FINAL TECHNICAL REPORT

PROJECT NO. A-2812

RESEARCH AND DEVELOPMENT OF A MILLIMETER-WAVE TRANSMITTER SYSTEM

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By

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FOREWORD

The purpose of this research project was to design, develop, and test a high power, 35-GHz transmitter system with variable pulse widths and pulse repetition rates for use in studies of the biological effects of millimeter-wave electromagnetic radiation. This system consisted of a millimeter-wave transmitter, its -12 kilovolt power supply, and associated interconnecting cables (the focused antenna was to be provided by the sponsor). This transmitter system was intended to simulate the operation of electro-optical countermeasures instrumentation with respect to pulse characteristics and power levels while providing a highly-controllable and repeatable dose of electromagnetic energy to the biological system under investigation.

Design and development of the transmitter system was conducted by personnel of the Biomedical Research Division in the Electronics and Computer Systems Laboratory at the Georgia Tech Research Institute of the Georgia Institute of Technology, Atlanta, GA. Mr. J. C. Toler served as Project Director. The project was sponsored by the Walter Reed Army Institute of Research of the Army Medical Research and Development Command at Fort Detrick in Frederick, Maryland under Contract No. DAMD17-80-C-0190. Dr. Larry Larsen of the Walter Reed Army Institute of Research served as Program Monitor. Within the Georgia Tech Research Institute, the project was designated as Project No. A-2812.

This report describes the technical activities that were undertaken in the process of designing, developing, and testing the transmitter system. Several persons contributed substantially to the technical activities, and the authors would especially like to identify the contributions of Dr. L. Larsen and Mr. J. Jacobi of the Walter Reed Army Institute of Research.

Respectfully submitted,

[redacted]

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SECTION I
INTRODUCTION

The purpose of this project was to design, develop, assemble, and test a high-power transmitter system that would subsequently be used with a focused antenna to investigate the possibility that biological systems are adversely affected by exposure to millimeter-wave electromagnetic environments. The need for such a transmitter system has resulted from the increasing use of millimeter-wave energy in applications such as short-range communications, radar (fire control, terrain, etc.), and electro-optical countermeasures.

Biologically, millimeter-wave energy may have unique effects due to frequency-specificity, locally-high power densities, and high energy deposition in small tissue volumes. Of particular interest in this frequency range are potential ocular hazards.

Frequency-specific effects on the respiratory control ratios of mitochondria exposed to high incident power densities (500 mW/cm^2 and 1000 mW/cm^2) have been reported by Motzkin [1] and Melnick [2]. Effects at specific millimeter-wave frequencies on the metabolism of metals in animals and on the growth of adenovirus have been reported in the Soviet literature [3,4]. A quasi-lattice vibration model for millimeter-wave and microwave electromagnetic (EM) field interactions with tissue has been described by Illinger [5], indicating the possiblity of damped resonant interactions with biological systems. Frequency-specific effects of 45-46 GHz irradiation on bacterial colicin synthesis were reported by Smolyanskaya [6]. These findings have been supported by Motzkin [7]; however, investigations by Swicord [8] did not support these findings. Conflicting results have also been reported concerning possible millimeter-wave athermal effects on the permeability of erythrocytes [1,2,9]. A panel discussion dealing primarily with potential cellular effects of millmeter waves identified dielectric dispersion and absorption phenomena as a possible mechanism with respect to EM field/biological system interaction.

Because of results reported in literature such as that cited above, a need has existed for a millimeter-wave source with a high output power capability in combination with a wide range of available pulse modulations. Such a transmitter system would permit bioeffects investigations under many possible exposure conditions. Thus, if some unique combination of pulse parameters happens to elicit a significant biological response, the probability of identifying the modulation condition is greatly improved when an exposure source with a wide range of pulse conditions is utilized.

The transmitter system developed during this project was of the master oscillator-power amplifier type. The oscillator was a low-power, solid-state Gunn diode that drove a multicavity klystron amplifier having a 50 dB power gain. Thus, one kilowatt of continuous output power could be achieved using a Gunn oscillator with a 10 mW power output. This approach offered several advantages. First, pulse modulation could be accomplished at a low-power level, thus significantly reducing modulator cost and complexity. Second, control of the overall output power from the system could be provided by varying attenuation between the oscillator and power amplifier. Third, the frequency of the Gunn oscillator could be controlled automatically using a simple DC error-correcting voltage. Finally, harmonic and spurious output suppression could be enhanced through the use of a lower-power waveguide filter between the oscillator and amplifier. Details related to the design, development, operation, and service of this transmitter system are provided in the following sections of this report. More specifically, Section II presents technical specifications to which the transmitter was designed and the design approaches considered during development of the transmitter are discussed in Section III. This section also identifies the design approach that was ultimately followed. In Section IV, the final design, including the limited acceptance test and delivery of the incomplete transmitter system, is presented by describing the waveguide interconnections that comprise the system. Finally, references cited in the report text are presented in Section V and operating instructions for the klystron amplifier are provided in the appendix.

SECTION II

TRANSMITTER SPECIFICATIONS

This research and development effort required the design and construction of a high-power, single-frequency, millimeter-wave transmitter with variable pulse widths and pulse repetition frequencies suitable for use in studies of the biological effects of exposure to millimeter-wave electromagnetic radiation. The transmitter had to simulate the operation of electro-optical countermeasures instrumentation with respect to pulse characteristics and power levels, and provide a highly-controllable and repeatable dose of electromagnetic energy to the sample under investigation. In order to accomplish these objectives, a transmitter operating at a frequency of 35 GHz with a peak power output of 1 kilowatt (kW) ± 0.5 dB was designed, developed, and fabricated. This millimeter-wave transmitter conformed to the specifications required by the original Request for Quotation (DAMD17-80-Q-0006). The primary power source was of the oscillator-amplifier type, and employed a low-power, Gunn diode oscillator to generate a fundamental signal with a noise power spectral density at least -35 dBc. The Gunn oscillator output was then (1) modulated to the desired pulse width (1-to-25 microseconds in 1.0 microsecond increments) and repetition frequency (100 Hz to 10 kHz), (2) leveled via a Faraday rotation ferrite modulator, and (3) amplified by a multicavity klystron amplifier to achieve the required peak output power level of 1 kW. The system was also capable of continuous operation at a 1-kW level.

The transmitter system incorporated devices for continuous monitoring of duty factor and frequency. Also, the average forward and reflected output power were controlled to within an accuracy of 0.5 dB. Associated with the frequency monitoring capability of the system, which was provided by an incorporated digital frequency counter, was an automatic frequency control (AFC) loop which maintained the transmitter's output frequency at 35 GHz ± 10 MHz. In addition, fault detection and prevention circuitry protected components of the system from damage resulting from improper usage or failure of other components. This circuitry would also protect against personnel safety hazards in the event of a component failure. One protection circuit monitored load VSWR, and provided a variable threshold (with a calibrated value of 1.1:1) which the load VSWR could not exceed without causing a total shutdown of the system. Other protective circuitry monitored (1) peak power output, which was not allowed to drift outside specified limits (1000 W ± 0.5 dB), (2) high-voltage arcing in the klystron amplifier, and (3) coolant temperature.

The millimeter-wave transmitter was designed such that the specifications listed above would be met for operating temperatures in the range from 55^o to 95^oF (12.7^o to 35^oC) and for operating relative humidity in the range from 10 to 80 percent. In addition, the transmitter was designed to withstand storage temperatures of 0^o to 110^oF (-17.8^o to 43.4^oC) and relative humidities of 10 to 95 percent.

SECTION III
DESIGN APPROACH

Technical considerations were given to a number of different design approaches that could be used to develop a millimeter-wave transmitter system. These technical considerations and design approaches are described in this section, which begins with a general discussion of low-power oscillators and klystron power amplifiers designed to operate in the millimeter-wave frequency range. Possible design approaches considered during the research and development of this transmitter system are then discussed. The specific design approach followed in developing the transmitter is then identified.

A. Technical Considerations

The desired configuration for the source of the high-power signal produced by the transmitter system is the low-power oscillator-power amplifier configuration. This configuration allows modulation at the more convenient low-power levels before signal amplification, as opposed to a situation in which a high-power oscillator (such as a magnetron) must be modulated at a high-power level. Modulation at the high-power level would result in undue circuit complexity and inefficiency as well as significant degradation of system capabilities. In addition, the oscillator-power amplifier source configuration is more adaptable to electronic leveling schemes than is the high-power oscillator. Sampling and detection of the output signal are performed at a low-power level with more economical low-power millimeter-wave components.

Typically, single-frequency millimeter-wave power sources designed in the oscillator-power amplifier configuration consist of a low-power solid state oscillator which generates fundamental frequency RF energy at power levels ranging from tens to hundreds of milliwatts. This oscillaotr is followed by either a solid-state or tube-type power amplifier, depending on the output power level desired. Low-power, solid state oscillators are usually a negative-resistance diode. Gunn diodes produce EM energy of high spectral purity and low-noise spectral density, but their output levels are far below those of IMPATT avalanche diodes which depend on an inherently noisy carrier multiplication process for the generation of EM energy. For the millimeter-wave transmitter developed during this project, spectral purity of the output signal was an important requirement. Therefore, a Gunn diode oscillator was selected as the source of low-power EM energy.

Besides operating as a source of millimeter-wave energy, negative-resistance diodes can also be used as amplifiers. For example, if an IMPATT diode is properly coupled into a resonant cavity, the resistive load of the cavity suppreses the oscillation of the diode. However, amplification will result if the diode is driven by a voltage waveform at or near the resonant frequency of the cavity. Semiconductor-type millimeter-wave amplifiers, however, operate at power levels of only a few watts. To achieve the kilowatt of peak output power required of this millimeter-wave transmitter, a klystron amplifier tube would be necessary.

Some background information on the performance characteristics and application considerations of these devices was necessary for the effective design of a millimeter-wave source utilizing them. The Gunn effect, on which the design of the Gunn diode is based, was first observed by J. B. Gunn in 1963 during the performance of noise experiments under conditions of high electric field intensity in gallium-arsenide (GaAs) semiconductor wafers [10]. Gunn observed microwave oscillations in GaAs wafers with applied DC electric-field intensities of 3200 V/cm, and conducted a series of experiments to determine the details of the oscillatory waveforms. These oscillations were later shown to be consistent with previously proposed theories of negative resistance based on quantum mechanical considerations.

Qualitatively, the Gunn effect is the result of the transition of electrons within the conduction band of certain compound semiconductor crystals to energy states characterized by a higher effective mass. This transition is excited by an applied electric field, and causes a decrease in electron mobility with increasing electric field intensity--a negative resistance characteristic. This decrease in electron mobility results in the formation of charge dipole layers which increase the field intensity until electron velocities within the dipole layer equal those outside. This layer then propagates to the anode, following which a new dipole layer is formed. The electron velocity at the velocity-field curve minimum for the semiconductor material is called the saturated drift velocity (v_s). It is this velocity with which the electrons in the dipole layer travel. Thus, the frequency of operation is approximately $f = v_s/L$, where L is the distance between the contacts on the semiconductor crystal. The length of the semiconductor conduction path, therefore, determines the frequency of oscillation. Modern Gunn oscillators actually operate in a somewhat different mode, known as the accumulation layer mode.

Several manufacturers (Hughes Electron Dynamics Division, Baytron, Nippon Electric Company, Alpha Industries, etc) of self-contained millimeter-wave Gunn oscillators were identified. Typical parameters specified for these oscillators included:

- frequency of operation (GHz),
- minimum tuning bandwidth (MHz),
- power output (mW),
- DC bias voltage (V), and
- DC bias current (mA).

Secondary specifications given by some manufacturers (a few of which were critically important in this transmitter design) included:

- power output stability (dB/^{o}C),
- frequency stability (MHz/^{o}C),
- load VSWR,
- AM noise (dBc),
- modulation sensitivity (MHz/V), and
- tuning voltage (V).

These oscillators were specified to operate at a nominally fixed frequency and output power level which was a function of their design. They were not generally amplitude-modulated by variation of the DC bias voltage, as this would cause frequency pulling in addition to the modulation. However, some were capable of frequency modulation, utilizing varactor-tuned cavities to vary the frequency of oscillation in response to an applied modulation (or tuning) voltage. This electronic tuning capability was utilized to provide the automatic frequency control (AFC) for the transmitter system. The AFC circuit was designed to compensate for the drift inherent in these oscillators due to power supply variations, temperature, and load VSWR. Pulsing and leveling of the power output were accomplished by EM components external to the oscillator.

Millimeter-wave modulators using the Faraday rotation effect were manufactured by most of the same companies that marketed millimeter-wave Gunn diode oscillators. These modulators could, in general, be used to pulse millimeter-wave sources. They exhibited rise times too slow for this design application, however, and were used only to level the output signal of the Gunn oscillator. PIN diode switches were used to pulse the low-power signal according to the preset pulse width and pulse repetition frequency ranges.

Klystron amplifiers are linear-beam (microwave or millimeter-wave) tubes which avoid the transit time limitations of more conventional grid-controlled amplifier tubes. They operate by velocity modulation of a focused electron beam rather than by density modulation of electrons with a fixed drift velocity as is the case with grid-controlled tubes. In the klystron amplifier, a beam of electrons generated by a small electron gun is directed through a central opening in a cavity resonator. Low-power EM energy is coupled into the cavity and interacts with the electron beam. In a klystron amplifier, the electron beam is directed into the central opening of another resonant cavity with the same resonant frequency as the input. In a two-cavity klystron, the simplest type of klystron amplifer, the amplified signal is excited in this cavity by the velocity-modulated electron beam and then coupled out of this cavity and into the working load. Cavities can also be cascaded, increasing the gain at the expense of bandwidth. In a multicavity klystron, the intermediate cavities function to increase the modulation of the electron beam. As the electron beam propagates toward the collector (the positive electrode of the klystron), it becomes defocused as a result of repulsion between the electrons in the beam. If positive ions are present, they tend to neutralize the negative space charge of the electron beam and keep it focused. However, in a multicavity klystron, a beam focusing apparatus (usually a series of electromagnets) is almost always required. Modern multicavity klystrons can achieve power gains as high as 60 dB, and exhibit linear amplification characteristics from zero-input signal levels to within 2-3 dB of saturation.

Klystron amplifiers exhibit excellent noise characteristics. For a well-designed klystron operating with a well-regulated power supply, the noise generated in the tube will typically be negligible compared to the amplified noise from the driving source. Power supply regulation on the negative cathode supply is important, however. Phase ripple with respect to variation in the power supply voltage is given by

$$\frac{\Delta\phi}{\phi} = \frac{1}{2}\frac{\Delta V}{V}, \qquad (1)$$

where ϕ = total phase transit angle through the klystron. Typically,

$$\phi \overset{\sim}{=} 10(N-1) \text{ rad}, \qquad (2)$$

where N = number of cavities. Thus, the effect of power supply variation increases with the number of cavities in an approximately linear fashion.

B. Design Approach

Initially, a preliminary block diagram of a transmitter system that would potentially provide the performance required by the design specifications was generated. This preliminary diagram is shown in Figure 1. The next step involved determining component availability and examining potential means for implementing each of the blocks in this preliminary block diagram. The major difficulty in implementing this initial design arose with respect to the modulator/leveler subsystem. At first, an attempt was made to combine these functions in a single component; however, devices for accomplishing both these functions (such as PIN diode modulators) at 35 GHz were not commercially available. Therefore, it was necessary to separate these functions by incorporating both PIN diode switches and ferrite modulators in the modulator/leveler subsystem. This change is reflected in an intermediate system block diagram shown in Figure 2. The following paragraphs discuss key design considerations of the final design approach.

1. Klystron Amplifier

Availability of a suitable klystron amplifier tube was found to be the single most critical factor in the design of the millimeter-wave transmitter system. Among the manufacturers contacted, only Varian Associates could supply an acceptable 1 kW, continuous-wave klystron amplifier operating at a frequency of 35 GHz. Varian offered three different approaches, the most economical of which utilized the Varian Type V-A928 Klystron Amplifier. This tube was a six-cavity klystron with a 50 dB power gain and a ± 30 MHz bandwidth. It provided a noise floor of -100 dBc and a phase sensitivity to power supply variations of 0.2 deg/V. This klystron amplifier was selected because it met the transmitter design specifications and it was the least expensive of the three tubes available from Varian.

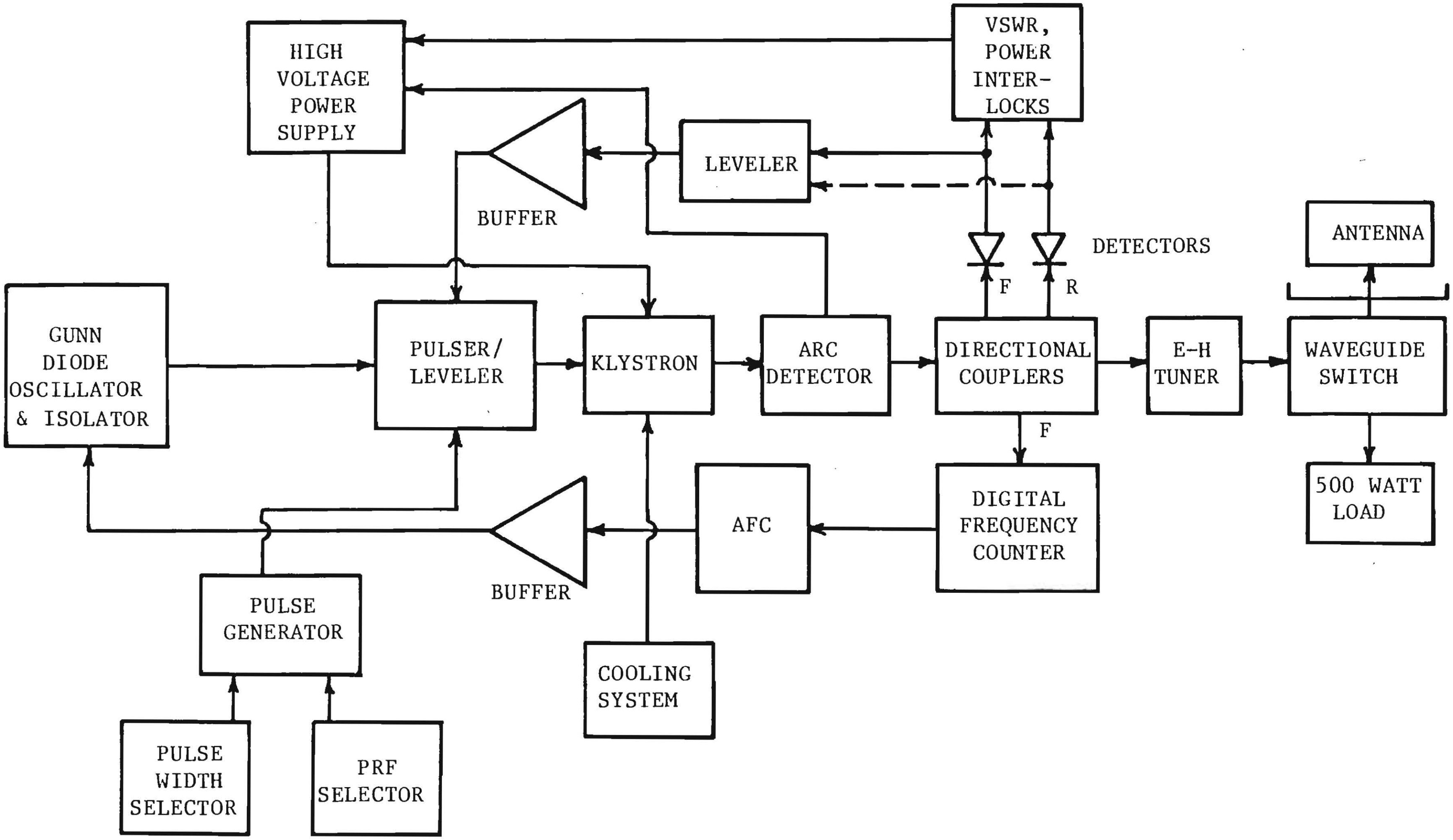


Figure 1. Preliminary block diagram for the millimeter-wave transmitter system.

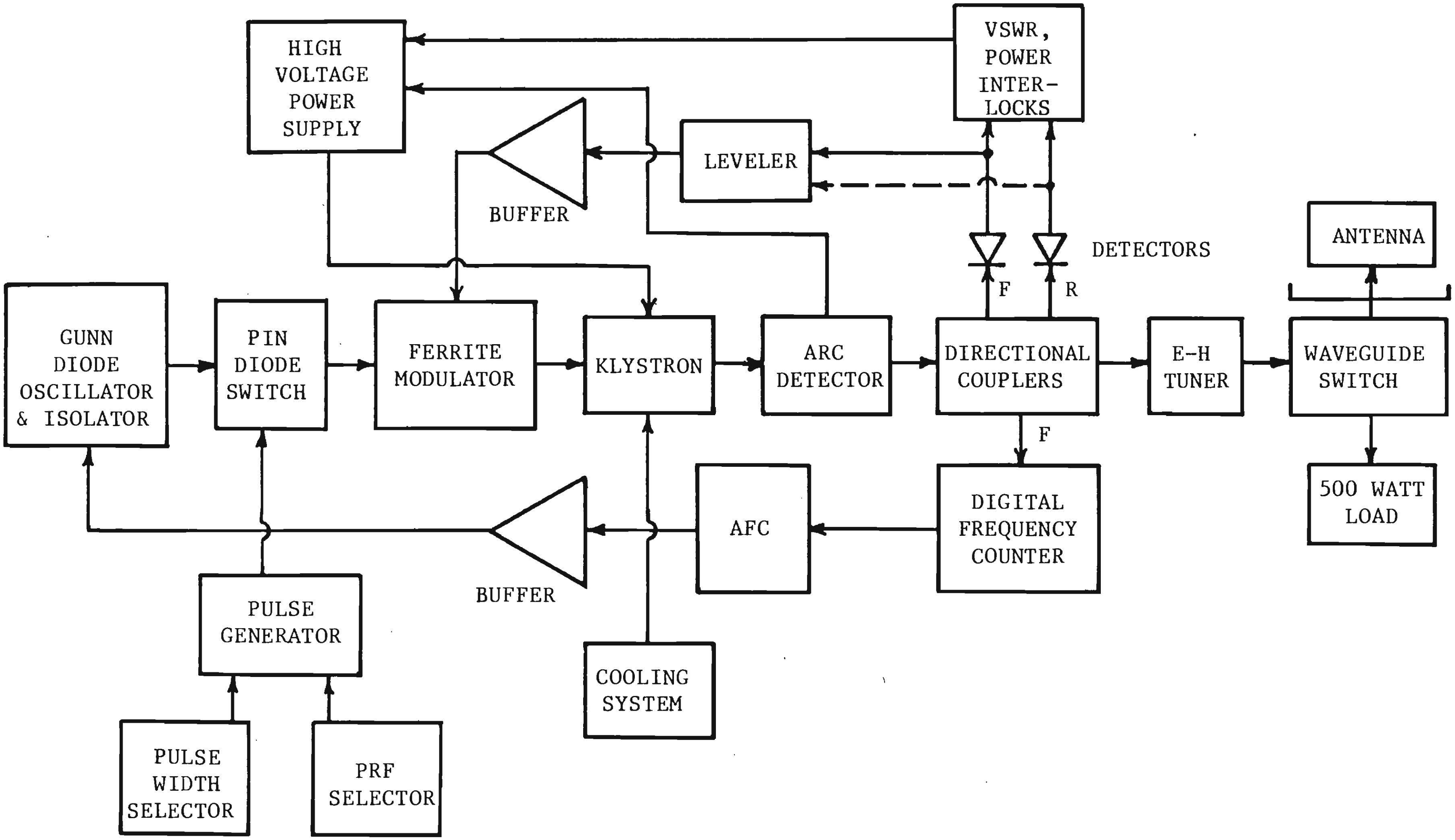


Figure 2. Intermediate block diagram for the millimeter-wave transmitter system.

2. Gunn Oscillator

Determination of the klystron amplifier to be used in the transmitter facilitated the specification of a suitable Gunn oscillator. Because the klystron amplifier provided 50 dB of power gain, the peak output power of the Gunn oscillator had to be only 10 mW (assuming no insertion loss through the PIN diode switch or the ferrite modulator). Because the leveler/modulator possessed a finite insertion loss, an additional 5 dB of power output was required of the Gunn oscillator, producing a final specification of 30 mW output power. This output power also satisfied the requirement on oscillator output power in the original Request for Quotation.

All of the Gunn oscillators examined met or exceeded the noise specification of -35 dBc. Also, these oscillators demonstrated a high degree of spectral purity. Following the examination of commercially-available Gunn diode oscillators, two candidate devices were identified. These were the Hughes Type 41661H and the Alpha/TRG Type A9500. The Hughes oscillator exhibited a much higher electrical tuning bandwidth (400 MHz as opposed to 100 MHz for the Alpha/TRG Oscillator), but the Alpha/TRG unit had slightly better frequency and power stability specifications (-1.5 MHz/^{o}C and -0.04 dB/^{o}C versus -2.0 MHz/^{o}C and -0.05 dB/^{o}C for the Hughes oscillator). The Hughes oscillator specifications quoted an AM noise-to-carrier ratio of -115 dBc in a 1-kHz bandwidth. The noise specification for the Alpha/TRG oscillator was not given in a comparable form.

To determine the drift and tuning requirements, the environmental conditions specified in the original Request for Quotation were employed analytically to determine the maximum drift of each oscillator over the temperature range. To provide a more demanding estimate of the temperature fluctuation, the storage temperature variation specified was used, rather than the operating temperature variation. This variation was 61.25^{o}C total. For the Hughes oscillator, this temperature variation would cause a frequency drift of 122.4 MHz and a power drift of 3.06 dB. For the Alpha/TRG oscillator, this variation would produce a frequency drift of 91.8 MHz and a power drift of 2.45 dB. While this frequency drift was within the electrical tuning range ($\pm$ 200 MHz) of the Hughes oscillator, it is not within that of the Alpha/TRG oscillator ($\pm$ 50 MHz). Therefore, the Hughes Type 41661H Gunn Diode Oscillator was selected.

The output waveguide for this oscillator was Ka-band with the WR28 designation. Therefore, all other millimeter-wave components were selected to mate with this rectangular waveguide.

3. PIN Diode Pulser

The PIN diode switch shown in the block diagram of Figure 2 was used to pulse-modulate the signal produced by the Gunn diode oscillator. In theory, pulsing could be accomplished using the ferrite modulator alone. However, available 35-GHz modulators did not satisfy the pulse rise time specification for the transmitter; therefore, a binary PIN diode switch, which did meet the rise time specification, was selected for pulsing the EM energy produced by the Gunn diode oscillator. A ferrite modulator was used to level the output of the transmitter.

Since the klystron was a linear amplifier from zero-input signal to over a kilowatt, the on/off ratio of the pulsed power was important. In a typical millimeter-wave radar, the output power is zero between pulses. However, achievement of true "off/on" radar operation was not possible with the configuration of Figure 2 since the PIN diode switch "leaked" a small fraction of the applied energy even in the "off" state. This leakage was minimized through judicious selection of a PIN diode switch. An on/off ratio of 60 dB would produce an output power level of 1.0 mW between pulses. This isolation was achieved by using two Alpha/TRG Type A75001 single-pole-single-throw PIN diode switches, each having 30 dB isolation.

This switch mated with the same waveguide (WR28) and flange (UG599/U) as the Gunn oscillator. A short, straight section of WR28 waveguide was used to join the two components.

4. Power Leveler

The ferrite modulator/leveler shown in the block diagram of Figure 2 was a Faraday rotation device which operated as an electronically-controlled variable attenuator capable of up to 30 dB attenuation. This was the operative device for the power-leveling loop. Under normal operating conditions, the modulator/leveler would provide an output to the klystron of approximately 10 mW (approximately -7 dB attenuation), pulsed according to the user-determined pulsing scheme. Under conditions which produced the maximum power drift in the oscillator of -3.06 dB, the modulator/leveler attenuation was automatically reduced to -4 dB, thus maintaining a level output.

Commercially-available ferrite modulators/levelers trade modulation rise time for bandwidth. Since modulation rise time (indicating ability to follow rapid changes in output level) was much more important than bandwidth in this single-frequency application, the ferrite modulator/leveler was chosen largely on the basis of modulation rise time. The Alpha/TRG Type A130 ferrite modulator/leveler was therefore selected as most suitable.

5. Pulse Generator

The pulse generator (which drove the PIN diode switch) controlled the EM energy produced by the Gunn oscillator in such a manner as to generate the desired pulse waveform. Characteristics of the pulse generator were dictated by the operating conditions of the modulator which operated on the EM energy produced by the oscillator. These conditions included bias voltage, bias current, voltage swing, and rise time.

With this transmitter design, a digital interface to the pulsing circuitry was also provided. This interface facilitated the setting and control of desired pulse widths and consisted of a hybrid analog/digital system that performed any necessary operations on the digitally-set, user-determined pulse characteristics. This digital information was then converted into a form which could be used to control the operation of the ferrite modulator.

6. Monitor Points

Monitor points within high-power signal sources are necessary for maintenance, to assure proper system operation, and to measure test parameters. Monitor points were desirable from the pulse generator, leveler, power supply, and klystron for ease of trouble shooting. To assure proper signal source operation, it was also desirable to monitor VSWR in the waveguide transmission line, and to monitor the cooling system operation. Test parameters such as pulse width, pulse repetition frequency, signal frequency, and output power were also measured.

The transmitter design requirements specified that the load VSWR be monitored and used in a variable-threshold, fail-safe control loop. The VSWR was therefore monitored by inserting a bidirectional coupler in the waveguide transmission line. By measuring the forward and reflected power on the two ports of the bidirectional coupler, the VSWR could be determined. This VSWR signal was then be used to control the VSWR fail-safe circuit, which would shut down the transmitter if the VSWR rose above the preset level.

Figure 3 shows a typical design approach for monitoring VSWR and other test parameters from a bidirectional coupler inserted in the waveguide transmission line. In the forward-power arm of the coupler, the signal is first attenuated to power levels compatible with the crystal detector, frequency meter, and power meter. The detected output of the crystal detector is displayed on an oscilloscope so pulse rate, width, and shape may be determined. The measured power level is corrected for losses and coupling factors to determine the true forward power. Either peak power or average power level can be determined. The detected forward power is also incorporated as an input to the automatic power control circuitry shown in Figure 2.

In the reflected-power arm of the bidirectional coupler, the power is first attenuated to measurable levels. The power meter in this arm indicates reflected power after being corrected for losses and coupling factors. A crystal detector and comparator circuit are used to provide an indication of the reflected power. Referring to Figure 2, a portion of the voltage from the reflected power detector may be routed to the automatic power control circuitry if it is desired that a constant net forward power to the load be maintained.

7. Safety Interlocks

A number of safety interlocks and circuits were necessary to protect the more expensive electronic components and to provide a high degree of personnel safety. To protect components, filament overvoltage interlocks, a VSWR interlock, and coolant interlocks were designed into the system. Also, to assure that the tube filaments had stabilized at their final operating temperature before high voltage was applied, warm-up delays were designed into the signal source. Likewise, when de-energizing the signal source, cool-down delays were provided.

Personnel safety was a prime consideration during the final design and testing of the transmitter. Micro-switches were therefore used on cabinet doors to shut down the high-voltage supply if a door was inadvertently opened. Also, keyed interlocks were used to prevent operation of the equipment by unauthorized personnel.

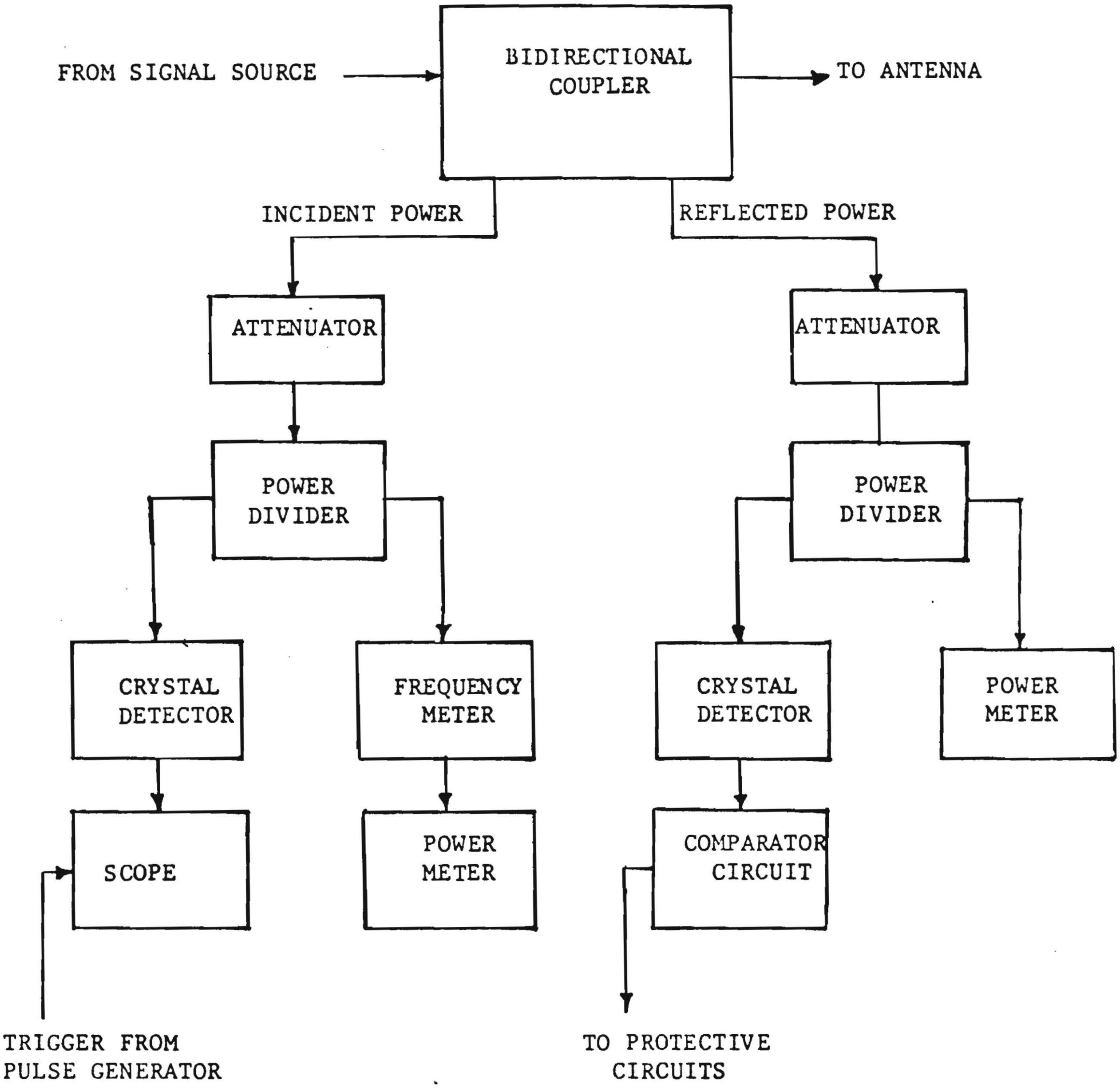


Figure 3. VSWR and test parameter monitoring.

8. Automated Power Control

Figure 4 illustrates the automatic power control concept. The difference between the detected forward and reverse power was used to maintain a constant net power delivered by the system under changing VSWR conditions. The set point voltage was used to determine the initial attenuation of the ferrite modulator, nominally 5-7 dB. The offset adjustment was required to compensate for the normal difference in the forward and reflected detected power levels. The new output of this circuitry was used to vary the modulator voltage and thereby control the klystron power output.

9. Automatic Frequency Control

In Figure 5, the automatic frequency control concept is illustrated. As indicated, the tuning capability of the Gunn diode oscillator was used to tune the transmitter output frequency to 35 GHz and maintain it to within ± 10 MHz.

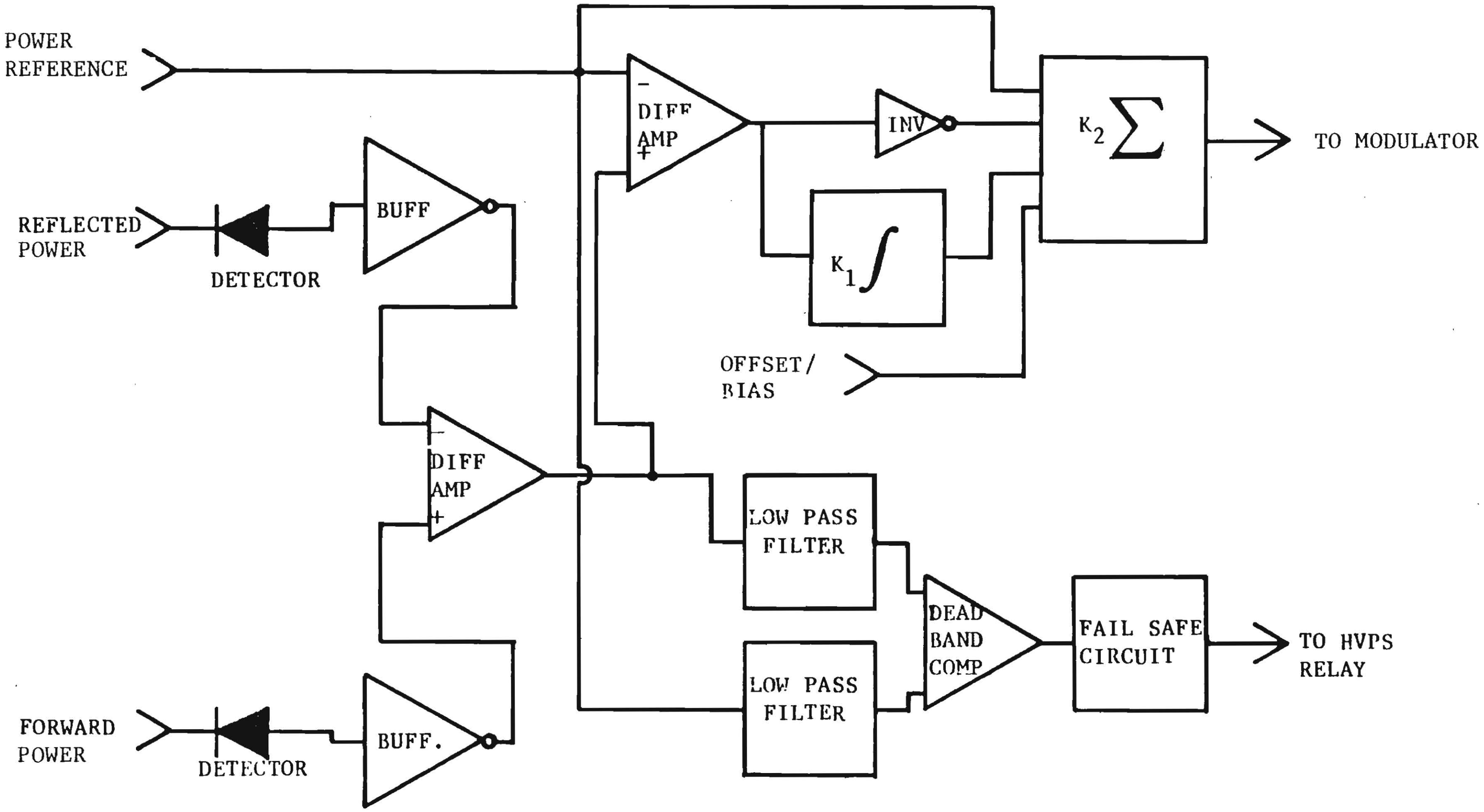


Figure 4. Block diagram of automatic power leveling and fail safe circuitry.

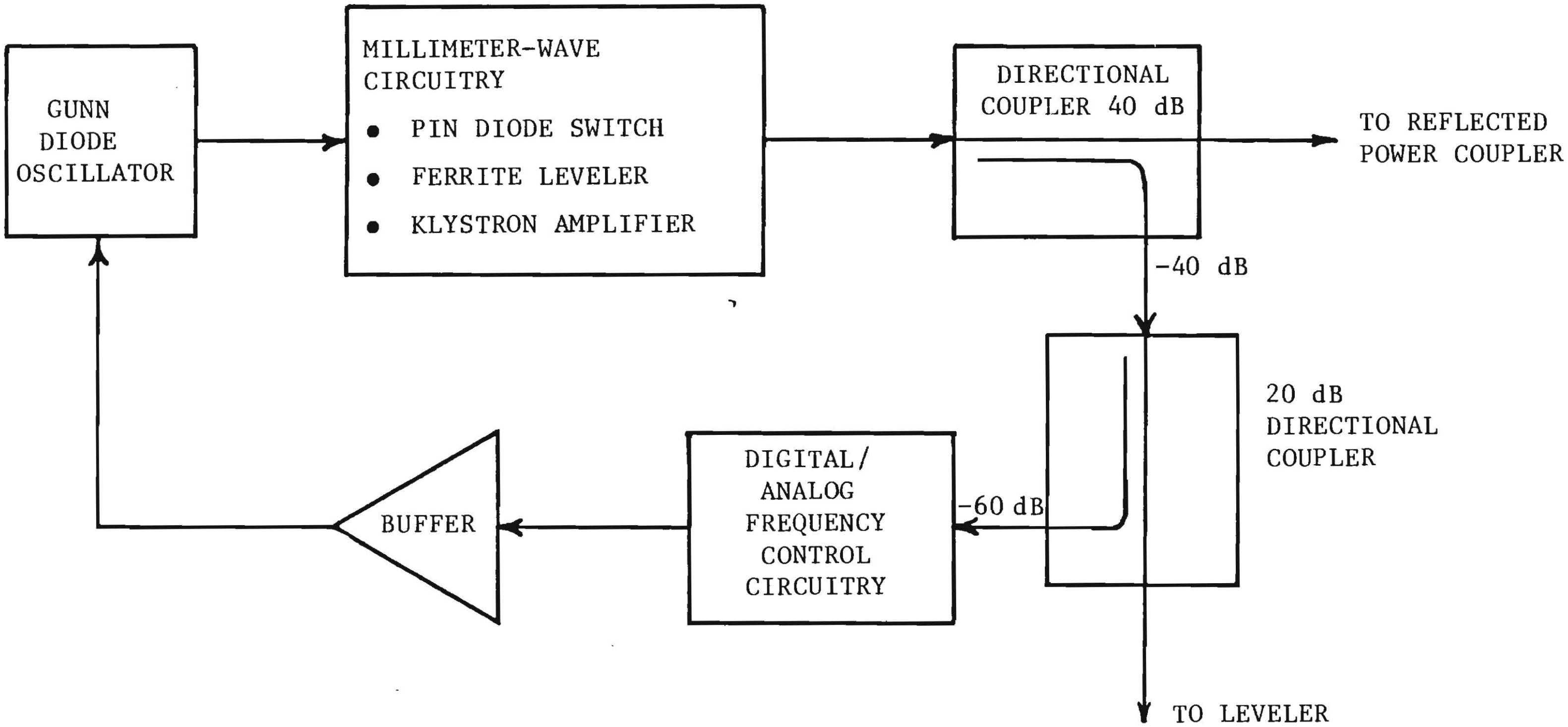


Figure 5. Automatic Frequency Control (AFC) conceptual block diagram.

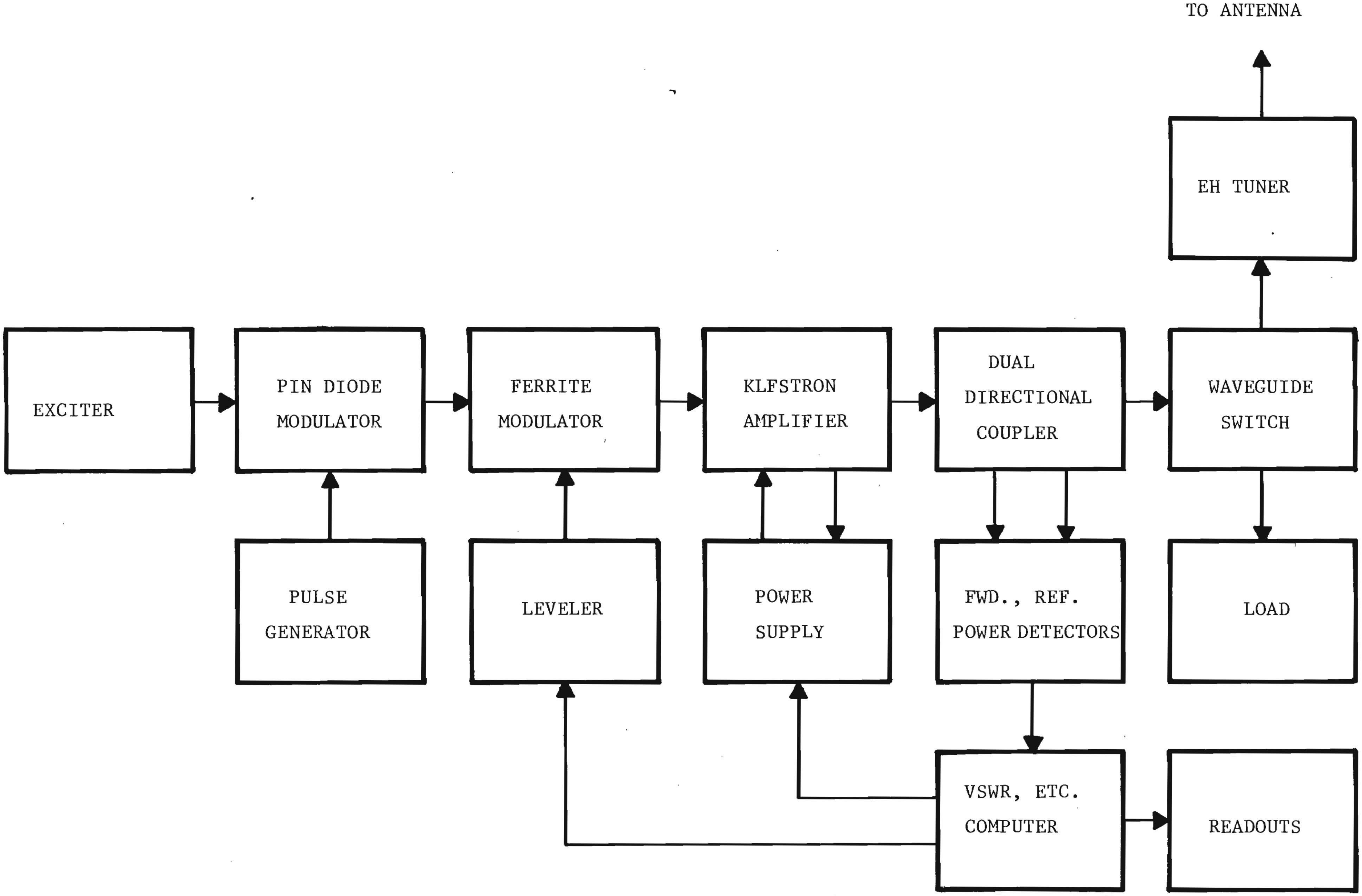


Figure 6. Final overall block diagram of overall transmitter system.

SECTION IV

FINAL DESIGN

After evaluating the performance capabilities of the transmitter subsystems shown in Figure 2, minor changes were incorporated and the design was frozen. The final design is shown in block diagram format in Figure 6. In this diagram, it can be seen that the signal from the 20-mW Gunn oscillator source was routed to PIN diode switches (two switches in series to provide the necessary attenuation in the "off" mode) where they were pulse-modulated by the output of the pulse generator. Next, the signal was leveled with a ferrite modulator. A manual amplitude control was also incorporated into this stage as an additional feature. After passing through these stages, the signal had experienced a maximum attenuation of 5 dB, resulting in 15 dBm to drive the klystron amplifier. Since the klystron amplifier was capable of producing 1 kW (+30 dBw) of power at 35 GHz at a gain of 50 dB, a 5 dB safety margin was provided in the driving signal. This stage incorporated the various safety features required in a high-power transmitter, i.e., thermal shutdown, arc detector, VWSR monitoring, etc. The signal from the klystron amplifier was next routed to a bidirectional coupler which provided samples of forward and reflected power. These power samples were detected and used to compute VSWR, net power, and duty factor. VSWR and net power were used in the shutdown and leveling circuits, respectively. In addition, front-panel readouts of these parameters were provided. Finally, the amplified signal was coupled to a waveguide switch where it was routed to either a 50 ohm resistive load or to an antenna through an EH-tuner. The antenna was provided by the Army Medical Research and Development Command, and was not available to this project.

The block diagram in Figure 7 documents the final design of circuits associated with the low-power subsystem's AFC loop and frequency counter. The fundamental signal source was the solid-state, voltage-controlled Gunn oscillator discussed earlier, and it had an associated AFC loop and digital frequency counter. A small sample of the 35-GHZ signal was obtained from the directional coupler and mixed in the harmonic mixer with the third harmonic of an 11.5-GHz signal from a phase-locked source. The resulting nominal 500-MHz intermediate frequency was amplified and divided by 10 in a UHF prescaler.

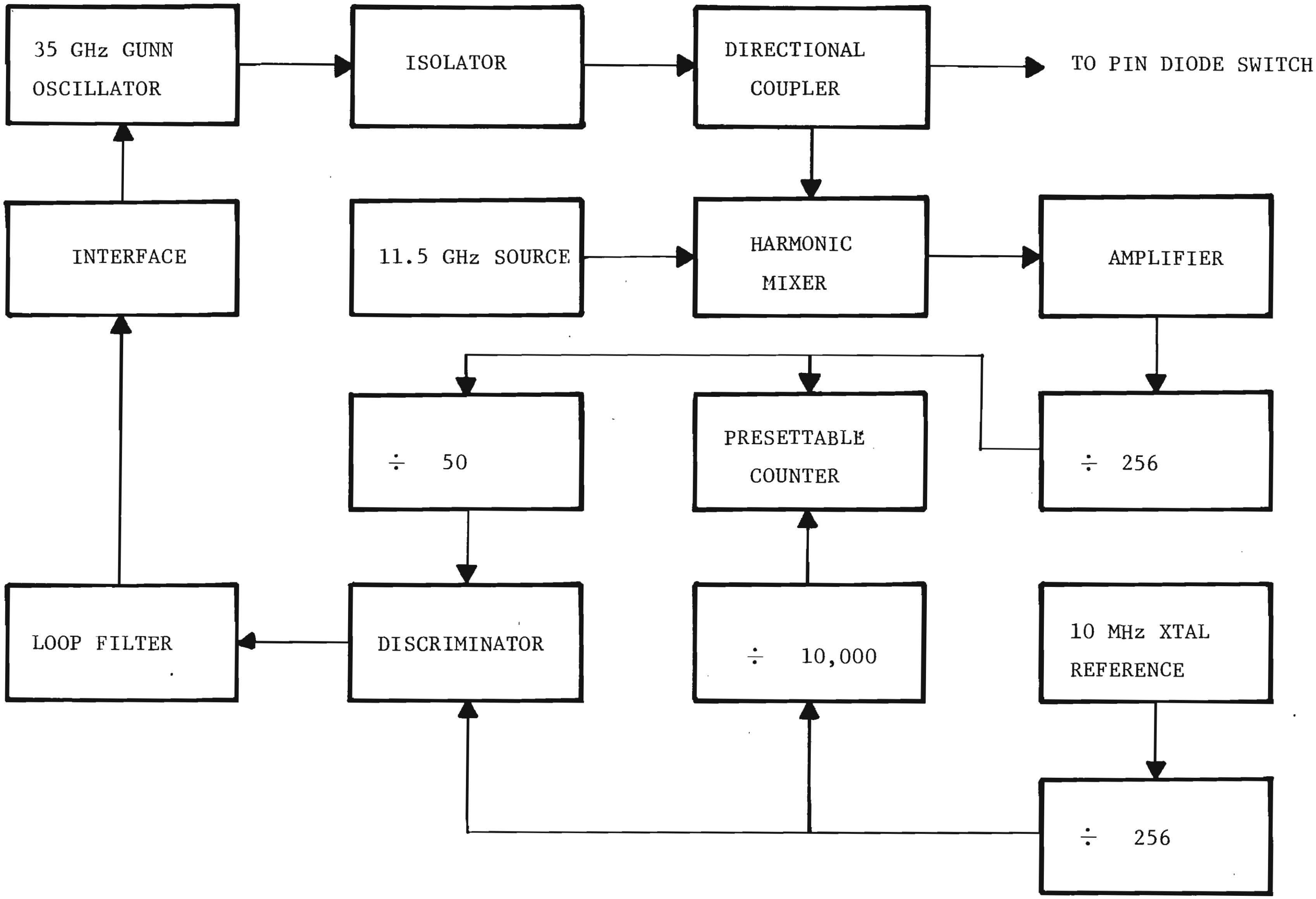


Figure 7. Final block diagram of the low-power subsystem's AFC loop and frequency counter.

This signal was then routed to both a discriminator and a counter. In the discriminator, the signal was compared with the output of a crystal-controlled reference and generated an appropriate error signal for correcting frequency drift in the oscillator. The frequency counter used the same reference to provide a readout of signal frequency. Accuracy of both the AFC loop and the frequency counter was ± 5 ppm (± 175 kHz) over the specified temperature range. The AFC loop in this final design corrects a major problem that would have occurred if the intermediate design shown in Figure 2 had been used. This problem was the fact that, in the event of a large initial frequency drift (as could occur at start-up), the AFC signal would be lost because of klystron shut-down. If this initial drift were outside the klystron bandwidth, the klystron would malfunction, thereby activating the shutdown subsystem and destroying the AFC signal. Thus, there would be no opportunity for the AFC loop to stabilize the output power. The final design eliminates this potential problem by deriving the AFC signal from a point ahead of the critical klystron stage.

Also associated with the low-power subsystem was the pulse generator circuitry shown in Figure 8. This circuitry incorporated a digital frequency synthesizer to control pulse repetition rate and a counter to control pulse duration. BCD thumbwheel switches were used to preset pulse rate from 100 Hz to 10 kHz in 100-Hz steps and pulse duration from 10 microseconds to 25 microseconds in 1-microsecond steps. The frequency synthesizer employed a phase lock approach in which a voltage controlled oscillator (VCO) was forced to operate at a frequency n times that of the reference frequency. Thus, a 100 Hz reference and values of n between 1 and 100 resulted in a pulse rate of 100 Hz to 10 kHz in 100-Hz steps, as required. Pulse duration was controlled with a presettable down-counter and a 1-MHz clock (which was also used to generate the reference for the frequency synthesizer). At the start of each pulse, the counter was preset to a number between 1 and 25 corresponding to the desired pulse duration as set on the thumbwheel switches. The counter then counted at the 1-MHz clock rate until zero was reached, at which point the pulse was terminated and the counter reset.

In developing the final design for the transmitter system's power supply, a decision was made to procure the supply from an external vendor rather than design and construct it inhouse. Therefore, a list of performance specifications and prospective vendors was developed for use in obtaining

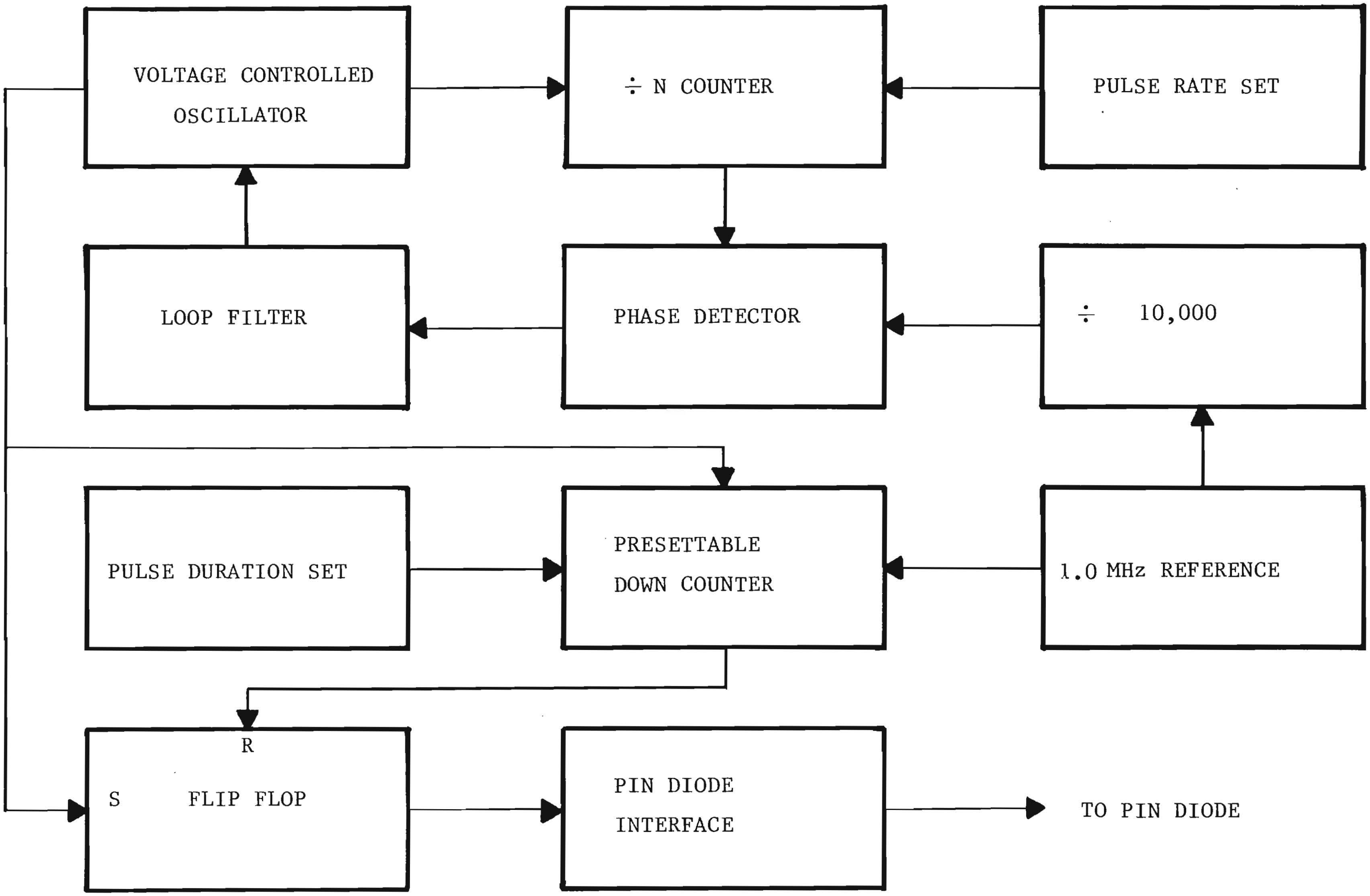


Figure 8. Final block diagram of the low-power subsystem's pulse generator circuitry.

cost and delivery quotations. It is noted that efforts to generate the performance specifications for the power supply were difficult because very little information was available from Varian Associates on the operational requirements for the Type VA-928A Klystron Amplifier. Part of this difficulty stemmed from the fact that the klystron amplifier was being procured by the sponsor and provided to this project as government furnished equipment; therefore, the major contacts with the klystron manufacturer were indirect (through the sponsor) rather than direct. The magnitude of this difficulty is evident in the fact that it was never possible to obtain a formal listing of klystron amplifier operational requirements from Varian Associates. Consequently, power supply requirements were generated on the basis of verbal conversations describing what was expected to be necessary for the klystron amplifier. These verbal requirements and the scoring of vendors capable of providing the power supply are presented in Table I. As a result of the scoring and in consultation with the sponsor, it was decided to procure the power supply from Megavolt Corporation in Hackensack, NJ.

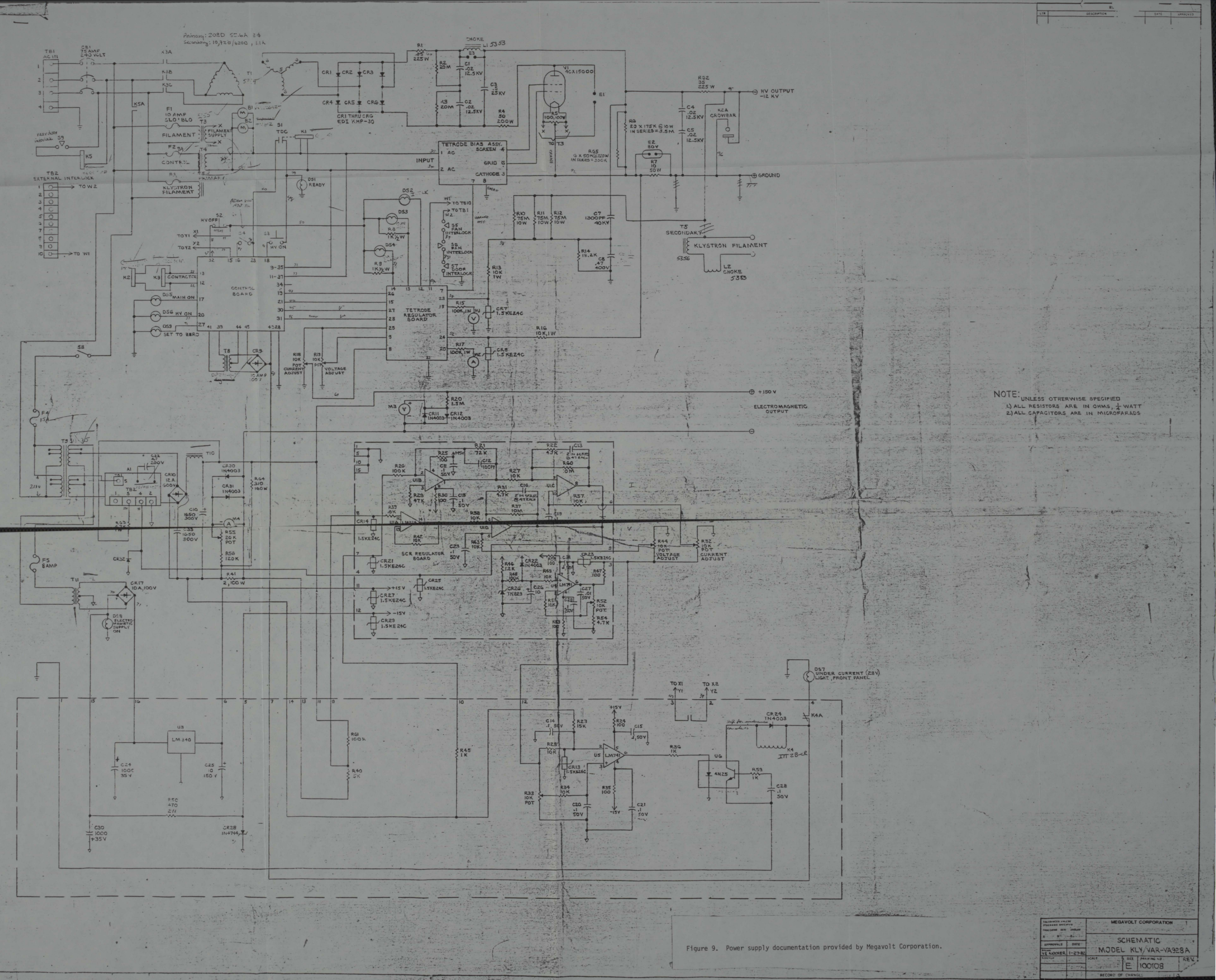
In the final analysis, the power supply procurement proved to be a problem in nearly every respect. Midway in the power supply construction effort, Megavolt Corporation moved their plant from Hackensack, NJ to Deer Park, NY. This resulted in major time delays in the delivery schedule. After extensive interactions with Megavolt Corporation on late delivery, the power supply was finally subjected to a formal Acceptance Test, which it satisfactorily passed with the exception that the ripple voltage under full load conditions was 0.013 percent instead of the required 0.010 percent. The acceptability of this higher ripple voltage and its possible effect on performance of the klystron amplifier were checked with Varian Associates. With their concurrence, the power supply was accepted with this performance deviation.

Immediately after the Acceptance Test, Megavolt Corporation failed as a business, and it was not possible to obtain assistance with difficulties encountered after delivery of the power supply. For example, the only documentation received with the power supply was an overall drawing (Figure 9) showing wiring interconnections between subassemblies in the power supply. No documentation was available on any of the subassemblies and, when the wiring interconnecitons were manually traced, many of them did not agree with the drawing. This necessitiated removing the subassemblies and tracing the

TABLE 1

COMPARISON OF POWER SUPPLY VENDORS FOR VARIAN TYPE VA928 KLYSTRON

Power Supply Requirements	Megavolt Corporation Hackensack, N.J.	Universal Voltronics Corp. Mount Kisco, N.Y.	Electromatic, Inc. Palo Alto, CA
12 kV output at 1.0 amp max. (adjust.)	Yes	Yes	Not adjustable
5.5 V output at 3.0 amps	Yes	Yes	Yes
0.1 percent HV regulation	Yes	Yes	Yes
0.01 percent HV ripple	Yes	Yes	Yes
20 microsecond crowbar response time	Yes	10 microseconds	10 microseconds
25 amp Hv current limit	Yes	Yes	Yes
150V output at 3-to-6 amps (adjust.)	Yes	Yes	Yes
Arcing protection (≈$2550)	No	No	Yes
Over temperature protection	Yes	Yes	Yes
Body current protection	Yes	Yes	Yes
Electromagnet undercurrent protection	Yes	Yes	Yes
VSWR protection	Yes	Yes	Yes
5.0 amp max. surge current for filament	3 increments voltage steps	current limit	current limit
Integration with klystron	No	No	Yes
Cooling system (≈$4000)	No	No	Yes
Primary power	208V, 3 , 70A	208V, 3 , 60A	208V, 3 , 60A
Delivery time	6 months	6 months	8 months
Weight	500 pounds	2000 pounds	1800 pounds
Size	19" x 24" x 72"	44" x 24" x 72"*	49" x 26" x 78"
Price	$27,900**	$36,850	$74,500
Company Size	25,000 ft.^{2}	60,000 ft.^{2}	-
Number of Employees	27	125	20
Enthusiasm toward program	Very high	Moderate	Low



NOTE: UNLESS OTHERWISE SPECIFIED
1.) ALL RESISTORS ARE IN OHMS, $\frac{1}{4}$ WATT
2.) ALL CAPACITORS ARE IN MICROFARADS

TOLERANCES UNLESS OTHERWISE SPECIFIED FRACTIONS DEC. ANGLES	MEGAVOLT CORPORATION	
APPROVALS	DATE	SCHEMATIC MODEL KLY/VAR-VA928A
DRAWN VE AKKNER	1-27-82	
CHECKED		SCALE · SIZE E · DRAWING NO. 100108 · REV.
		RECORD OF CHANGES

Figure 9. Power supply documentation provided by Megavolt Corporation.

direct and printed-circuit-board wiring between components until schematic diagrams could be derived. In doing this, numerous under-rated and otherwise inappropriate components were identified and replaced.

After power supply documentation was generated and necessary design modifications were incorporated, efforts were begun to interconnect the power supply and klystron amplifier. This involved an increased direct interaction with engineers from Varian Associates, and numerous design requirements not previously identified began to surface. The most serious of these were as follows:

- the "hard-on" 5.5 volt AC filament requirement stated on the klystron amplifier data sheet was changed to a gradually-applied 6.3-volt DC requirement with a surge limiting capability to assure that the filament current did not exceed 5.0 amps,
- a 5.0 volt, 10 amp power supply for an additional coil on the klystron magnet was required,
- x-ray shielding of the klystron amplifier was specified,
- a waveguide pressure monitor was required to remove beam voltage from the klystron when the waveguide pressure dropped below 18 psia, oprotective circuits were required to remove beam voltage from the klystron within 30 microseconds after the body current exceeds 120 percent of the name plate value, and
- a front panel monitoring capability was required for the klystron body current.

These new requirements tended to surface one-at-a-time rather than all at one time; therefore, it was not possible to view them all at one time and define an optimized overall course of remedial action. Three of the new requirements were resolved in a straight-forward manner as follows:

- A new 5.0 volt, 10 amp power supply for the additional coil on the klystron magnet was ordered and installed in the transmiter cabinet. The only real difficulties with this were the last-minute rearrangement of previously-installed components and the addition of more interconnect wiring.
- Records of X-ray emission levels measured by Varian Associates prior to shipping the klystron amplifier were reviewed relative to

the metal shielding provided by the transmitter cabinet. It was concluded that no additional shielding of the installed tube would be necessary.

- The requirement for a waveguide pressure monitor that would remove the beam voltage at pressures below 18 psia was relaxed by Varian Associates to the extent that the existing pressurization system and monitor were acceptable. The existing system provided a pressure 1-to-2 pounds above the atmospheric level and was determined to be sufficient to prevent arcing that might result from pulse-to-pulse breathing of the waveguide.

Resolution of the changed requirement for the filament voltage was considerably more involved than resolution of the above new requirements. First, the 5.5-volt AC supply in the megavolt power supply was disabled. Then a new constant-current supply with a 6.3-volt DC output at 2.8 amps was designed and constructed. Following construction, it was bench-tested to assure its compliance with performance requirements. Since this supply had to float at -12 kV, locations for its installation within the transmitter cabinet were extremely limited. It was, in fact, finally mounted to the bottom side of one of the cabinet shelves. Because this supply floated at -12 kV, it was mounted on a Plexiglas bracket provided with standoffs to isolate if from ground potential. After completion of the filament supply mounting and wiring interconnection, Varian personnel requested that voltage and current monitors also be provided. This requirement apparently resulted from concern that, as a result of filament aging, there would be a need for frequently readjusting the supply output in order to maintain the specified power from the klystron amplifier. Voltage and current meters were therefore purchased and mounted on another Plexiglas bracket in an area beneath the bottom shelf of the transmitter cabinet. This mounting location was inconvenient for visual observation, but since the requirement did not exist during layout of the front panels, no *a priori* provisions were made for a more convenient location. To facilitate reading the voltage and current values, a hinged front panel was obtained and mounted on the cabinet in front of the meters. With this approach, a safety feature was provided for the -12 kV voltage, yet the meters could be accessed by physically opening a hinged front panel.

Resolution of the new requirement for removing beam voltage within 30 microseconds after the klystron's body current exceeded 120 percent of its nameplate value involved several design changes. In understanding these changes, it is noted that provisions for quickly removing the beam voltage following any one of several unacceptable performance conditions were designed into the Megavolt power supply. However, this design involved routing the "kill" signal through relay contacts, and the response time of the total circuit was approximately 20 milliseconds. This 20-millisecond time period was the one initially provided by Varian Associates when the power supply design specifications were being generated. To provide a 30-microsecond beam voltage removal time, the "kill" circuit was first redesigned and the relay contacts were replaced with silicon controlled rectifiers whose switching time was less than 10 microseconds.

Simultaneous with the redesign and installation of the circuit to remove the beam voltage in 30 microseconds or less, another new design was being installed to provide a monitoring circuit for the klystron body current. This involved isolating the klystron body from ground at all points except for one path through an added 200-ohm resistor. Current through this resistor was monitored and used to trigger the beam voltage removal circuit if a level 120 percent of the klystron's nameplate value occurred.

While the above-described efforts were underway, plans were also progressing for performance of the transmitter system's Acceptance Test; however, because of uncertainities related to beam voltage removal time, this test was considered to be preliminary. Preparatory efforts for this preliminary test were primarily concerned with designing and constructing a temporary cooling system and coordinating the Test Plan with persons at Varian Associates.

A temporary cooling system was required because the sponsor planned to ultimately connect the transmitter system to a central cooling system to be provided in the Department of Microwave Research at the Walter Reed Army Institute of Research. Therefore, this research and development effort did not require a cooling system as an integral part of the transmitter. However, for the preliminary Acceptance Test, coolant was required at the following six locations: klystron collector, klystron body, klystron window, klystron magnets, system load, and arc detector. Consistent with the lack of key information for the electronic design efforts, coolant flow rates were not available for the klystron window, arc detector, or load. After unsuccessful telephone conversations attempting to define these rates, it was decided to use a flow rate of 2 gallons per minute (GPM) for the klystron window (the specified flow rate for the klystron body), and a flow rate of 0.5 GPM for the arc detector and load (the same flow rate for the klystron magnets). Using these flow rates, a cooling system with six parallel branches was designed and constructed. On the supply side, each branch included a flow indicator (circulating red ball in a clear plastic enclosure), a flow valve (for adjusting the flow rate), and a flow switch (to shutdown the beam voltage if the flow dropped below specified minimum rates). On the return side, each branch included a coolant temperature monitor capable of de-energizing the beam voltage if the temperature exceeded the specified level of 40^{o}C. The flow switches were obtained from Proteus Manufacturing Company in Mountain View, CA, and were precalibrated to the flow rates required by the various transmitter components.

The procedure generated for use during the preliminary Acceptance Test required that first efforts be directed to the low-power section of the waveguide circuit. This circuit would be terminated at the klystron input while monitoring instrumentation was used to demonstrate (1) the range and selection of pulse parameters and (2) the operation of the AFC circuit. The Megavolt power supply would then be energized and operated at full voltage into a dummy load while measurements were made to show that all required voltages were present and within specification. The ability to adequately shutdown the power supply would be demonstrated under the following simulated conditions: (1) anode over-current, (2) magnet under-current, (3) body over-current, and (4) shutdown bus (are detector, VSWR monitor, door interlocks, etc.). Next, the approach used to monitor the output power would be demonstrated and verified. Finally, the klystron would be energized and the high-power portion of the transmitter tested. This would initially involve applying a power supply voltage that yielded a 100-to-200 watt output, during which body current, reflected power, forward power, temperature rise in the power supply and transmitter cabinets, and leveling loop performance would be monitored. The output power level would then be gradually increased while the pulse waveform was displayed for observation.

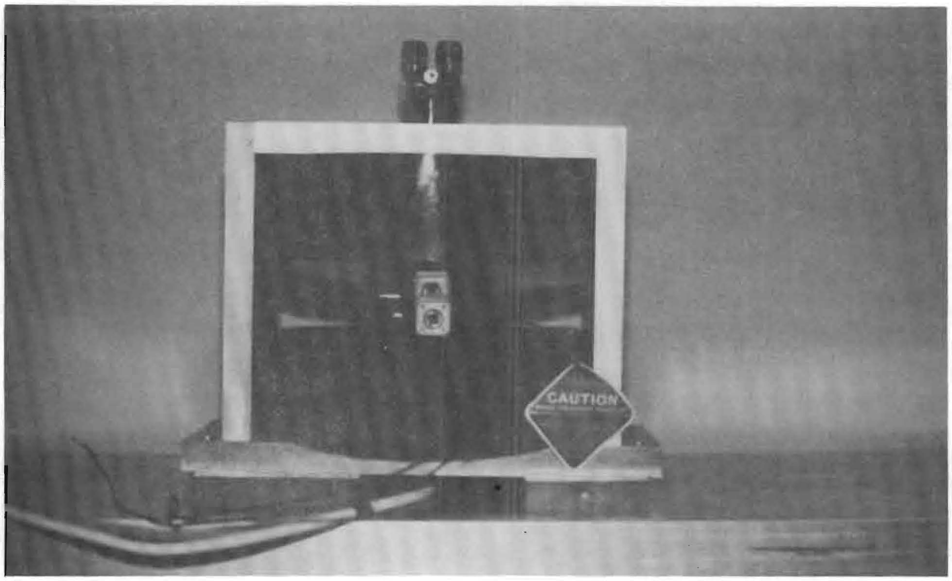
During May 1983, Mr. Brian Roach of Varian Associates directed the preliminary Acceptance Test. Individual electronic and waveguide circuits were meticulously checked out, their operational status was verified, and the power monitoring circuit was calibrated. The Acceptance Test then proceeded in accordance with the previously-defined procedure and the transmitter output power level was gradually increased to 400 watts. At this point, all electronic and waveguide circuitry was functioning satisfactorily and within specifications, and there was no measurable increase in the collector coolant temperature. Mr. Roach then requested that the test be terminated until final decisions were reached regarding shutdown time for the beam voltage in the case of excessive klystron body current.

Tests conducted to determine the ability of the body current monitor to remove the beam voltage within 30 microseconds revealed that it would, in fact, remove high voltage within 20 microseconds. However, when adjusted to do this, noise generated by interwinding capacitance in the Megavolt power supply transformer caused premature triggering. When filtering was added to remove the noise, the response time of the shutdown circuit was unacceptable. It was concluded that replacement of the main transformer in the Megavolt power supply was the only way to realize a body current monitor capable of removing beam voltage within 30 microseconds. However, this would be a costly and time-consuming effort that would be made even more difficult by the fact that the replacement transformer would be larger than the existing one. In view of the crowded conditions in the power supply cabinet, it did not appear possible to locate a larger transformer in the existing cabinet.

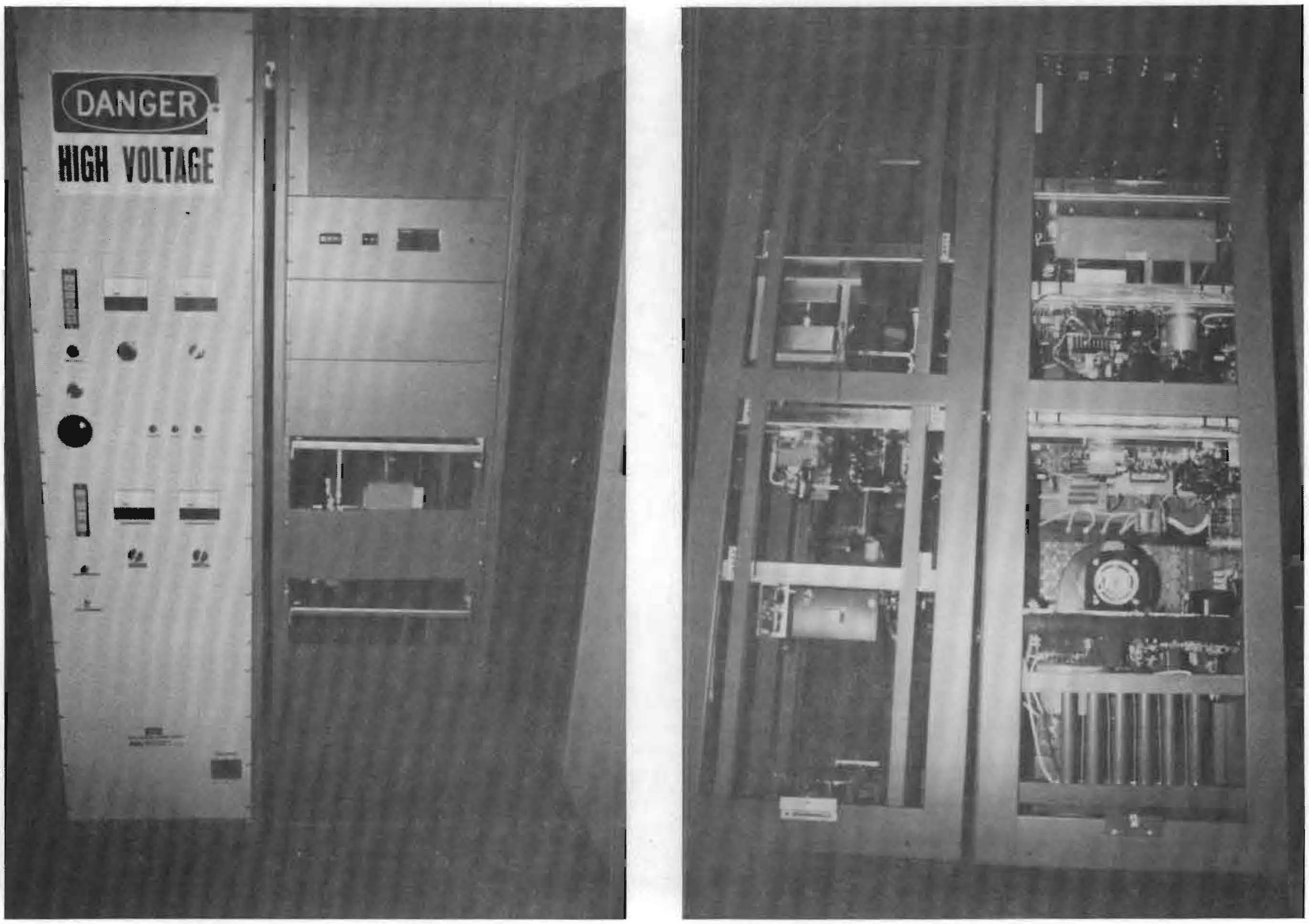
In view of this situation, extensive conversations were held with the sponsor and design engineers at Varian Associates. The major concern of these conversations was whether or not a 30-microsecond shutdown time was absolutely necessary for klystron protection, and, if not, what relaxed time requirement must be met. These conversations resulted in Mr. Roach and other Varian engineers verbally agreeing that a 20-millisecond shutdown time was acceptable; however, they would not document this opinion in a way such that the warranty on the $48,500 klystron amplifier could be maintained.

Prior to directing that the beam voltage shutdown time for the body current monitor be increased to 20 milliseconds without written agreement from Varian Associates, the sponsor decided to convene a panel of transmitter design experts. The shutdown situation would be described to these experts and their opinions regarding the relaxed shutdown time would be sought. However, before this panel could be convened, the Contracting Office at the Army Medical Research and Development Command decided that the requested contract time extension should be denied. This Office then required that the incomplete transmitter system be delivered to the Walter Reed Army Institute of Research (WRAIR). This requirement was reluctantly complied with and the transmitter system, minus the klystron amplifier, was shipped. Subsequent to the transmitter system's arrival at WRAIR, the klystron amplifier plus a updated schematic of the Megavolt power supply and schematics of the Georgia Tech-designed circuits were delivered. The klystron amplifier was installed, the system was visually inspected and operation of the low-power subsystem was demonstrated satisfactorily. Checkout of the high-power subsystem was not attempted because the issue of body current shutdown time was still unresolved.

As delivered, the transmitter system consisted of a transmitter cabinet, a power supply cabinet, a power cable for interconnection with three-phase 60-Hz power, and a high voltage (17 kV) cable for interconnecting the transmitter and power supply cabinets. Photographs of this system just prior to delivery are shown in Figure 10 and a waveguide-based diagram of the system is presented in Figure 11. A copy of the specification sheet and general operating instructions for the Varian Type VA 928A Klystron Amplifier is provided in the Appendix. It is the opinion of the authors that a 20-millisecond shutdown time for excessive klystron body current would be acceptable. This opinion is based primarily on the fact that magnet current was being monitored and was demonstrated to remove the beam voltage within the specified time.



Varian Type VA 928A Klystron Amplifier



Transmitter Front View

Transmitter Side View

Figure 10. Photographs of transmitter system.

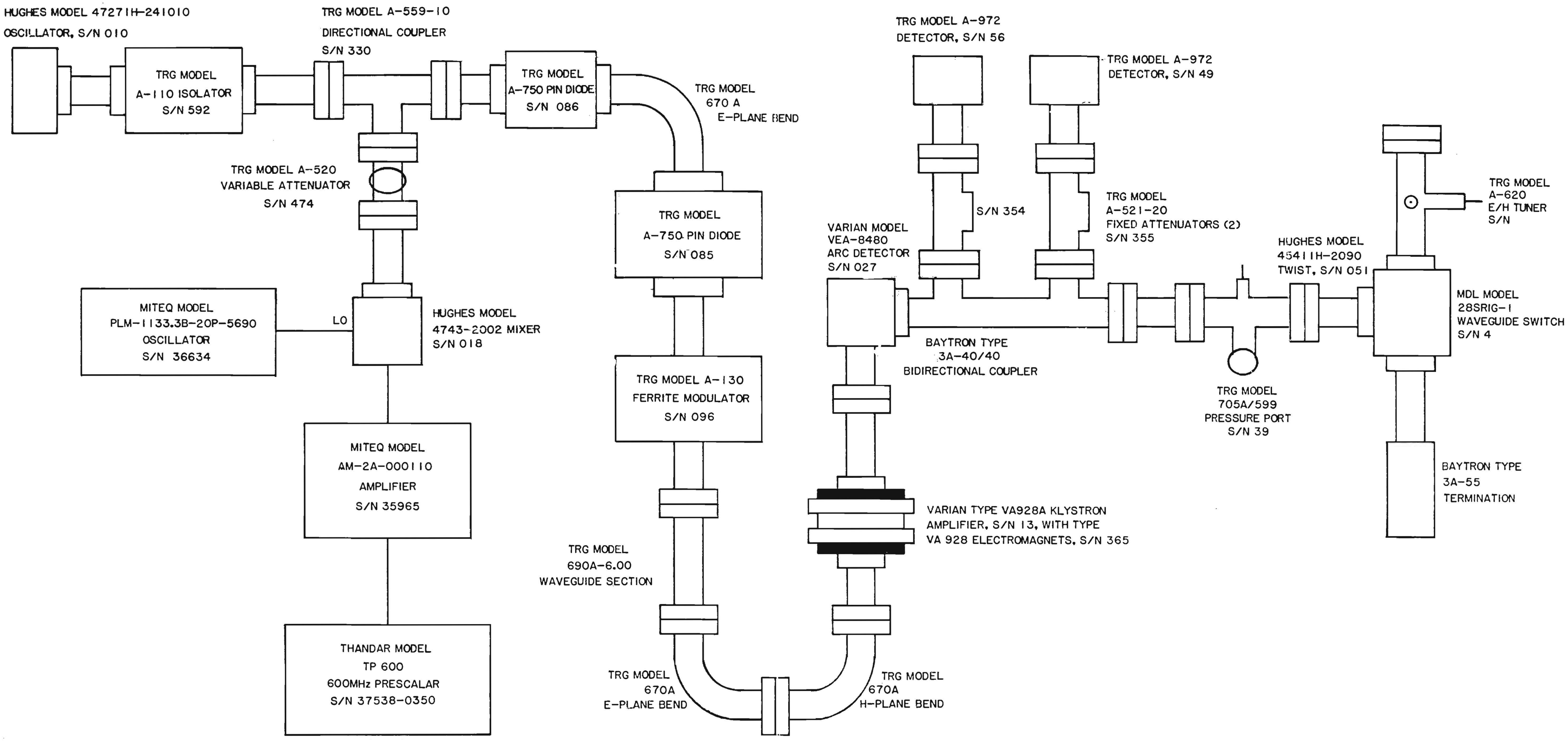


Figure 11. Waveguide based diagram of the final transmitter system design.

SECTION V

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APPENDIX

VA-928 A
cw Klystron Amplifier
Serial No. 13

QUALITY CONFORMANCE INSPECTION DATA FORM

ACCEPTANCE TESTS

TEST	TEST CONDITION	SPECIFICATION MIN	SPECIFICATION MAX	TUBE PERFORMANCE
COOLANT	Coll. Flow = 6.0 gpm	---	50 psi	45 psig
	Body Flow = 2.0 gpm	---	50 psi	33 psig
	Mag. Flow = .5 gpm	---	50 psi	5.5 psig
HEATER CURRENT	E_f = 6.3 volts	I_f: 2.0	3.0 amps	I_f 2.8
CATHODE CURRENT	E_f = 6.3 volts			
	E_b = 12.0 kV	I_b: ---	1.2 amps	I_b = 1.0 amps
	(without rf drive)			I_{by} = 3.8 ma
POWER OUTPUT	E_b = 11.0 kV	Po: 1	--- kW	SEE RF DATA BELOW
		E_b: ---	12 kV	
		Imag: ---	6 Adc	
		BW: 30	--- MHz (-3 db)	
		Pd: ---	10 mW	
		Igun Coil	10 Adc	

RF TEST PERFORMANCE	Imag Adc	Igc Adc	Δf MHz	Po kW	Iby ma	Pd mW
F_o = 35 GHz	4.4	4.4	56	1.0	4	1.7

APPROVED BY: Reid Isaksen Q A VA E 306

DATE: 7-23-82

TESTED WITH VARIAN
MAGNET VA 1928
S/N 365

6/3/82

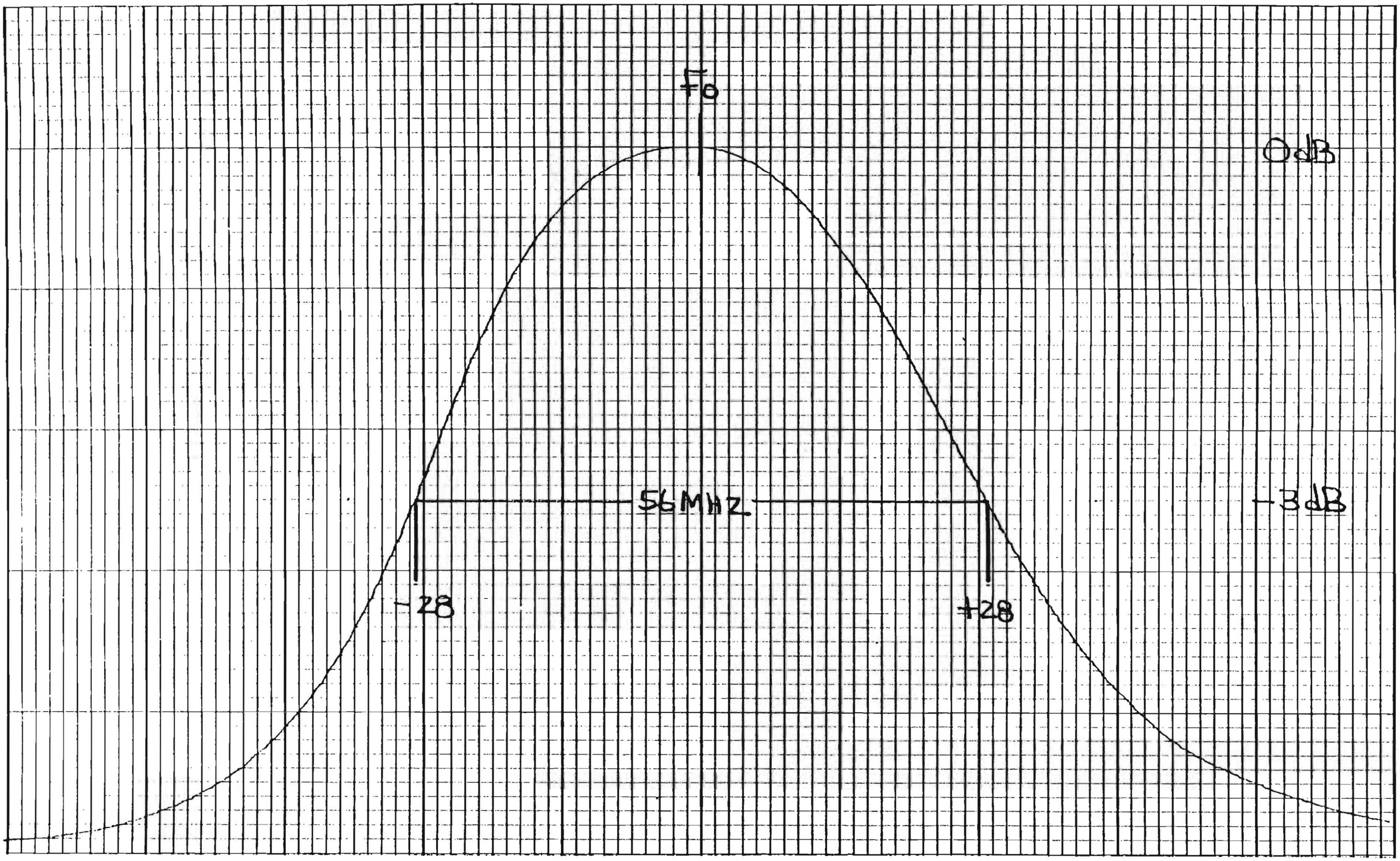
TEST DATA SHEET

VA928 A SERIAL NO. 13 CHANNEL 35000 MHz DATE: 7-23-82 BY: REID

FILAMENT VOLTAGE 6.3 V
FILAMENT CURRENT 2.8 A
MAGNET CURRENT 4.4 A

BEAM VOLTAGE 11.0 kV
BEAM CURRENT .880 A
BODY CURRENT 4 mA

POWER OUTPUT 1.0 kW
DRIVE POWER 1.7 mW
GAIN 57.7 dB



FREQUENCY MHz

AMENDED OPERATING INSTRUCTIONS

The VA-928A, S/N 13 has several modifications to the existing Operating Instructions.

1. The klystron utilizes a built-in gun coil to supplement the main VA-1928 Electromagnet. The leads for this coil are attached to the input waveguide run.

   The VA-1928 Electromagnet should be connected according to the polarity shown on the electromagnet's frame. The gun coil should be connected as shown on its polarity tags. If desired, the gun coil may be connected in series with the electromagnet.

   With proper polarity on both coils, body current should not exceed 5 ma for beam voltages up to 11 kilovolts.

2. It is recommended that the resistances of both electromagnet coils and the gun coil be recorded upon installation of the system.

3. The heater voltage should be 6.3 volts D.C. The common heater-cathode lead (white) should be connected to the positive side of the heater supply.

4. To ensure stable operation, the drive powers given on the data package should not be exceeded.

S.E. Allen
B. Roach
26 July 1982

CW KLYSTRON AMPLIFIER

VA-928A

INTRODUCTION

These Operating Instructions provide basic information for installing and operating the VA-928A klystron amplifier. Additional information is given in the Test Performance Sheet and the Technical Specification. The Technical Specification contains characteristics, operating values, and an outline drawing. The Test Performance Sheet, which is shipped with the tube, contains results of electrical tests at specific frequencies for the individual tube. Requests for copies of this publication or additional information should be addressed to:

Manager, Tube Sales
Varian Associates, Inc.
Palo Alto Microwave Tube Division
611 Hansen Way
Palo Alto, California 94303
(415) 493-4000
TWX: 910-373-1731

For more detailed tube operating procedures in specific equipments, consult the applicable equipment manuals and equipment performance standards. In case of conflict, equipment manuals and performance standards shall govern, except for the absolute maximum ratings on the tube. Additional information may be obtained from the equipment manufacturer. Some operational details specified by the equipment manufacturer may vary from those given herein.

WARNING

SERIOUS HAZARDS EXIST IN THE OPERATION OF MICROWAVE TUBES. BEFORE ATTEMPTING ANY TUBE OPERATION, CAREFULLY READ AND UNDERSTAND THE "OPERATING HAZARDS" SECTION FOLLOWING THESE OPERATING INSTRUCTIONS, AS WELL AS THESE INSTALLATION AND OPERATING INSTRUCTIONS. A COPY OF "OPERATING HAZARDS" IS ALSO SHIPPED WITH EACH TUBE.

VA-928A — SPECIFIC HAZARDS

Varian as a component supplier can assume no responsibility for any damage or injury resulting from operation of Varian microwave tubes. The transmitter connected with this tube must be designed to protect personnel against all operating hazards. Installation and operating precautions should be observed, and ratings given in the Test Performance Sheet must not be exceeded.

High Voltage — Voltages required for operation of this tube are extremely dangerous to life. The equipment must be designed so that the operator cannot come into contact with high voltages. High voltage circuits and terminals must be enclosed, and interlocking switch circuits must be maintained so that they open the primary circuits of the power supply and discharge high voltage condensors when access is required

WARNING

DO NOT HI-POT

Microwave Radiation — Precautions should be taken to prevent exposure of personnel to the strong microwave fields generated by this tube. Exposure to rf radiation generated by this tube during operation may cause serious bodily injury, possibly resulting in blindness or death. Cardiac pacemakers may be affected. Microwave radiation due to leakage at the waveguide flange should be prevented by making tight rf input and output connections. For this reason, rf energy must be contained by waveguides and shielding. Never operate this tube without a microwave energy absorbing load or antenna attached. Never look into an open waveguide or antenna while the tube is energized.

If voltages are to be applied when the tube is not connected into a waveguide system, the rf input and the output flange should be closed tightly with shielded terminations.

X-Radiation — This tube may produce dangerous x-radiation during operation. Serious exposure can occur without personnel being aware, and serious personal injury or death may occur as a consequence at some later date.

The shielding provided by the transmitter manufacturer must be in place whenever high voltage is required.

Beryllium Oxide — This tube may utilize a beryllium oxide output window ceramic. The dust and fumes from beryllium oxide are highly toxic and can cause serious injury or death.

Also, a beryllium ceramic insulator is contained within the electron gun section of this tube. Do not alter, disassemble, grind, lap, fire, chemically clean, or perform any other operation which could possibly generate lethal dust or fumes on this part of the tube.

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Printed in U.S.A.

Implosion Hazard — Ceramic windows in microwave tubes can shatter on impact or crack in use, possibly resulting in injury from flying particles or from beryllium oxide dust or fumes.

Elevated Temperature — Portions of this tube may attain elevated temperatures (notably the collector and gun coolers) during operation. Avoid physical contact for a sufficient period after operation is terminated to permit adequate cooling.

Corrosive and Poisonous Compounds — Some dielectric gases may be used in the external waveguide portion of microwave tubes, which may, upon microwave or high-voltage breakdown, combine with impurities to form highly toxic and corrosive compounds.

These hazards are specifically described in the Operating Hazards Section immediately following these operating instructions. Equipment using these tubes must be designed to minimize risk to personnel from these hazards. Equipment manufacturers and users must develop and institute procedures suitable for the particular equipment and specific use to guard against all hazards which are not eliminated through equipment design.

WARNING

DO NOT ATTEMPT TO OPERATE THIS TUBE UNTIL IT HAS BEEN DETERMINED THAT ALL PRECAUTIONS HAVE BEEN TAKEN TO PROTECT PERSONNEL FROM ALL HAZARDS. PROTECTIVE DEVICES SUCH AS SHIELDS AND INTERLOCKING SWITCH CIRCUITS MUST BE IN OPERATION. REREAD AND COMPLY WITH ALL PRECAUTIONS AND PROCEDURES SPECIFIED IN THE "OPERATING HAZARDS" SECTION.

PROTECTIVE MEASURES

This tube must be used in equipment which provides automatic protection as described below. In addition, installation and operating precautions must be observed and ratings shown within the Test Performance Sheet must not be exceeded. Failure to comply fully with the foregoing may result in tube failure, damage or decreased operating life. Any tube damage or failure resulting from failure to comply with those requirements or which, in Varian's opinion, could have been avoided by compliance with these requirements will void the Varian warranty.

Heater Voltage — Heater voltage must be applied for at least 10 minutes before applying beam voltage. Heater surge current must be limited to 5 amperes.

The heater voltage supply may be either ac or dc. When a dc heater supply is used, the positive side of the supply should be connected to the WHITE lead.

Beam Voltage — Protective circuitry must be provided to limit the maximum beam voltage. Interlocks must prevent the application of beam voltage before the heater has warmed up, coolants are flowing, and the focusing-coil currents are applied. Beam voltage must be removed within 30 microseconds if the focusing field fails.

Beam Current — Protective circuitry must be provided to remove the beam voltage within 30 microseconds if the beam current exceeds 120% of nameplate beam current.

Body Current — Protective circuitry must be provided to remove the beam voltage within 30 microseconds if the tube body current exceeds 120% nameplate value.Thi nameplate value may fall in the range of 3-10 milliamperes.

Focusing-Field Protection — If the focusing field fails, causing a large portion of the beam energy to be dissipated in a small area, tube failure can result within a few milliseconds, therefore, beam voltage must be removed within 30 microseconds in the event of focusing field failure. Protective circuitry in the focusing coil circuit must remove beam voltage if the current falls 0.5 ampere below the magnet current stamped on the nameplate. When a constant current supply is in use, a 10% rise in applied electromagnetic voltage over the steady-state value must trigger removal of beam voltage.

Liquid Cooling — The tube must be used with a properly designed and operated cooling system. Scaling and corrosion must be minimized to realize optimum tube performance and life. Metals used in the cooling system should be close to copper in the galvanic series. Zinc bearing alloys should be avoided.

If the coolant is to be subjected to sub-freezing environments, steps must be taken to prevent its freezing in the tube. The use of coolant heaters is recommended under such conditions. Contaminants such as soaps, foaming detergents and water soluble oils as well as particulate matters must be kept to a minimum. Exposure of the coolant to air should be minimized. A coolant purification loop and/or coolant filtering may be desirable adjuncts. Freedom from contamination in the cooling system is an important consideration in obtaining maximum life. Only pure fluids should be used. The system should be drained, cleaned, and refilled with fresh fluids at least annually. All possible sources of oils or greases should be eliminated.

The tube body, collector and magnet inlet coolant temperatures must not exceed 40°C. Interlocks must remove the beam and magnet voltages if the inlet coolant temperature exceeds this limit and/or the flow is inadequate.

Protective flow rate interlock circuits should also be provided. The maximum static pressure must not exceed 125 psia in the tube body, in the electromagnet, or in the collector system.

The coolant should never be permitted to freeze in the tube. The permitted inlet coolant temperature range without damage is from 10 °C to 40 °C. The body coolant temperature range for specified performance is 10 °C to 40 °C.

The following information is based on liquid cooling in a system at atmospheric pressure and sea level. Interlocks should be provided to remove the beam voltage if the coolant flow falls below any of the following values (numbers refer to gallons per minute):

	Water
Collector	6
Tube Body	2
Electromagnet	0.5

With different coolants or conditions, other values of minimum flow or maximum temperature can be used, but the Varian Tube Sales Department should be consulted for recommendations.

Reflected Power — The VA-928A must be operated into a matched load for optimum performance. The klystron should not be used with loads which produce reflected power greater than 12 watts. This is approximately equivalent to a VSWR of 1.25:1 at 1 kilowatt output. Higher values of reflected power may damage the output window. Protection should be provided between the tube and any transmission line components. A sample of reflected power obtained from a directional coupler should operate a circuit which will remove rf drive from the tube within 10 microseconds if the reflected power exceeds 12 watts. It is not necessary to remove beam voltage. Operation of the protective circuit should be checked regularly.

The input drive line and output waveguide VSWRs must be checked before tubes are initially installed into the system. The rf driver should be protected against reflected power by inserting an isolator between it and the tube. The isolator should give sufficient isolation to protect the rf driver.

Waveguide Pressurization — To prevent arcing in the output waveguide, it is recommended that it be pressurized between 20 and 30 psia using dry nitrogen or dry air. A pressure activated switch must remove beam voltage from the tube when the waveguide pressure drops below 18 psia. See Operating Hazards Sections.

Arcs (In the Tube) — The power supply must have sufficient impedance in series with the klystron to prevent arc damage. The power supply must also have a protective device which will remove the beam voltage within 30 microseconds in the event of an arc in the tube.

RF Leakage — Under certain conditions, regeneration or oscillation can occur if rf energy from the output line or radiation from antenna reaches the input by way of faulty rf connectors, leaky cable, or inadequate shielding. External leakage will be prevented by making good rf input and output connections. RF radiation is hazardous.

HANDLING

Heavy Weight — Do not attempt to lift the VA-928A klystron or the VA-1928 electromagmet without a hoist and appropriate lifting devices.

Unpacking — The tube is shipped in an approved package which will protect the tube from handling abuse. If the outer container shows evidence of being dropped or is punctured, open the package and inspect the tube for damage.

Inspection — Inspect the tube when it is removed from the container. If any obvious defects appear, a report should be sent to the factory at once. Any damage during shipment should be reported to the carrier.

INSTALLATION

Tube Handling — Sufficient care in handling the tube must be used to avoid bending any of the metal parts, or breaking any of the ceramic insulators, or the output waveguide window. More specifically, do not put any unsupported weight on the end of the output waveguide. Also, do not lift the tube by the collector, the output waveguide, the cathode assembly, or the lead wires. It is recommended that the tube be handled by the magnet side plates.

Tube Inspection — Check the rf output window. No foreign particles of any kind should be between the copper flange and the ceramic window. The ceramic window must be perfectly clean. If necessary, clean the window using acetone and a camel's hair brush.

Mounting

Drawing D128198 VA-928A and Magnet

CAUTION

USE MAGNET FRAME AS A HAND-HOLD FOR LIFTING TUBE. DO NOT HANDLE THE TUBE BY THE WAVEGUIDE FLANGES.

1. Mount the VA-1928 electromagnet, with its major axis vertical, using the four mounting holes at the bottom of the magnet structure.
2. Lift off the upper magnet coil by removing the four 5/16-24 socket head cap screws holding it to the magnetic frame. These screws are located on the two side plates. The coil assembly is quite heavy and must be adequately supported when removing the screws.
3. Lift the klystron with one hand by gripping the cylindrical section of the collector as much on the body side of the ceramic collector seal as possible. Guide the tube into the electromagnet with the other hand placed lightly around the silicone rubber insulator at the top of the cathode seal next to the tube body.

CAUTION

NEVER LIFT THE TUBE BY THE CATHODE LEADS OR MOLDING, INPUT OR OUTPUT FLANGES, THE INSULATED SECTION OF THE COLLECTOR, OR THE COOLANT FITTINGS ON THE COLLECTOR OR BODY. THE KLYSTRON SHOULD BE SEATED IN THE LOWER MAGNET ASSEMBLY GUN END FIRST.

4. Connect the body coolant lines to the body coolant fittings. The fittings are 1/4" 37° flared tube fittings. Always use two wrenches to minimize the stresses transmitted to the body of the klystron from the coolant fittings.
5. Replace the upper magnet coil and check to be sure it is mated properly with the klystron. Use extreme care to prevent the electromagnet from contacting the collector.
6. Replace the four 5/16-24 screws to secure the upper magnet coil assembly to the magnet frame. Carefully connect the collector coolant lines to the 3/8" 37° flared tube fittings located at the end of the collector. The fittings are marked inlet and outlet. The coolant source must be connected to the fitting marked inlet. Two wrenches must be used when securing the coolant lines to the collector fittings to minimize the stresses applied to the collector.

The waveguide system must be carefully aligned to the tube so that when it is connected no stress will be placed on the tube waveguides. Also check that there are no electrical discontinuities at the flange faces when the screws are tightened.

It is always preferred to let the exact location of the tube be governed by the output waveguide flange. Refer to the Outline Drawing for the location of the mounting bracket and holes.

CAUTION

ERRORS IN ALIGNMENT CAN RESULT IN WINDOW FAILURE AND LOSS OF THE TUBE.

Coolant Connections — *Mating* coolant fittings for the coolant connectors on the tube and electromagnet are as follows:

Collector	Inlet Outlet	3/8", 37° Flared Tube
Body	Inlet Outlet	1/4", 37° Flared Tube
Electromagnet		1/8-27 NPT

The collector hoses should not apply stress to the collector, which is attached to the tube by a ceramic insulator. The hoses should be of insulating material to electrically isolate the collector from ground. Teflon-lined hoses are recommended to minimize coolant contamination.

1. Attach the body coolant hoses to the electromagnet. The lower body hose connects to the upper fitting on the lower coil. The upper body hose connects to the lower fitting on the upper coil.
2. Attach the coolant inlet to the lower fitting of the lower coil. The system should be designed to gravity drain from this inlet. Attach the coolant outlet to the upper fitting of the upper coil.

NOTE

Avoid stressing the tube during installation and removal of the coolant connections. Be sure that the quick connect fittings have been locked into place. Avoid spilling the coolant.

Electrical Connections — The most usual operating arrangement is with the tube body at ground potential. The heater is connected to the cathode internally to make sure the heater and cathode operate at the same dc potential, thereby minimizing noise. Connections to the heater and cathode are made by means of flying leads. The common heater-cathode lead is white, and the other heater lead is yellow.

If a dc heater supply is used to minimize heater hum, connect the common heater-cathode lead to the positive side of the heater supply. The heater supply should be insulated to withstand the full beam voltage.

1. Attach the white heater-cathode lead to the heater-cathode connection.
2. Attach the yellow heater lead to the heater supply.
3. Attach the collector connection to the stud provided on the SIDE of the collector shell near the top. DO NOT ground to the collector shield shell.
4. Attach the ground lead to the stud provided on the body.

OPERATION

WARNING

DO NOT ATTEMPT TO OPERATE THIS TUBE UNTIL IT HAS BEEN DETERMINED THAT ALL PRECAUTIONS HAVE BEEN TAKEN TO PROTECT PERSONNEL FROM ALL HAZARDS PROTECTIVE DEVICES SUCH AS SHIELDS AND INTERLOCKING SWITCH CIRCUITS MUST BE IN OPERATION. REREAD AND COMPLY WITH ALL PRECAUTIONS AND PROCEDURES SPECIFIED IN THE "OPERATING HAZARDS" SECTION.

Preliminary Check — Check the following conditions before applying voltages to the tube.

1. Heater and cathode leads are connected correctly.
2. Collector is connected to supply correctly.
3. Tube body and magnet are grounded.
4. Electromagnet connected correctly.
5. Gun coil connected correctly.
6. Arc-reflected power protective circuitry and all interlocks operating correctly.
7. Waveguide system connected to klystron output flange, pressure adjusted for proper operating value.
8. Input/waveguide connected, pressure adjusted for proper operating value.

NOTE

If certain pressurizing gases such as Freon and sulphur hexafluoride are used, special precautions must be taken as highly toxic and corrosive compounds may form upon electrical or microwave breakdown.

NOTE

If not connected into the system, the input and output flanges must be firmly attached to shielded waveguide terminations before beam voltage is applied.

9. Collector, body and electromagnet coolants are flowing/on. Check for leaks.
10. RF drive is at correct frequency.

WARNING

HIGH VOLTAGE — VOLTAGES REQUIRED FOR OPERATION OF THIS TUBE ARE EXTREMELY DANGEROUS TO LIFE; EQUIPMENT MUST BE DESIGNED WITH PROTECTIVE INTERLOCK CIRCUITS TO MAKE PHYSICAL CONTACT WITH THESE VOLTAGES IMPOSSIBLE. SEE OPERATING HAZARDS SECTION.

WARNING

X-RAYS — THIS TUBE MAY PRODUCE DANGEROUS X-RADIATION DURING OPERATION. THE EQUIPMENT IN WHICH THIS TUBE IS USED MUST PROVIDE ADEQUATE X-RAY SHIELDING AROUND THE TUBE, INCLUDING THE GUN REGION, FOR THE PROTECTION OF PERSONNEL. BOTH TUBE AND SYSTEM MUST NEVER BE ALTERED IN ANY WAY WHICH MIGHT DECREASE SHIELDING. RADIATION LEVELS SHOULD BE CHECKED PERIODICALLY TO ENSURE SAFE OPERATING CONDITIONS AND COMPLIANCE WITH STATUTORY AND REGULATORY REQUIREMENTS. NEVER APPLY BEAM VOLTAGES WITHOUT HAVING X-RAY SHIELDING IN PLACE. X-RAYS ARE DEADLY AND CANNOT BE DETECTED EXCEPT WITH SPECIAL EQUIPMENT. SERIOUS EXPOSURE MAY OCCUR WITHOUT PERSONNEL BEING AWARE. SERIOUS PERSONAL INJURY OR DEATH MAY OCCUR AT SOME LATER DATE AS A CONSEQUENCE.

WARNING

RF RADIATION — THIS TUBE IS DESIGNED TO PRODUCE HIGH ENERGY RF RADIATION. EVEN LOW LEVELS OF RF RADIATION CAN BE HAZARDOUS TO HUMAN HEALTH. PRECAUTIONS MUST BE TAKEN TO PREVENT EXPOSURE OF PERSONNEL TO THE STRONG RF FIELDS GENERATED BY THIS TUBE. RF RADIATION DUE TO LEAKAGE AT THE WAVEGUIDE FLANGE SHOULD BE PREVENTED BY MAKING GOOD RF OUTPUT CONNECTIONS. NEVER OPERATE THIS TUBE WITHOUT HAVING AN APPROPRIATE ENERGY ABSORBING LOAD ATTACHED. NEVER LOOK INTO AN OPEN WAVEGUIDE OR ANTENNA WHILE THIS TUBE IS ENERGIZED.

Application of Voltages — Recommended operating voltages and currents are shown on the Test Performance Sheet which accompanies each tube.

1. Apply reduced heater voltage if possible. Increase the voltage slowly to the value specified on the Test Performance Sheet. Surge current should never exceed 5 amperes. Allow at least 10 minutes for the cathode to warm up. The heater current should be approximately the value specified on the Test Performance Sheet.

2. Turn on the electromagnet power supply and set the focusing current to the value shown on the Test Performance Sheet. Set the gun coil current to the value shown on the Test Performance Sheet.

3. Apply reduced beam voltage (about 1/2 normal) and observe the operating conditions. As soon as the beam current has stabilized, gradually increase the beam voltage to the full operating value.

4. Apply nameplate rf drive and check power output and body current.

5. Trim magnet current for minimum body current.

Removal of Voltages

CAUTION

FOR NORMAL SHUTDOWN AND/OR IN THE EVENT OF A POWER INTERRUPTION, THE POWER SUPPLY DESIGN MUST INSURE THAT ADEQUATE ELECTROMAGNET CURRENT IS MAINTAINED (APPROXIMATELY 50 WATTS MINIMUM OF MAGNET POWER FOR EACH kV OF BEAM VOLTAGE) UNTIL BEAM VOLTAGE IS SUBSTANTIALLY ZERO. DAMAGE TO THE TUBE MAY RESULT IF THESE PRECAUTIONS ARE NOT TAKEN.

It is preferable to remove beam voltage first. Then remove heater voltage, RF drive, and the magnet.

If you have tube trouble ... please check the following things before "giving up".

1. Recheck all protection circuits for proper operation.
2. Recheck all operating voltages and currents to verify their correspondence with those recorded on that serial-numbered tube's Test Performance Sheet (supplied with the tube in its packing case). If a tube has gone "down to air" its heater current will be about 25% higher than the value recorded on the Test Performance Sheet at its specified heater voltage.
3. Check operation at reduced beam duty cycle. (Sometimes tubes require slow "seasoning" after an extended storage period before full power operation can be performed stably.)

WARNING

DO NOT HI-POT WITHOUT SPECIFIC INSTRUCTIONS FROM THE MANUFACTURER.

WARRANTY CLAIM FORM

Before any product is returned for repair and/or adjustment, written authorization from Varian for the return and instructions as to how and where the product should be shipped must be obtained. The product type and serial numbers and a full description of the circumstances giving rise to the warranty claim should be included. Such information will help establish the cause of failure and expedite adjustment or repair. For this purpose, a Warranty Claim Form is shipped with each product.

TRANSPORTATION AND STORAGE

Use the original packing case for both transporting and storing the tube. The tube should be stored in the packing case when not in service. Before placing in the packing case, drain the tube and blow out the remaining coolant with warm, dry air.

The protective covers for the input and output flange should be in place whenever the tube is not installed. The tube should not be exposed to an icing or salt spray environment during storage. Tubes should be placed at least 12 inches apart to keep their magnetic fields from affecting each other.

SUMMARY OF SPECIFICATIONS FOR OPERATING INSTRUCTIONS

Min warm-up time of heater before applying beam voltage	10	min
Max heater surge current	5	A
Max inlet coolant temperature	40	°C
Max static pressure in coolant system	125	psia
Max reflected power	12	watts
Max VSWR at 1.0 kilowatt output	1.25:1	
Min pressure in output waveguide (recommended)	20	psia
Input/Output waveguide flange - mate with UG-599		
Coolant fittings:		
Collector - Inlet/Outlet	3/8"-37°	Flared Tube
Body - Inlet/Outlet	1/4-37°	Flared Tube
Electromagnet - Inlet/Outlet	1/8-27 NPT	

Min: Coolant flow values in gallons per minute:

	Water
Collector	6
Tube Body	2
Electromagnet	0.5

OPERATING HAZARDS

READ THIS SHEET AND TAKE ALL SAFETY PRECAUTIONS

PROPER USE AND SAFE OPERATING PRACTICES WITH RESPECT TO MICROWAVE TUBES ARE THE RESPONSIBILITY OF EQUIPMENT MANUFACTURERS AND USERS OF SUCH TUBES. VARIAN PROVIDES INFORMATION ON ITS PRODUCTS AND ASSOCIATED HAZARDS, BUT IT ASSUMES NO RESPONSIBILITY FOR AFTER-SALE OPERATING AND SAFETY PRACTICES. LIMITED LIFE AND RANDOM FAILURES ARE INHERENT CHARACTERISTICS OF ELECTRON TUBES. TAKE APPROPRIATE ACTION THROUGH REDUNDANCY OR OTHER SAFEGUARDS TO PROTECT PERSONNEL AND PROPERTY FROM THE CONSEQUENCES OF TUBE FAILURE.

ALL PERSONS WHO WORK WITH OR ARE EXPOSED TO MICROWAVE TUBES OR EQUIPMENT WHICH UTILIZES SUCH TUBES MUST TAKE PRECAUTIONS TO PROTECT THEMSELVES AGAINST POSSIBLE SERIOUS BODILY INJURY. DO NOT BE CARELESS AROUND SUCH PRODUCTS.

OPERATING INSTRUCTIONS

This sheet, the Test Performance Sheet and the Operating Instructions can help you to operate this tube safely and efficiently. READ THEM. The Test Performance Sheet is a record of individual product test conditions and test results at the factory. Special operating considerations and precautions will be found in the Operating Instructions. Uninformed or careless operation of this tube can result in poor performance, damage to the tube or other property, serious bodily injury and, possibly death.

Address written questions regarding tube operation to the Manager, Tube Sales, at the address at the bottom of this sheet.

WARNING – SERIOUS HAZARDS EXIST IN THE OPERATION OF MICROWAVE TUBES

The operation of microwave tubes involves one or more of the following hazards, any one of which, in the absence of safe operating practices and precautions, could result in serious harm to personnel:

a. HIGH VOLTAGE – Normal operating voltages can be deadly.

b. RF RADIATION – Exposure to rf radiation may cause serious bodily injury possibly resulting in blindness or death. **Cardiac pacemakers may be affected.**

c. X-RAY RADIATION – High voltage tubes can produce dangerous, possibly fatal, x-rays.

d. BERYLLIUM OXIDE POISONING – The dust or fumes from beryllium oxide (BeO) ceramics used in microwave tubes are highly toxic and can cause serious injury or death.

e. CORROSIVE AND POISONOUS COMPOUNDS – If a dielectric gas is used in the external waveguide or around the high voltage bushing portions of microwave tubes, highly toxic or corrosive compounds may be produced by either RF voltage breakdown or high voltage DC breakdown.

f. IMPLOSION HAZARD – Ceramic windows in microwave tubes can shatter on impact or crack in use, possibly resulting in injury from flying particles or from beryllium oxide (BeO) dust or fumes.

g. HOT COOLANT AND/OR STEAM – The electron collector and water used to cool it reach scalding temperatures. Touching or rupture of the cooling system can cause serious burns.

h. HOT SURFACES – Surfaces of air-cooled collectors and other parts of tubes can reach temperatures of several hundred degrees centigrade and cause serious burns if touched.

Additional specific information about microwave tube hazards:

HIGH VOLTAGE

Many microwave tubes operate at voltages high enough to kill through electrical shock. Design equipment utilizing these tubes to prevent personnel contact with high voltages. Securely attach prominent hazard warnings. Personnel should always break the primary circuits of the power supply and discharge high voltage condensers when direct access to the tube is required.

RADIO FREQUENCY RADIATION

EXPOSURE OF PERSONNEL TO RF RADIATION SHOULD BE MINIMIZED. PERSONNEL SHOULD NOT BE PERMITTED IN THE VICINITY OF OPEN ENERGIZED WAVEGUIDES OR ENERGIZED ANTENNAS. It is generally accepted that exposure to "high levels" of rf radiation can result in severe bodily injury including blindness. **Cardiac pacemakers may be affected.**

The effect of prolonged exposure to "low-level" rf radiation continues to be a subject of investigation and controversy. While there continues to be support for lower limits, it is generally agreed among official standard-setting groups in the U.S. that prolonged exposure of personnel to rf radiation at frequencies of 10 MHz – 100 GHz should be limited to average power densities of ten milliwatts per square centimeter (10 mW/cm^2) or lower, using any possible one tenth of an hour (.1 hour) as the averaging period. It is also generally agreed that exposure should be reduced in working areas where temperatures are above normal. The 10 mW/cm^2 average level has been adopted by several U.S. Government agencies including the Occupational Safety and Health Administration (OSHA) as the standard or protection guide for employee work places.

ALL INPUT AND OUTPUT RF CONNECTIONS, WAVEGUIDES, FLANGES AND GASKETS MUST BE RF LEAKPROOF. NEVER OPERATE A MICROWAVE TUBE WITHOUT A PROPERLY MATCHED RF ENERGY ABSORBING LOAD ATTACHED. NEVER LOOK INTO OR EXPOSE ANY PART OF THE BODY TO AN ANTENNA OR OPEN WAVEGUIDE WHILE THE TUBE IS ENERGIZED. MONITOR THE TUBE AND RF SYSTEM FOR RF RADIATION LEAKAGE AT REGULAR INTERVALS AND AFTER SERVICING.

X-RAY RADIATION

As voltages increase beyond 15 kilovolts metal-body tubes are capable of producing progressively more dangerous X-ray radiation. Provide adequate X-ray shielding on all sides of these tubes, particularly the cathode and collector ends, as well as the modulator and pulse transformer tanks. Check X-ray levels. NEVER OPERATE HIGH VOLTAGE TUBES WITHOUT ADEQUATE X-RAY SHIELDING IN PLACE. MONITOR THE TUBE AFTER SERVICING AND AT REGULAR INTERVALS FOR POSSIBLE CHANGES IN X-RAY LEVELS DUE TO AGING.

varian/palo alto microwave tube division/611 hansen way/palo alto/california/94303

DANGER – BERYLLIUM OXIDE CERAMICS (BeO) – AVOID BREATHING DUST OR FUMES

Some microwave tubes contain beryllium oxide (BeO) ceramics; usually the output waveguide window or around the cathode. Do not perform any operations on BeO ceramics which produce dust or fumes; for example, grinding, grit blasting, and acid cleaning. BERYLLIUM OXIDE DUST AND FUMES ARE HIGHLY TOXIC AND BREATHING THEM CAN RESULT IN SERIOUS PERSONAL INJURY OR DEATH. If a broken window is suspected, carefully remove the tube from its waveguide and seal the output flange of the tube with tape. Because BeO warning labels may be obliterated or removed, we urge you to contact Varian before performing any work on ceramics in any Varian microwave tube. Some tubes have BeO internal to the vacuum envelope.

Take precautions to protect personnel working in the disposal or salvage of tubes containing BeO. All such personnel should be made aware of the deadly hazards involved and the necessity for great care and attention to safety precautions. Varian will dispose of tubes without charge provided they are returned to Varian freight prepaid, with a written request for disposal by Varian.

CORROSIVE AND POISONOUS COMPOUNDS

External output waveguides and cathode high voltage bushings of microwave tubes are sometimes operated in systems that use a dielectric gas to impede microwave or high voltage breakdown. If breakdown does occur, the gas may decompose and combine with impurities, such as air or water vapor, to form highly toxic and corrosive compounds. Examples are Freon gas which may form LETHAL PHOSGENE, and sulfur hexafluoride (SF_6) gas which may form highly toxic and corrosive sulfur or fluorine compounds such as BERYLLIUM FLUORIDE. When breakdown does occur in the presence of these gases, VENTILATE THE AREA TO OUTSIDE AIR, AVOID BREATHING ANY FUMES OR TOUCHING ANY LIQUIDS WHICH DEVELOP, TAKE PRECAUTIONS APPROPRIATE FOR BERYLLIUM COMPOUNDS AND FOR OTHER HIGHLY TOXIC AND CORROSIVE SUBSTANCES, before permitting personnel to perform any work on or near the tube. If a coolant other than pure water is utilized follow the precautions supplied by the coolant manufacturer.

IMPLOSION HAZARD

Due to the internal vacuum in microwave tubes the glass or ceramic output window can shatter inward (implode) if struck with a hard object or subjected to mechanical shock. Flying debris could result in bodily injury, including cuts and puncture wounds and, if made of BERYLLIUM OXIDE ceramic, produce highly toxic dust or fumes. DO NOT BREATHE SUCH DUST OR FUMES.

HOT COOLANT AND/OR STEAM

EXTREME HEAT occurs in the electron collector portion of microwave tubes during operation. *Coolant* channels used for cooling also reach high temperatures (as high as boiling, 100°C or above), and the hot *coolant* is under pressure (typically as high as 100 psi). *Some collectors are cooled by boiling the coolant and forming steam.*

A rupture of the *coolant* channel or *the coolant* or *steam line* or other contact with hot portions of this tube could scald or burn. Carefully check that all fittings and connections are secure and monitor backpressure for changes in cooling system performance. Replace any defective fittings and tighten any loose fittings or connections. If backpressure is increasing above normal operating values shut the system down and clear the restriction.

HOT SURFACES

The electron collector portion of microwave tubes is often air-cooled or conduction-cooled. The air-cooled external surface normally operates at a high temperature (typically 200° to 300°C). Other portions of the tube may also reach high temperatures, especially the cathode insulator and the cathode/heater surfaces. All hot surfaces may remain hot for an extended time after the tube is shut off. To prevent serious burns, take care to prevent and avoid any bodily contact with these surfaces both during and for a reasonable cool-down period after tube operation.

varian
611 hansen way
palo alto, california

VA-928A
EO 10-59797
July 20,1972

SPECIFICATION

TYPE VA-928A KLYSTRON AMPLIFIER

Description: Series of CW Klystron Amplifiers, 1000 watts, 30 to 36 GHz, Six Integral Cavities, Electromagnet Focusing, Waveguide Input and Output, Liquid Cooling.

ABSOLUTE RATINGS: Notes 1 & 2

Parameter:	Ef	If(surge)	Eb	Ik	Collector Dissipation
Unit:	V	A	kVdc	Adc	kW
Maximum:	6.0	5	12	1.2	14
Minimum:	---	---	---	---	---
	Note 3	Note 4			

			Coolant Flow (Water)		
Parameter:	tk	Load	Collector	Body	Magnet
Unit:	minutes	VSWR	gpm	gpm	gpm
Maximum:	---	1.25:1	---	---	---
Minimum:	10	---	6 Note 5	2	0.5

Test Cond:	Ef	Eb	Load VSWR	tk	Collector Water Flow
	V	kVdc		minutes	gpm
	5.5	12.0	1.1:1(max)	10	6 Note 5

<u>Mounting Position:</u> Any

<u>Cooling:</u> Liquid; Note 5

<u>Focusing:</u> VA-1928 Electromagnet 0/L ED15816D

<u>Weight:</u> 80 lb approximate (including electromagnet)

<u>RF Connectors:</u> Mate with UG-599/U, or equivalent

GENERAL

Ref.	Test	Conditions	Min.	Max.
(3.6.4)	Marking	Per Contract		
4.8.5	Holding Period	t = 168 hours		

QUALITY CONFORMANCE INSPECTION, PART I

Ref.	Test	Conditions		Min.	Max.	
[D-30(b)(1)]	Dimensions	Per Outline Drawing, Page 3				
1301	Heater Current		If:	2.0	3.0	A
1256	Cathode Current		Ik:	0.9	1.2	Adc
---	Power Output	Pd = 10 mW Fo = Note 6	Po:	1000	---	W
---	Bandwidth (-3 dB)	Power Output Note 7	ΔF:	30	---	MHz

QUALITY CONFORMANCE INSPECTION, PART 3

Ref.	Test	Conditions		Min.	Max.	
(4.6.6)	Service Life Guarantee	Per Contract				
(4.6.2)	Service Life End Point	Power Output	Po:	800	---	W

VSWR ? 1.25 : 1

VA-928A
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Reference numbers not enclosed in parentheses refer to paragraphs in "MIL-STD-1311A, Test Methods for Electron Tubes". References shown in parentheses refer to paragraphs in "MIL-E-1G, Military Specification for Electron Tubes". Only those paragraphs of MIL-STD-1311A and MIL-E-1G referenced in this specification shall apply.

Note 1: The absolute ratings are values which are not to be exceeded under any service conditions. These ratings are limiting values beyond which the serviceability of any individual tube may be impaired. In order not to exceed absolute ratings, the designer has the responsibility of determining an average design value for each rating relative to the absolute value of that rating by a safety factor so that the absolute values will never be exceeded under any usual conditions of supply-voltage variation, load variation, or manufacturing variations in the equipment itself. It does not necessarily follow that combinations of absolute maximum ratings can be attained simultaneously.

Note 2: All voltages except the heater voltage are referenced to the cathode, except as specified otherwise.

Note 3: The positive side of the heater supply must be connected to the heater-cathode terminal.

Note 4: Heater voltage must be applied gradually or else there must be sufficient reactance in the heater supply circuit to limit the surge current to the specified value.

Note 5: The maximum coolant pressure drop is 50 psi.

Note 6: The tube is factory tuned to any center frequency between 30 and 36 GHz.

Note 7: Bandwidth is defined as the difference in frequency (ΔF) between the half-power points. With the tube operating at optimum output power and the drive power held constant, the drive frequency shall be varied both upward and downward to reduce output power to half its original value in each case.

Waveguide at body potential
~100 [illegible]
[illegible]

Electromagnet current [illegible] 1% [illegible]

OPERATING HAZARDS

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PROPER USE AND SAFE OPERATING PRACTICES WITH RESPECT TO MICROWAVE TUBES ARE THE RESPONSIBILITY OF EQUIPMENT MANUFACTURERS AND USERS OF SUCH TUBES. VARIAN PROVIDES INFORMATION ON ITS PRODUCTS AND ASSOCIATED HAZARDS, BUT IT ASSUMES NO RESPONSIBILITY FOR AFTER-SALE OPERATING AND SAFETY PRACTICES. LIMITED LIFE AND RANDOM FAILURES ARE INHERENT CHARACTERISTICS OF ELECTRON TUBES. TAKE APPROPRIATE ACTION THROUGH REDUNDANCY OR OTHER SAFEGUARDS TO PROTECT PERSONNEL AND PROPERTY FROM THE CONSEQUENCES OF TUBE FAILURE.

ALL PERSONS WHO WORK WITH OR ARE EXPOSED TO MICROWAVE TUBES OR EQUIPMENT WHICH UTILIZES SUCH TUBES MUST TAKE PRECAUTIONS TO PROTECT THEMSELVES AGAINST POSSIBLE SERIOUS BODILY INJURY. DO NOT BE CARELESS AROUND SUCH PRODUCTS.

OPERATING INSTRUCTIONS

This sheet, the Test Performance Sheet and the Operating Instructions can help you to operate this tube safely and efficiently. READ THEM. The Test Performance Sheet is a record of individual product test conditions and test results at the factory. Special operating considerations and precautions will be found in the Operating Instructions. Uninformed or careless operation of this tube can result in poor performance, damage to the tube or other property, serious bodily injury and, possibly death.

Address written questions regarding tube operation to the Manager, Tube Sales, at the address at the bottom of this sheet.

WARNING – SERIOUS HAZARDS EXIST IN THE OPERATION OF MICROWAVE TUBES

The operation of microwave tubes involves one or more of the following hazards, any one of which, in the absence of safe operating practices and precautions, could result in serious harm to personnel:

a. HIGH VOLTAGE – Normal operating voltages can be deadly.

b. RF RADIATION – Exposure to rf radiation may cause serious bodily injury possibly resulting in blindness or death. **Cardiac pacemakers may be affected.**

c. X-RAY RADIATION – High voltage tubes can produce dangerous, possibly fatal, x-rays.

d. BERYLLIUM OXIDE POISONING – The dust or fumes from beryllium oxide (BeO) ceramics used in microwave tubes are highly toxic and can cause serious injury or death.

e. CORROSIVE AND POISONOUS COMPOUNDS – If a dielectric gas is used in the external waveguide or around the high voltage bushing portions of microwave tubes, highly toxic or corrosive compounds may be produced by either RF voltage breakdown or high voltage DC breakdown.

f. IMPLOSION HAZARD – Ceramic windows in microwave tubes can shatter on impact or crack in use, possibly resulting in injury from flying particles or from beryllium oxide (BeO) dust or fumes.

g. HOT COOLANT AND/OR STEAM – The electron collector and water used to cool it reach scalding temperatures. Touching or rupture of the cooling system can cause serious burns.

h. HOT SURFACES – Surfaces of air-cooled collectors and other parts of tubes can reach temperatures of several hundred degrees centigrade and cause serious burns if touched.

Additional specific information about microwave tube hazards:

HIGH VOLTAGE

Many microwave tubes operate at voltages high enough to kill through electrical shock. Design equipment utilizing these tubes to prevent personnel contact with high voltages. Securely attach prominent hazard warnings. Personnel should always break the primary circuits of the power supply and discharge high voltage condensers when direct access to the tube is required.

RADIO FREQUENCY RADIATION

EXPOSURE OF PERSONNEL TO RF RADIATION SHOULD BE MINIMIZED. PERSONNEL SHOULD NOT BE PERMITTED IN THE VICINITY OF OPEN ENERGIZED WAVEGUIDES OR ENERGIZED ANTENNAS. It is generally accepted that exposure to "high levels" of rf radiation can result in severe bodily injury including blindness. **Cardiac pacemakers may be affected.**

The effect of prolonged exposure to "low-level" rf radiation continues to be a subject of investigation and controversy. While there continues to be support for lower limits, it is generally agreed among official standard-setting groups in the U.S. that prolonged exposure of personnel to rf radiation at frequencies of 10 MHz – 100 GHz should be limited to average power densities of ten milliwatts per square centimeter (10 mW/cm^2) or lower, using any possible one tenth of an hour (.1 hour) as the averaging period. It is also generally agreed that exposure should be reduced in working areas where temperatures are above normal. The 10 mW/cm^2 average level has been adopted by several U.S. Government agencies including the Occupational Safety and Health Administration (OSHA) as the standard or protection guide for employee work places.

ALL INPUT AND OUTPUT RF CONNECTIONS, WAVEGUIDES, FLANGES AND GASKETS MUST BE RF LEAKPROOF. NEVER OPERATE A MICROWAVE TUBE WITHOUT A PROPERLY MATCHED RF ENERGY ABSORBING LOAD ATTACHED. NEVER LOOK INTO OR EXPOSE ANY PART OF THE BODY TO AN ANTENNA OR OPEN WAVEGUIDE WHILE THE TUBE IS ENERGIZED. MONITOR THE TUBE AND RF SYSTEM FOR RF RADIATION LEAKAGE AT REGULAR INTERVALS AND AFTER SERVICING.

X-RAY RADIATION

As voltages increase beyond 15 kilovolts metal-body tubes are capable of producing progressively more dangerous X-ray radiation. Provide adequate X-ray shielding on all sides of these tubes, particularly the cathode and collector ends, as well as the modulator and pulse transformer tanks. Check X-ray levels. NEVER OPERATE HIGH VOLTAGE TUBES WITHOUT ADEQUATE X-RAY SHIELDING IN PLACE. MONITOR THE TUBE AFTER SERVICING AND AT REGULAR INTERVALS FOR POSSIBLE CHANGES IN X-RAY LEVELS DUE TO AGING.

varian/palo alto microwave tube division/611 hansen way/palo alto/california/94303

DANGER — BERYLLIUM OXIDE CERAMICS (BeO) — AVOID BREATHING DUST OR FUMES

Some microwave tubes contain beryllium oxide (BeO) ceramics; usually the output waveguide window or around the cathode. Do not perform any operations on BeO ceramics which produce dust or fumes; for example, grinding, grit blasting, and acid cleaning. BERYLLIUM OXIDE DUST AND FUMES ARE HIGHLY TOXIC AND BREATHING THEM CAN RESULT IN SERIOUS PERSONAL INJURY OR DEATH. If a broken window is suspected, carefully remove the tube from its waveguide and seal the output flange of the tube with tape. Because BeO warning labels may be obliterated or removed, we urge you to contact Varian before performing any work on ceramics in any Varian microwave tube. Some tubes have BeO internal to the vacuum envelope.

Take precautions to protect personnel working in the disposal or salvage of tubes containing BeO. All such personnel should be made aware of the deadly hazards involved and the necessity for great care and attention to safety precautions. Varian will dispose of tubes without charge provided they are returned to Varian freight prepaid, with a written request for disposal by Varian.

CORROSIVE AND POISONOUS COMPOUNDS

External output waveguides and cathode high voltage bushings of microwave tubes are sometimes operated in systems that use a dielectric gas to impede microwave or high voltage breakdown. If breakdown does occur, the gas may decompose and combine with impurities, such as air or water vapor, to form highly toxic and corrosive compounds. Examples are Freon gas which may form LETHAL PHOSGENE, and sulfur hexafluoride (SF_6) gas which may form highly toxic and corrosive sulfur or fluorine compounds such as BERYLLIUM FLUORIDE. When breakdown does occur in the presence of these gases, VENTILATE THE AREA TO OUTSIDE AIR, AVOID BREATHING ANY FUMES OR TOUCHING ANY LIQUIDS WHICH DEVELOP, TAKE PRECAUTIONS APPROPRIATE FOR BERYLLIUM COMPOUNDS AND FOR OTHER HIGHLY TOXIC AND CORROSIVE SUBSTANCES, before permitting personnel to perform any work on or near the tube. If a coolant other than pure water is utilized follow the precautions supplied by the coolant manufacturer.

IMPLOSION HAZARD

Due to the internal vacuum in microwave tubes the glass or ceramic output window can shatter inward (implode) if struck with a hard object or subjected to mechanical shock. Flying debris could result in bodily injury, including cuts and puncture wounds and, if made of BERYLLIUM OXIDE ceramic, produce highly toxic dust or fumes. DO NOT BREATHE SUCH DUST OR FUMES.

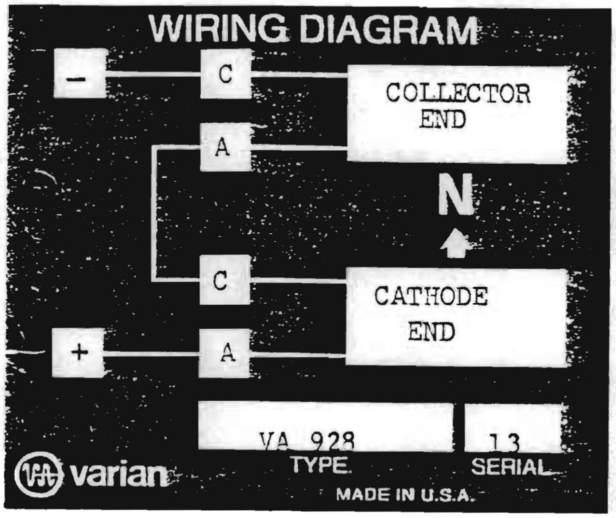
HOT COOLANT AND/OR STEAM

EXTREME HEAT occurs in the electron collector portion of microwave tubes during operation. *Coolant* channels used for cooling also reach high temperatures (as high as boiling, 100°C or above), and the hot *coolant* is under pressure (typically as high as 100 psi). *Some collectors are cooled by boiling the coolant and forming steam.*

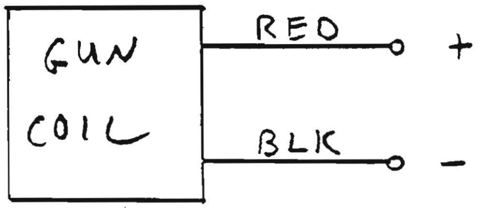
A rupture of the *coolant* channel or *the coolant* or *steam line* or other contact with hot portions of this tube could scald or burn. Carefully check that all fittings and connections are secure and monitor backpressure for changes in cooling system performance. Replace any defective fittings and tighten any loose fittings or connections. If backpressure is increasing above normal operating values shut the system down and clear the restriction.

HOT SURFACES

The electron collector portion of microwave tubes is often air-cooled or conduction-cooled. The air-cooled external surface normally operates at a high temperature (typically 200° to 300°C). Other portions of the tube may also reach high temperatures, especially the cathode insulator and the cathode/heater surfaces. All hot surfaces may remain hot for an extended time after the tube is shut off. To prevent serious burns, take care to prevent and avoid any bodily contact with these surfaces both during and for a reasonable cool-down period after tube operation.



ELECTROMAGNET



REV	DATE	CHANGE

VA 928 WIRING DIAGRAM

varian engineering sketch

ENGINEER B. ROACH

DATE 27 JUL 82

MATERIAL —

JOB ORDER —

SCALE —

USE —

SKETCH NO. BCO-008