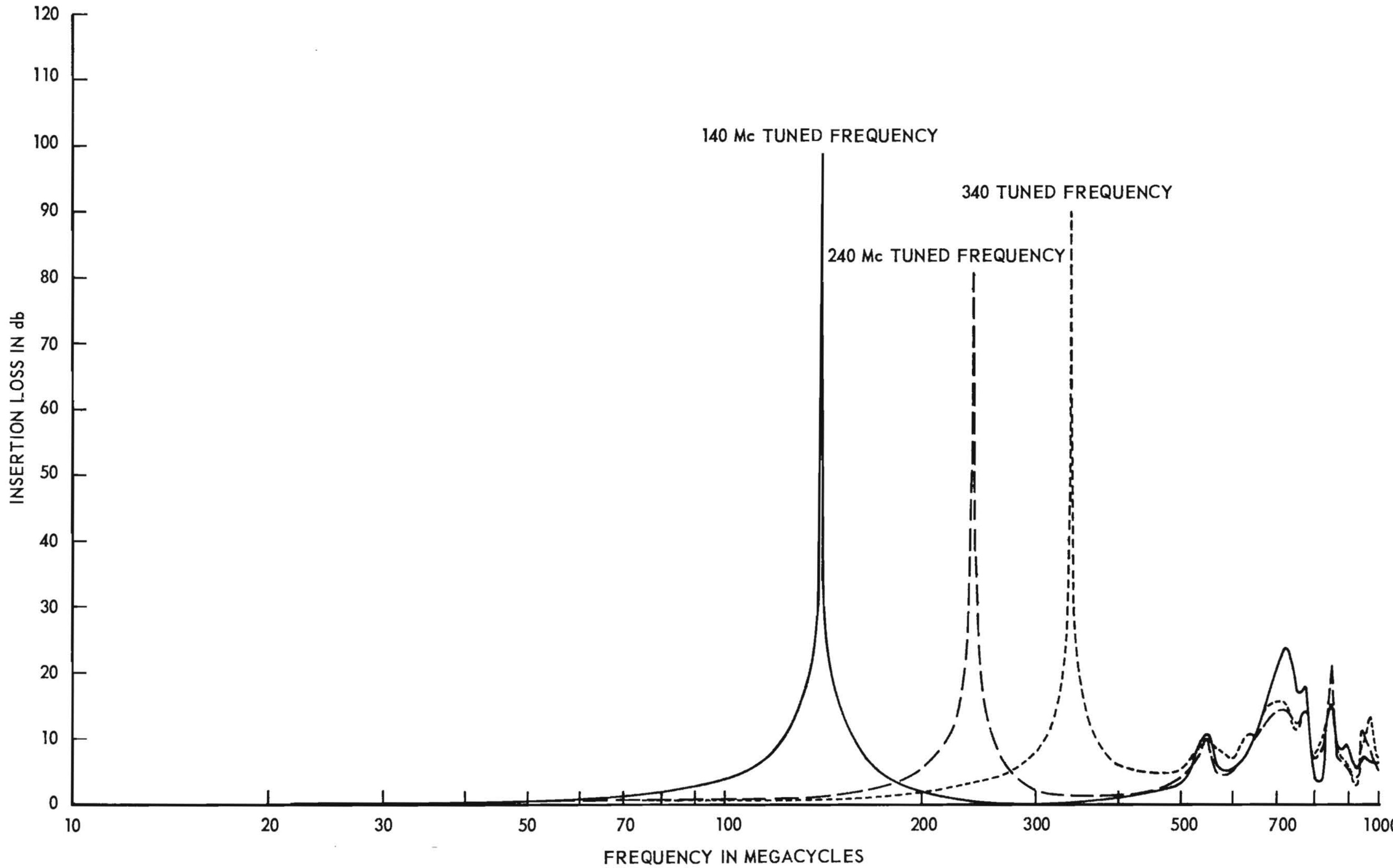


Figure 14. Insertion loss versus frequency characteristics of the EMCO rejection filter.

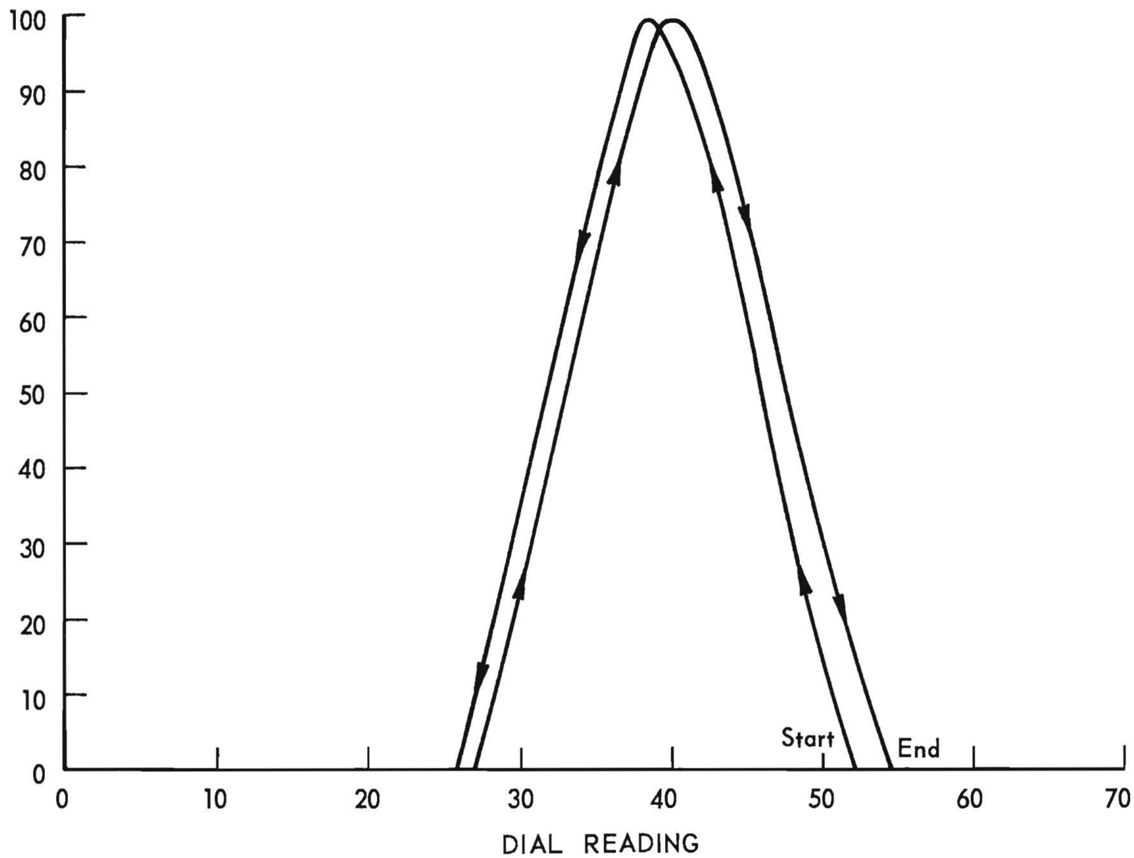


Figure 15. Backlash behavior of the capacitor tuning control.

of 80 db or more; (2) mechanical backlash in the tuning controls render tuning even more difficult; and (3) skirt attenuation is too broad for measurement of adjacent signals.

F. Audio susceptibility tester

The audio susceptibility test is a procedure wherein an audio signal voltage is inserted in series with a nonsignal line of a piece of equipment to determine wheter or not these signals, so inserted, will degrade the performance of the equipment under test. Insertion of this voltage in the nonsignal line is usually accomplished by means of an isolation transformer. The audio amplifier and isolation transformer are not readily available items at this time.

A design has been prepared on the contract for an audio susceptibility tester, which consists of a coupling transformer and audio amplifier. This susceptibility tester is to provide 3 volts rms open circuit voltage in the frequency range from 50 to 15000 cps for series injection into the power line of the equipment being tested, with harmonic distortion less than 5 per cent, and is to have an output impedance of less than 0.3 ohms. Design goals were set at 50 amperes of line current as a maximum value from dc to 400 cps with no more than 5 per cent of the supply voltage drop across the susceptibility tester transformer winding coupling into the power line of the equipment under test.

Although it is required only that the tester deliver an open circuit voltage of 3 volts rms, it seems desirable that this voltage should be developed across some impedance which might approximate the actual load seen by the transformer during operation. An approximate load impedance can be arrived at by assuming that the line impedance is zero and that the minimum impedance of the equipment under test is that which applies for the lowest voltage system at the highest operating current. For this situation with a supply voltage of 24 volts and a load current of 50 amperes, the minimum load impedance will be approximately 1/2 ohm. To deliver 3 volts rms across a resistive 1/2 ohm load, the tester must supply a minimum power of 18 watts. Any line impedance greater than zero will reduce the power required to deliver the required voltage.

The design approach followed was to construct an amplifier having a low output impedance and to transform this low output impedance into the transformer winding in series with the equipment under test by use of a step-down transformer.

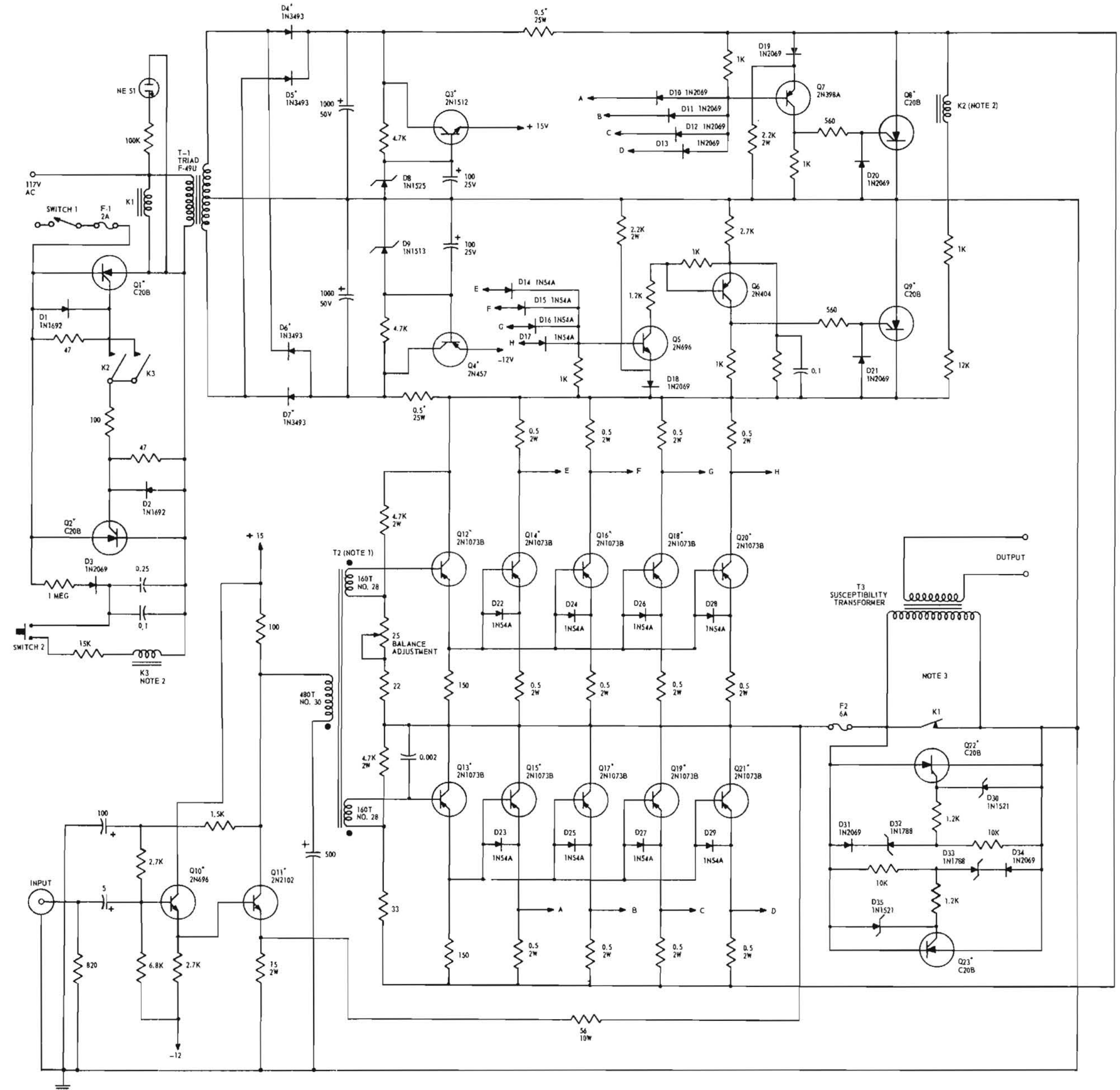
The susceptibility amplifier and transformer designs are interdependent. It was decided to construct a transistorized audio amplifier, making use of the low impedance characteristics of the transistors. The transistors selected were the 2N1073B's which are PNP germanium types having a typical "β" cutoff frequency of 30 kc, a power rating of 50 watts, and a back voltage rating of 120 volts. The power output stage using these transistors is a conventional arrangement of the PNP power transistors in a bridge configuration, one half of the bridge being made up of a series connection of the power transistors, and the other half of the bridge being the positive and negative power supplies. The load is connected between the midpoint of the power supplies and the point between the power transistors so that dc current can be balanced out of the load, which in this case is the primary of the coupling transformer. Additional sets of power transistors in the output stage may be connected in parallel to increase the power handling capabilities of the amplifier.

Since the rated back voltage on the transistors is 120 volts and the power supply voltage was selected to be 50 volts dc, a margin of 70 volts was left for the audio signal voltage and power feedback voltage on the power transistors. This is the maximum voltage that could be tolerated. The required voltage on the secondary of the isolation transformer is 3 volts rms or 4.2 volts peak. The problem was then the selection of a turns ratio for the susceptibility transformer. Several considerations entered into this selection. The voltage from the ac power source that is fed back into the amplifier is controlled by the turns ratio of the transformer, and the impedance presented by the transformer secondary winding in series with the power line. This impedance in the secondary winding is also dependent on the transformer turns ratio since the amplifier output impedance is depended upon to keep this secondary impedance low. The power signal current that the amplifier must handle is also dependent upon the transformer turns ratio, decreasing as the turns ratio increases.

A turns ratio of 8:1 was selected as a compromise in view of these considerations. With the required 3 volts rms in the secondary winding, this would require the amplifier to produce a voltage at its output terminals of 24 volts rms or 34 volts peak. This would allow a margin of 35 volts on the breakdown voltage of the transistors which must include power feedback voltage plus a safety factor. If the impedance in the secondary of the transformer were 0.01 ohms, 50 amperes of ac power would result in a 0.5 volt drop across the secondary winding. This would be transformed to the primary as 4 volts rms or 5.5 volts peak reducing the safety factor to 30 volts. The current feedback into the amplifier would be 1/8 the line current or 6.25 amperes for a line current of 50 amperes. This places the worst power dissipation conditions on the amplifier transistors, which are subjected to a high voltage due to the dc power supply voltage when this power feedback current exists. Additional pairs of output power transistors and forced air cooling limits the temperature rise to a safe value.

A schematic diagram of the amplifier is shown in figure 16. Transistor Q-10 is an emitter follower used to supply signal to the driver transistor Q-11. Bias stabilization for the driver is obtained by dc feedback from the collector of Q-11 to the base of the emitter follower Q-10, and then to the base of Q-11. Transformer T-2 provides audio drive signals to the output drivers Q-12 and Q-13 through the split secondary arrangement shown. Eight transistors are used in the output stage to provide dissipation capabilities for the power feedback. Transformer T-3 is the susceptibility coupling transformer connected from the center of the amplifier transistors to the midpoint of the power supplies. Signal sources such as the Hewlett-Packard 200CD signal generator provide adequate drive for the amplifier. Feedback is taken from the output of the amplifier at the primary of the coupling transformer to the emitter of Q-11. Approximately 30 db of feedback is used to reduce the output impedance of the amplifier.

The susceptibility transformer is constructed as shown in figure 17. Two sheets of 0.005 by 4 inch copper strips are wound in a bifilar configuration with eight strips of 0.020 by 0.375 inch copper. Twenty turns are used for the secondary winding while the primary consists of 160 turns, thus giving the turns ratio of 8:1. Interlayer insulation used in the transformer was 0.003 inch teflon which kept the insulation build low while providing a high level



*MUST BE OPERATED WITH A HEAT SINK.

NOTES:

1. CORE 3/4 IN. STACK OF 0.0185 IN. THICK EI-75 SILICON STEEL LAMINATIONS 100% INTERLEAVED.
2. RELAYS K-2 AND K-3 MAGNECRAFT RELAY, SPST NO, CAT. NO. W102PCX4.
3. RELAY K-1, SPST NC, COIL 115V, CONTACTS 15 AMPS.
4. ALL CAPACITORS IN μf AND ALL RESISTORS IN OHMS UNLESS OTHERWISE SPECIFIED. ALL RESISTORS 1/2 WATT UNLESS NOTED.

Figure 16. Schematic diagram of audio susceptibility tester amplifier.

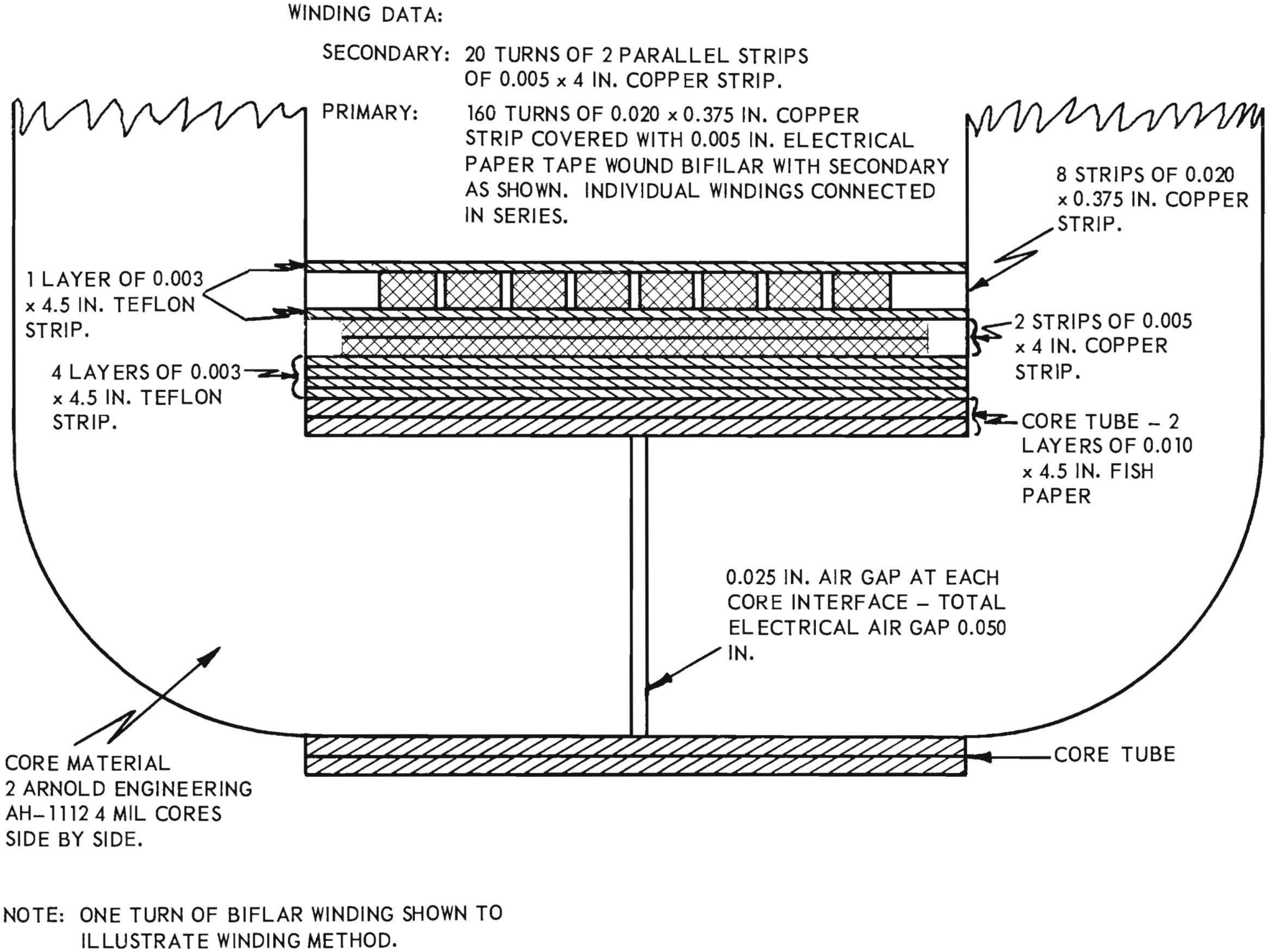


Figure 17. Winding configuration of coupling transformer.

of dielectric strength. The air gap provided in the core was 0.050 inch total. Core material used for the transformer consisted of two Arnold type AH-1112 cores. The dc flux density for a secondary line current of 50 amperes was calculated to be 12,000 gauss and the ac component was 1450 gauss at 50 cps due to the audio component with the required 3 volts rms in the secondary winding.

The dc resistance of the secondary was measured as 0.0058 ohm and the leakage reactance as measured with a Tektronix type 130 LC meter was 0.15 μh. Primary open circuit inductance was 130 mh, providing an inductive reactance of 41 ohms at 50 cps. The primary resistance was 0.25 ohm. A compromise was made with the primary open circuit inductance in that to raise this inductance while maintaining the same turns ratio meant increasing the secondary turns with the attendant increase in secondary resistance, and at the same time increasing the build of the winding. This would increase the number of layers of insulation thereby increasing the leakage reactance. To decrease the inductance while maintaining the same turns ratio would require the audio amplifier to supply more reactive current at the low frequencies, thereby placing undue power dissipation requirements on the output transistors. Since the secondary open circuit inductance, which is approximately 2 mh, would present too much impedance in series with the power line, the output impedance of the susceptibility amplifier must be relied on to reduce this inserted impedance.

Protection devices for the amplifier are included in the design. Silicon controlled rectifiers (SCR's), Q-8 and Q-9, are used as electronic crowbars across each dc power supply to remove the power supply voltage in case of an overcurrent condition in any of the output power transistors. A common cause of such an overcurrent condition would be an accidental short circuit of the coupling transformer output when an audio signal was being supplied by the amplifier.

Relay K-2, a reed type, is used to detect the loss of either one of the dc power supplies which can be caused by the operation of either of the electronic crowbar circuits. When relay K-2 is de-energized its contacts open and the solid state circuit breaker consisting of Q-1 and Q-2 operates within one half cycle of the power frequency to remove power from the power transformer T-1. Sensing resistors for overcurrent conditions are inserted in the emitters of transistors Q-15, Q-17, Q-19, and Q-21. When the voltage across any of these resistors exceeds a predetermined level, transistor Q-7 conducts and the SCR Q-8 is fired shorting the positive power supply through Q-8 and the associated 0.5 ohm resistor. The SCR's are in parallel with the output transistors so that the voltage across these transistors falls very rapidly, thus preventing damage. Sensing resistors for Q-14, Q-16, Q-18, and Q-20 are in the collectors of these transistors. An overcurrent condition in these transistors results in transistors Q-5 and Q-6 conducting, thus firing SCR Q-9 which shorts out the negative dc power supply in the same manner as discussed for the positive supply. It has been found that this circuit works well to protect the output transistors.

Transient and instantaneous overvoltage protection on the primary of the coupling transformer is provided by SCR's Q-22 and Q-23. These two SCR's are connected with 50 volt zener diodes in their gate circuits and are connected back to back so that if the voltage across them exceeds slightly more than 50 volts in either direction, one of them will fire. Each time the voltage reverses across one of the SCR's that has been fired by overvoltage, that SCR no longer conducts. Thus, for a transient voltage condition the longest period that either SCR would remain fired would be one half cycle of the audio signal voltage.

To prevent power feedback from being dissipated in the amplifier during the time that the amplifier is turned off, or after the operation of the solid state circuit breaker, the normally closed contacts of relay K-1 are connected across the primary of the coupling transformer. When power is removed from the primary of power transformer, T-1, for any reason, relay K-1 shorts the primary of the coupling transformer so that the minimum impedance is coupled into the equipment power line. This impedance is the low secondary resistance and leakage reactance of the coupling transformer.

The frequency response and harmonic distortion characteristics of the amplifier are shown in figure 18. These tests were made with the amplifier loaded in a 0.5 ohm resistor on the secondary of the coupling transformer and include the response of the coupling transformer. The output voltage for these tests was the required 3 volts rms at the transformer secondary. Output impedance of the audio susceptibility tester is shown in figure 19 at the output terminals of the coupling transformer. This test was performed with a current of 0.43 amperes rms into the secondary of the transformer.

Tests were conducted with 50 amperes of dc current in the secondary of the isolation transformer and 35 amperes of 60 cps ac current. The

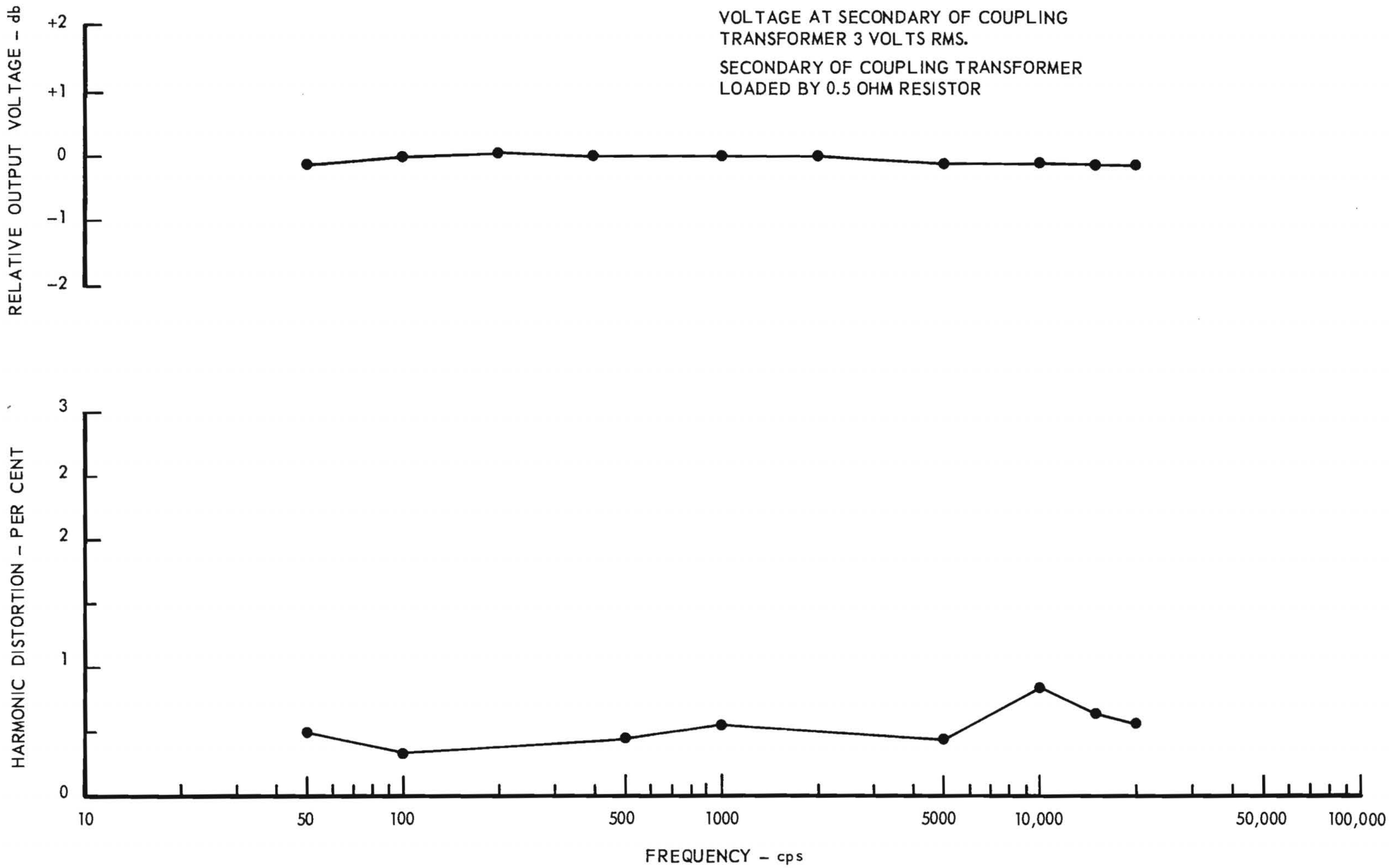


Figure 18. Frequency response and harmonic distortion of susceptibility coupling transformer and amplifier.

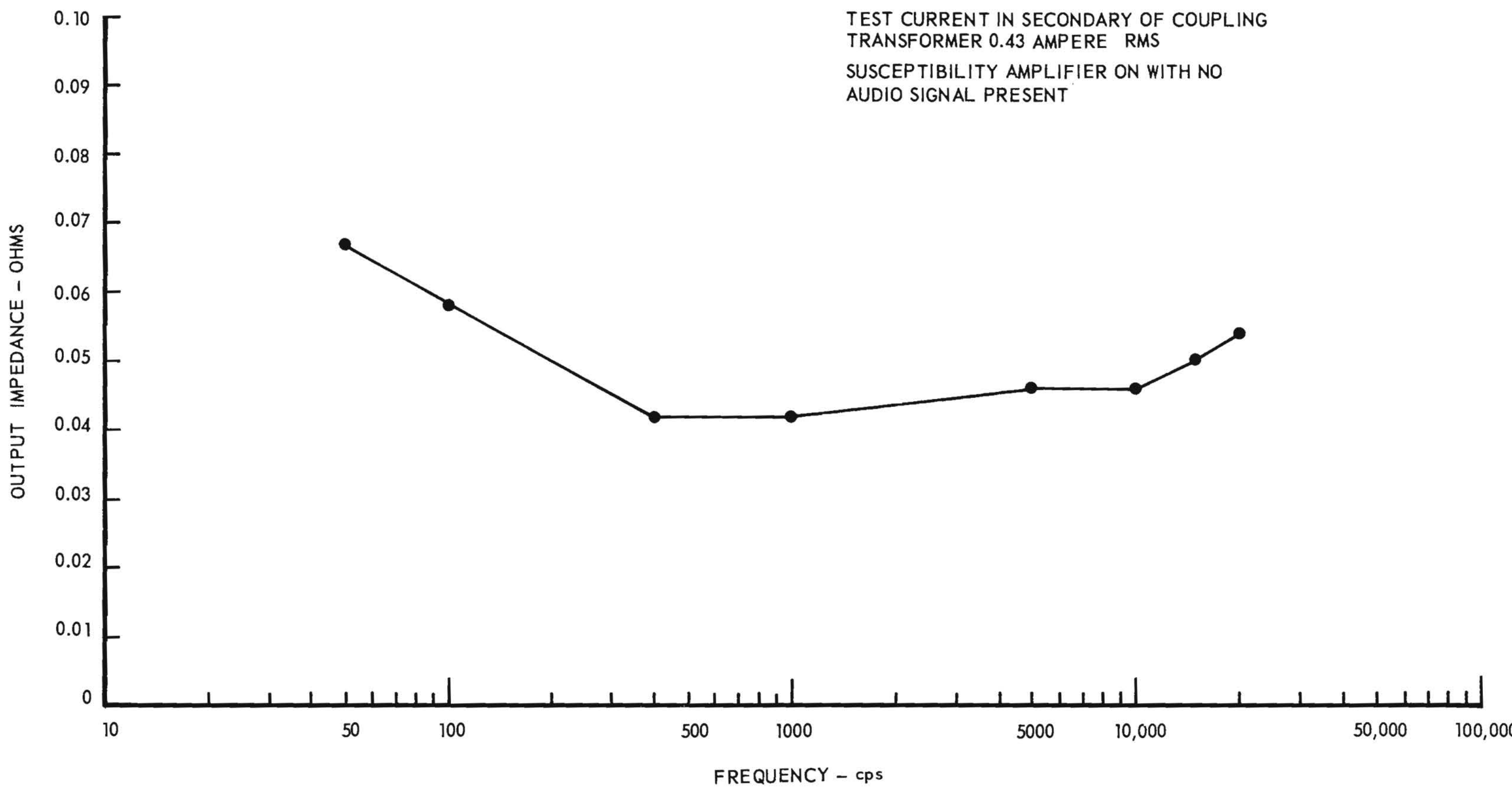


Figure 19. Output impedance of audio susceptibility tester at the output terminals of coupling transformer.

susceptibility tester operated satisfactorily under these conditions. Above 20 amperes ac current, the amplifier requires forced air cooling for the output transistors. Above 35 amperes of ac current in the secondary, some clipping was noted in the audio voltage waveform when the amplifier was delivering approximately 18 watts of audio power. No power line tests were conducted at 400 cps because of lack of power equipment and time. When the audio susceptibility testing signal is nearly equal in frequency to the ac power frequency, dissipation problems may occur in the power output transistors because of the possibility of extremely low frequency transistor currents and voltages. Because of the transistor's thermal time constant, excessive heating in the power transistors may occur when operating at high line currents. Operation at an audio susceptibility testing frequency close enough to the power line frequency to cause this difficulty is not considered necessary because the susceptibility of the equipment should be taken care of in the design of the equipment. If not, the power line frequency itself should provide an excellent susceptibility test signal.

Normal operating procedure for the amplifier is to connect the equipment to be tested and turn this equipment on with the susceptibility amplifier off and no audio drive signal applied. The susceptibility amplifier is then turned on and the audio drive signal is applied. The solid state circuit breaker is equipped with a protection circuit which prevents the hold-in of the circuit breaker.

V. CONCLUSIONS

A Design Plan for a radio frequency compatibility accessory set has been established and is presented in the form of equipment specifications, system block diagrams, and general equipment layout. The exact placement and detailed arrangement of equipments can only be determined after the specific components have been designated. The system as presented should provide the required capability for making the measurements prescribed by MIL-I-11748 using commonly accepted measurement techniques.

Theoretical calculations based on empirical data indicate that fairly stringent requirements on individual components such as switches, attenuators, and couplers are necessary if the required specifications are to be met. For example, the broadband requirements of the system require that the specified VSWR of each component be low over the entire frequency range. The characteristics of these devices are such that they usually exhibit varying VSWR's over broad frequency ranges. Statistically, these higher VSWR regions of many components in tandem would not be likely to occur at the same frequency. If they did not occur at the same frequency, the VSWR maximum on any one item could be relaxed. Because of such considerations, it was concluded that assembly of the system and application of corrective measures would be preferable to an unrealistic specification of individual components. Once the system is assembled, corrected for VSWR, and calibrated, much more repeatability of measurements should be possible than with the usual assembly of test equipment.

An audio susceptibility tester consisting of a transistorized amplifier and a coupling transformer has been designed. A transistorized audio amplifier was used which has a low output impedance with a further reduction of the inserted power line impedance obtained by the stepdown ratio of the coupling transformer. Although extensive tests were not made on the audio susceptibility tester, the results obtained from the tests performed indicated that the amplifier, transformer, and protective circuits performed satisfactorily.

Techniques for the deposition of a thin film resistive element for a high power dummy load were investigated. A resistive element was deposited using electron beam techniques, but difficulty was encountered in obtaining a sufficiently thick, uniform film. Further investigation into electron beam techniques for the deposition of thin film resistive elements seems desirable.

VI. OVERALL CONCLUSIONS

A Design Plan for a radio frequency compatibility accessory set has been prepared. This accessory set provides the equipment setups required to perform the measurements specified in MIL-I-11748 with emphasis on Class I equipment. Measurements on Class II and Class III equipments can be made with little or no modifications. The accessory set Design Plan has been prepared with testing techniques which are in common use at present. Although these techniques do provide a standard method of performing these tests, the actual equipment arrangement is not specified. Consequently, the use of different equipments and arrangements leads to possible errors. The Design Plan for the accessory set should, while not eliminating all possible sources of errors, provide a repeatable measurement setup which will significantly increase the reliability of the data obtained.

An audio susceptibility tester has been designed which performed satisfactorily in tests conducted in the laboratory. While tests were not extensive, it was concluded that the principle used in the design of the audio susceptibility tester presents a useful approach to the problem. An improved susceptibility amplifier should be possible using silicon power transistors.

Line stabilization networks (LSN's) present a problem in that their input impedance is required to be useful from 14 kc to 100 Mc. To obtain a useful impedance at the lower frequencies requires a network which exhibits unsatisfactory self-resonant characteristics in the higher frequency range of interest. At present, the best approach seems to be the use of two LSN's to cover the required frequency range, one for the low frequency range and one for the higher frequencies. Lossy filter techniques may be useful in these devices.

Thin film resistive elements for high power dummy loads have been investigated. Using a firing technique, films of an alloy of gold and platinum were deposited which exhibited a good temperature coefficient of resistance but which were not capable of withstanding the desired temperature of operation. Electron beam techniques for deposition of a uniform film over a required area appear feasible.

A commercial rejection filter in the vhf region was evaluated. This filter was found to be rather difficult to adjust to high values of rejection, had a broad skirt attenuation region around the rejection frequency, and showed an appreciable and irregular increase in insertion loss at frequencies above the notch frequency.

A receiver input coupler which allows a 300 ohm system to be coupled to a 50 ohm system has been constructed. The configuration of the coupler is that of a resistive minimum loss pad. The VSWR and insertion loss characteristics of this coupler are satisfactory to better than 400 Mc.

VII. RECOMMENDATIONS

It is recommended that several areas of equipment development be undertaken to provide needed measurement capabilities, or to extend the capabilities of present equipment.

A need exists for a microwave frequency deviation detector to provide a capability for measuring deviations in higher frequency military equipments. Present methods such as the "zero count" method are time consuming and hard to apply in the frequency range above 1 Gc.

An extension of the standard response indicator which presently exists for pulse systems to FM and AM systems would be desirable. Such an instrument would remove much of the operator judgement from the measured data and also expedite the measurements program. For AM systems, an extension of the distortion analyzer technique for setting up a standard response using signal-plus-noise to noise ratio derived by use of a 400 or 1000 cps modulation applied to the system seems to be preferable. For FM systems, consideration should be given to synchronization of the signal generator with the standard response indicator so that the carrier (signal generator output) could be turned on and off. In this mode of operation, response as measured by the standard response indicator would be based on the quieting criterion.

All broadband coaxial attenuators investigated had VSWR's in excess of 1.2, the specification of overall VSWR for the accessory set. Therefore, improvement in the VSWR characteristics of broadband coaxial attenuators is desirable.

Dummy loads capable of handling high power and presenting a good termination over a broad frequency range are needed for the closed system tests.

Several approaches to this problem are possible. One approach, which was investigated on this project, is the possible use of thin film dummy loads capable of operation at elevated temperatures. Such loads could be fairly small for a given power rating, thus extending their useful frequency range before multimode problems become troublesome. A second approach may be the use of a conventional high power load preceded by a low-pass lossy filter element. Such a termination would rely upon the dummy load at the lower frequencies to dissipate the power, but at the higher frequencies the power would be dissipated in the lossy filter element.

A problem exists in coaxial to waveguide adapters in that they are not available above 18 Gc. To be useful in this frequency region, a smaller coaxial transmission system would have to be used to avoid multimode problems. It appears desirable to investigate the possibilities of a coaxial measurement system to 40 Gc to avoid the problems of higher order modes in waveguide.

Line impedance stabilization networks should be improved so that one network would present a useful impedance in the frequency range from 14 kc to 100 Mc. At present, two networks are required in this region. Lossy filter techniques seem to offer a possible approach to this problem.

The problem of multimode propagation in transmission systems should receive additional consideration. A system exists which apparently gives reasonable results but the elaborate equipment requirements are a handicap. Determination of the degree to which this problem affects measurement accuracy should be established.

VIII. IDENTIFICATION OF KEY TECHNICAL PERSONNEL

The technical backgrounds of the key personnel and the approximate man-hours of work performed by each on this contract are given below.

Name	Title	Approximate hours
Hugh W. Denny	Assistant Research Engineer	2291
William R. Free	Research Engineer	111
Neil T. Huddleston	Graduate Research Assistant	1165
D. W. Robertson	Head, Communications Branch	276
Joseph R. Walsh, Jr.	Project Director	1901
W. Bruce Warren	Research Engineer	55
E. Wendell Wood	Assistant Research Engineer	288

The background and qualifications of these men are presented in the following paragraphs.

Mr. Denny joined the project shortly after it was initiated in April 1963. He received a B.E.E. degree from Tennessee Polytechnic Institute in 1960 and an M.S. degree in Electrical Engineering in 1964 from the Georgia Institute of Technology. His previous experience includes work in design, construction, and testing of transistorized, crystal controlled vhf oscillators. As an Army Officer, he served as a Wire Communications Officer with a combat area Signal Batallion in Texas and Germany. While at Florida Power and Light Company, he worked in the System Control Division in the planning of load control systems and in the Relay Division.

Mr. Free joined the project in November 1963. He received a B.S. degree in Electrical Engineering in 1954 and an M.S. degree in Electrical Engineering in 1959, both from the Georgia Institute of Technology. His previous experience includes 3 years as an Electronic Engineer with Sperry Gyroscope Company in Great Neck, New York; 3 years as an Assistant Research Engineer with the Engineering Experiment Station, Georgia Tech; and 4-1/2 years as a Senior Staff Engineer with Sperry Microwave Electronics Company at Clearwater, Florida. Mr. Free's experience has been in the fields of communications, RFI, and pulse circuit design.

Mr. Huddleston joined the project on June 24, 1963. He received his B.E.E. degree from Tennessee Polytechnic Institute in 1963 and is presently working toward an M.S.E.E. degree at Georgia Tech.

Mr. Robertson is Head of the Communications Branch. He has been associated with the Georgia Institute of Technology since 1947. He received a B.S. degree in E.E. in 1950 and an M.S.E.E. degree in 1957. From 1941 to 1947, he was employed by Civil Service where his work included maintenance and installation of airborne radio and radar equipments. At Georgia Tech, he has been a staff member and director of various projects.

Mr. Walsh assumed duties as Project Director when the project began in April 1963. He received a B.E.E. from the Georgia Institute of Technology in 1949 and an M.S.E.E. in 1961. His previous experience includes work with Westinghouse Electric Corporation in electronic design and with the Civil Aeronautics Administration where he installed and tested VOR and ILS navigation systems. At Georgia Tech, he was an assistant director of a project to design and construct a radar system for studying characteristics of ground clutter and target return, and was concerned with applications of these results in an experimental radar system. He has been associated with the design and development of electronic circuitry of a radar system for study of the polarization and statistical properties of sea return, and with field operation of this equipment. He has been connected with several projects concerned with radio frequency interference.

Mr. Warren received a B.E.E. degree from the Georgia Institute of Technology in 1953, and an M.S.E.E. degree in 1955. He was first associated with Georgia Tech from 1953 to 1957 doing electronic design work in the fields of radar and communications. He was later associated with Bell Telephone Laboratories working on missile guidance systems. After his return to Georgia Tech, he has been concerned with communication systems and radio frequency interference. He is the holder of several patents in the electronics field.

Mr. Wood received a B.E.E. degree from the Georgia Institute of Technology in 1960 and an M.S.E.E. degree in June 1963. His previous experience includes 3 years with the Federal Communications Commission at the Atlanta Field Office where he worked with radio interference cases; 15 months as a Test Assistant for the Georgia Power Company; 2 years as a Radio Engineer with an Atlanta broadcasting company; and 2 years as a radio and TV technician in Thomas County, Georgia.

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