GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. B-559 DATE 6/11/82

Project Director: Dr. J. Schaefer ~~School~~/Lab ECSL/BRD

Sponsor: Biomedical Research Support Grant

Type Agreement: DHHS/PHS/NIH Grant No. 507-RR07024-17

Award Period: From 6/1/82 To 3/31/83 (Performance) 4/30/83 (Reports)

Sponsor Amount: $4,125 Contracted through:

Cost Sharing: NA ~~GTRI~~/GIT

Title: Research and Development of Non-Contact Electromagnetic and Acoustic Tonometers for Use in Glaucoma Detection

ADMINISTRATIVE DATA

OCA Contact Faith G. Costello

1) Sponsor Technical Contact:

2) Sponsor Admin/Contractual Matters:
(Internal)
Dr. Thomas G. Tornabene
Chairman
Biomedical Research Support Grant
Commiteee
School of Biology

Defense Priority Rating: N/A

Security Classification: N/A

RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with N/A

COMMENTS:

Subproject under G-32-608

Reporting Schedule: (Internal only) Summary Report due by April 30, 1983.

JUN 1982 RECEIVED Research Reports Office

COPIES TO:

RAN

Administrative Coordinator
Research Property Management
Accounting
Procurement/EES Supply Services

Research Security Services
~~Reports Coordinator (OCA)~~
Legal Services (OCA)
Library

EES Public Relations (2)
Computer Input
Project File
Other B Bullock / Bio

FORM OCA 4:781

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

Date August 16, 1983

Project Title: Research and Development of Non-Contact Electromagnetic and Acoustic Tonometers for Use in Glaucoma Detection

Project No: B-559

Project Director: Dr. J. Schaefer

Sponsor: Biomedical Research Support Grant

Effective Termination Date: 3/31/83

Clearance of Accounting Charges: 3/31/83

Grant/Contract Closeout Actions Remaining:

NONE

- [ ] Final Invoice and Closing Documents
- [ ] Final Fiscal Report
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ______________

Subproject under G-32-608 (17th year)

Assigned to: ECSL/BRD (~~School~~/Laboratory)

COPIES TO:

Administrative Coordinator
Research Property Management
Accounting
Procurement/EES Supply Services
Research Security Services
✓Reports Coordinator (OCA)
Legal Services (OCA)
Library
EES Public Relations (2)
Computer Input
Project File
Other Schaefer

FINAL TECHNICAL REPORT

Project B-559

RESEARCH AND DEVELOPMENT OF NON-CONTACT ELECTROMAGNETIC AND ACOUSTIC TONOMETERS FOR USE IN GLAUCOMA DETECTION

June 1983

By

Daniel J. Schaefer
BIOMEDICAL RESEARCH DIVISION
ELECTRONICS AND COMPUTER SYSTEMS LABORATORY
ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GA 30332

FOREWORD

The non-contact tonometers described in this report were developed in the Biomedical Research Division of the Electronics and Computer Systems Laboratory of Georgia Tech's Engineering Experiment Station. This work was supported by a Biomedical Research Support Grant (DHHS/PHS/NIH Grant No. 507-RR07024-17). The period of technical performance was from June 1, 1982 to March 31, 1983.

The goals of this research were to investigate the feasibility of determining either absolute or relative pressures with non-contact devices employing either ultrasonic or electromagnetic interferometry. This was done and suggestions were made to make such devices practical. It is anticipated that the knowledge developed and the data obtained on this project will be used to write a National Institutes of Health proposal and a journal publication.

Respectfully submitted,

Daniel J. Schaefer
Principal Investigator

TABLE OF CONTENTS

Section		Page
I.	INTRODUCTION.	1
II.	EXPERIMENTAL METHODS.	5
III.	DATA.	9
IV.	SUMMARY AND CONCLUSIONS	12

LIST OF FIGURES

Figure		Page
1.	Basic interferometer scheme	2
2.	Experimental design for non-contact pressure measurements . .	6
3.	10 GHz Electromagnetic interferometer	7
4.	Ultrasonic interferometer	8

LIST OF TABLES

Table		Page
1.	PRESSURE AND AMPLITUDE EXPERIMENTAL DATA FOR SMALL PRESSURE VARIATIONS.	10
2.	PRESSURE AND AMPLITUDE EXPERIMENTAL DATA FOR LARGE PRESSURE VARIATIONS.	11

RESEARCH AND DEVELOPMENT OF NON-CONTACT ELECTGROMAGNETIC AND ACOUSTIC TONOMETERS FOR USE IN GLAUCOMA DETECTION

I. INTRODUCTION

The goal of this project was to conduct a pilot study to determine whether non-contact, biomedical pressure measurement techniques could be developed. The development of non-contact pressure measurement devices (non-contact tonometers) would be a highly useful contribution to biomedical instrumention. Specifically, in the area of glaucoma detection such devices would be useful in performing quick, non-traumatic screening examinations. Non-contact tonometers would also permit blood pressure measurements to be made on burn patients without causing discomfort. Continuous monitoring of pressure should be possible if non-contact pressure measurement techniques are developed. Finally, the accuracy of non-contact measurement techniques in principle should surpass the accuracy of currently-used contact techniques [1-5] since the contact pressure itself will perturb the pressure of the system.

The normal range of intraocular pressures is from 12 to 21 mm of Hg [3]. Values above this may be indicative of glaucomas, though further tests would be required. Current methods of measuring intraocular pressures involve indentation tonometry [1-5] with devices such as the Schiotz' tonometer and applanation tonometry [1-5] using devices such as the Goldman-type tonometer. In indentation tonometry, the amount of corneal indentation produced by a known weight is measured. In applanation tonometry, the force required to flatten a known (and usually small) surface area of the cornea is converted into a pressure measurement. Non-contact air-puff applanation tonometers [3] have been developed, but they are expensive and sometimes traumatic to the patient. The need of non-traumatic non-contact tonometers for glaucoma screening is clear.

Several approaches were conceived for making non-contact pressure measurements. The approaches all made use of either ultrasonic or electromagnetic interferometry to remotely monitor small displacements. The basic interferommetry system is shown in Figure 1. A interrogating signal is obtained from a signal source and is then split into two signals of equal power and phase.

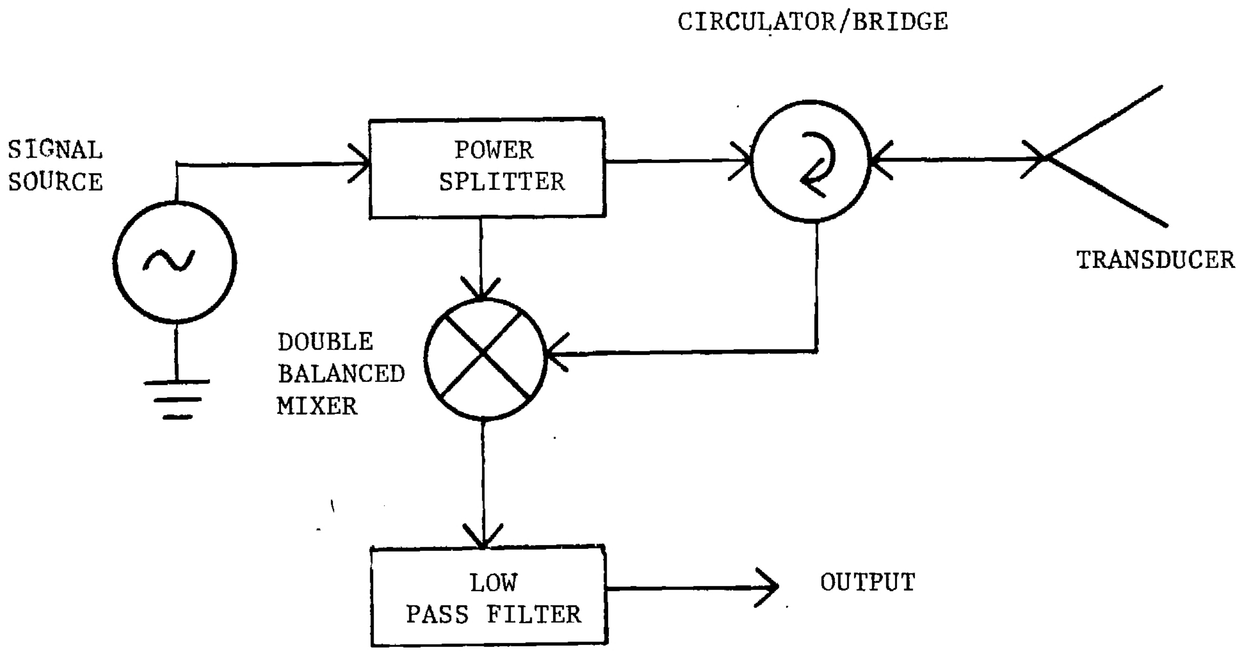

Figure 1. Basic interferometer scheme.

One output of the power splitter goes through a circulator (electromagnetic signals) or through a balanced bridge (ultrasonic signals) which ideally permit power to be coupled only from the power splitter to the interrogating transducer (antenna or piezoelectric crystal) and from the transducer to the mixer. The other output of the power splitter feeds into the mixer. The transmitted and received signals are summed and squared, subtracted and squared, and the results subtracted in the double balanced mixer so that only the product of these two terms becomes the mixer output. The transmitted (or local oscillator) signal, V_L is a sinusoid:

$$V_L = A \cos \omega t \tag{1}$$

where A is a constant, ω is the radian frequency, and t is the time referenced to the local oscillator (signal source). Similarly, the received signal is a sinusoid:

$$V_R = B \cos \omega t_R \tag{2}$$

where V_R is the amplitude of the received signal, B is a constant related to propagation losses, transducer characteristics, and the transmitted signal level, and t_R is the time referenced to the receiver. The interrogating signal leaves the transducer, travels to the target and is reflected back to the transducer in a round trip time, τ. Hence:

$$t_R = t + \tau \tag{3}$$

and,

$$\tau = \frac{2D}{C} = \frac{2D}{\lambda f} = \frac{4\pi D}{\lambda\omega} \tag{4}$$

where D is the distance between the target and the transducer, C is the propagation velocity of the interrogating signal, λ is the wavelength of the interrogating signal, and f is the frequency of the interrogating signal. The product, V_I of the transmitted and received signals is:

$$V_I = AB \cos \omega t \cos \omega(t + \tau) \tag{5}$$

or

$$V_I = \frac{AB}{2} \cos \omega(2t + \tau) + \frac{AB}{2} \cos \omega\tau. \tag{6}$$

After low pass filtering this signal, only the slowly varying term remains:

$$V_I{}' = \frac{AB}{2} \cos \omega\tau = \frac{AB}{2} \cos \frac{4\pi D}{\lambda} \tag{7}$$

where $V_I{}'$ is the low pass filtered signal. For this application, the displacements are small and along the direction of propagation of the interrogating signal (or opposite to this direction). As a result, the amplitude terms in equation (7) are nearly constant for very small displacements (small changes in D). If this signal is passed through a hard limiter, only the phase information is retained, since the signal is converted into a square wave. The change in the period of the square wave is inversely proportional to the change in the displacement. Other methods of finding the phase change are also possible such as quadrature methods to find the tangent. The point is to find the phase change so that the net displacement may be ascertained.

The intensity, I, of a sound wave is related to the peak pressure, P, in the propagation medium, the density of the medium, ρ_o, and the velocity of propagation, C, by the equation:

$$I = \frac{P^2}{2\rho_o C} \quad . \tag{8}$$

This intensity in watts per square meter may exert a force, F, upon an object with a cross-sectional area, A, moving it a distance, d, over a period of time, T, indicating that the object had an internal pressure, $\underline{P}$:

$$\underline{P} = \frac{F}{A} = \frac{IT}{d} \quad . \tag{9}$$

Note that T is one-half the period of the exciting energy. If the same intensity and frequency of sound are used to vibrate an object at two different pressures then two different displacements will be measured. If the pressures P_2 and P_1 correspond to displacements d_2 and d_1, then their relationship may be described as follows:

$$\frac{P_2}{P_1} = \frac{d_1}{d_2} . \tag{10}$$

These types of measurements were carried out on this project.

II. EXPERIMENTAL METHODS

In Figure 2, the basic experimental design is illustrated. A signal source was used to drive a speaker at a fixed, sinusoidal frequency. The sound wave vibrated a plastic membrane attached to the bottom of a Plexiglas tube which was partially filled with water. The Plexiglas tube was fourteen inches long with an outer diameter of two inches and a wall thickness of 0.113 inches. The column of water exerted a pressure, P, on the membrane that depended on the density of the water, ρ, the acceleration of gravity, g, and the height of the water column, h:

$$P = \rho gh. \tag{11}$$

Hence, the pressure was readily adjusted by changing the height of the water column. The amplitude of the vibrating membrane may be found by using either ultrasonic or electromagnetic interferometry. Both types of systems were developed. The ultrasound system was preferred because it used a smaller transducer and used a smaller wavelength interrogating signal than the electromagnetic interferometer. Both systems used only a single channel to get relative displacement information. A quadrature system connected to a digital computer would be useful for absolute measurements. The electromagnetic system worked at 10 GHz (a wavelength of 3 centimeters), while the ultrasonic interferometer had an operating frequency of 40 kHz (a wavelength of 0.83 centimeters). The electromagnetic interferometer is shown schematically in Figure 3, while the ultrasonic unit is shown in Figure 4. The horn antenna of the 10 GHz interferometer was a five-inch square, while the ultrasonic transducer was only one centimeter in diameter. Both units were operated in the continuous wave (CW) mode. Each system was designed to use only a single transducer. The systems both operated by the principles described

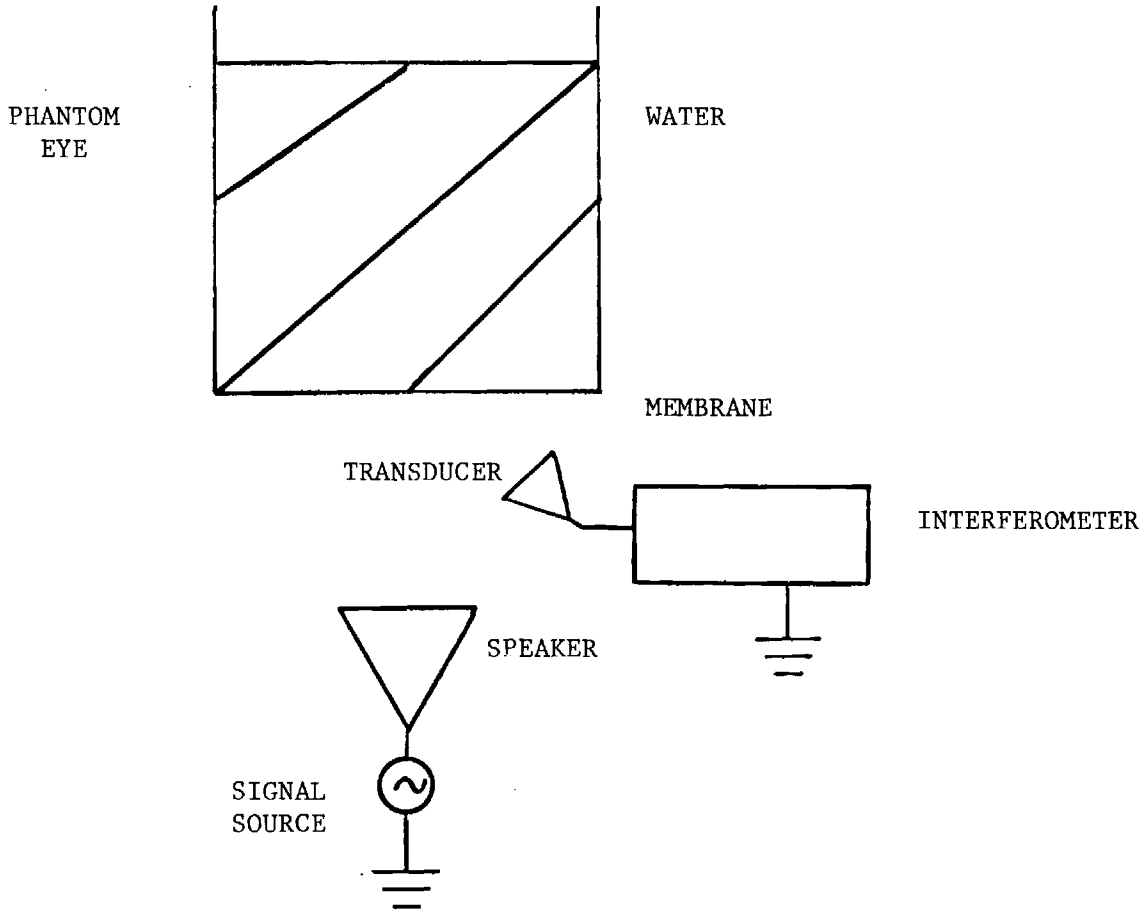

Figure 2. Experimental design for non-contact pressure measurements.

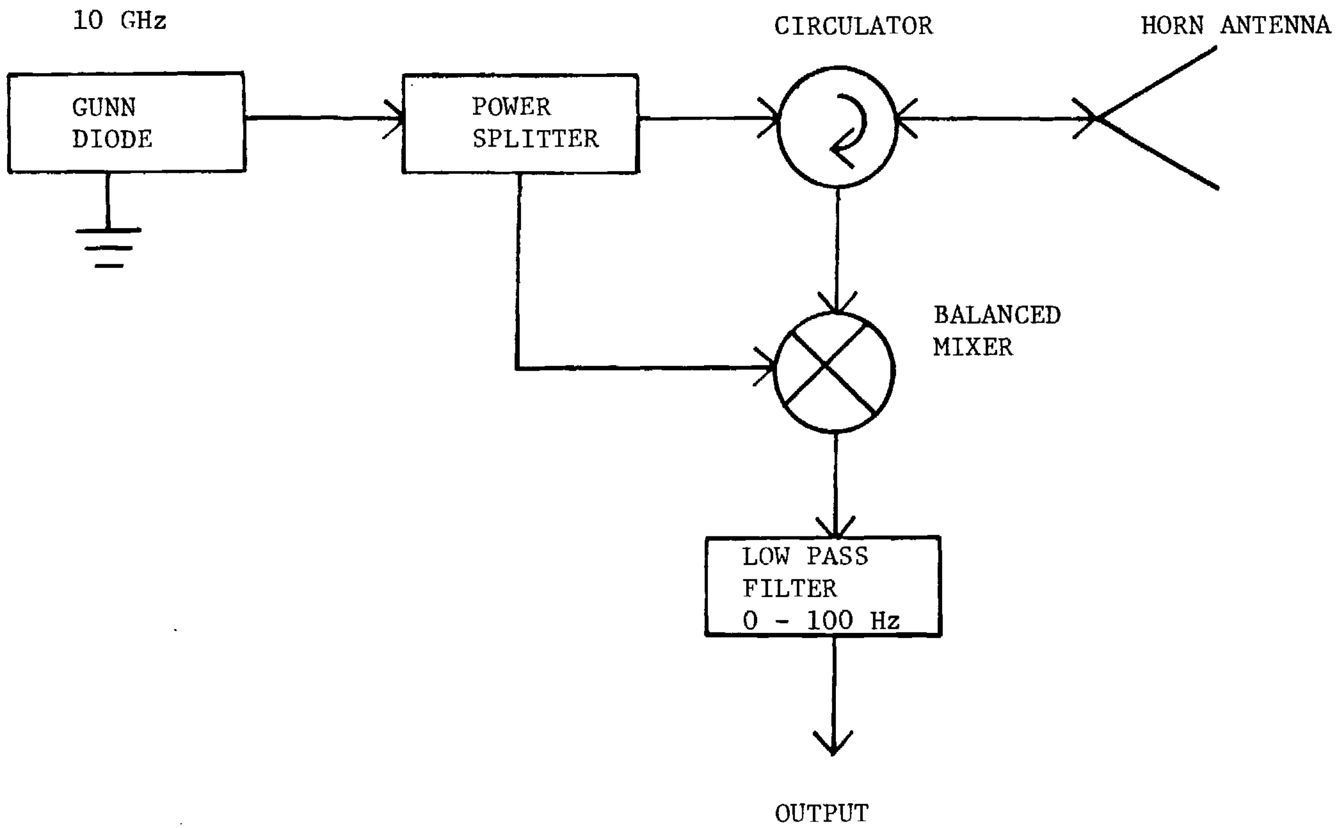

Figure 3. 10 GHz Electromagnetic interferometer.

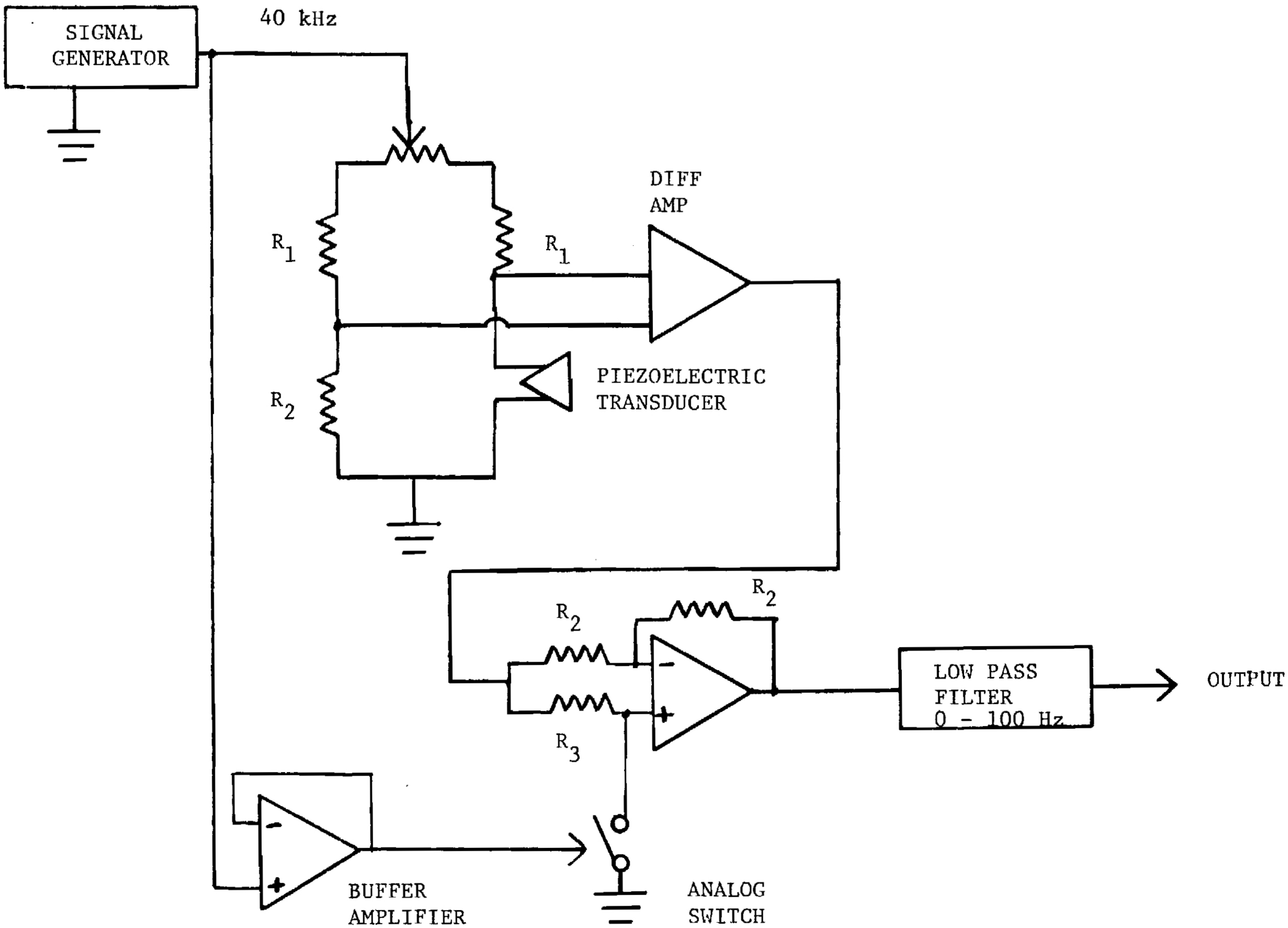

Figure 4. Ultrasonic interferometer.

earlier. The ultrasonic system used a balanced bridge to serve the same purpose as an ultrasonic circulator and it used an operational amplifier/analog switch arrangement to serve as the mixer. Some versions of the ultrasonic interferometers utilized radio frequency power splitters, directional couplers, and mixers, though such systems were somewhat bulky.

III. DATA

Experimental data were taken using both electromagnetic and ultrasonic interferometers to measure displacements, ΔR, caused by an acoustic transducer at a range R_o as discussed earlier. The acoustic transducer was excited by sinusoidal source at a frequency ω_m. The filtered output of the transducer given by equation (7) becomes:

$$V_I' = \frac{AB}{2} \cos \omega\tau = \frac{AB}{2} \cos \omega \frac{2 (R_o - \Delta R \sin \omega_m t)}{C} . \qquad (12)$$

This equation may be rewritten as:

$$V_I' = \frac{AB}{2} \cos \left(\frac{2\omega R_o}{C}\right) \cos \left(\frac{2 \omega \Delta R \sin \omega_m t}{C}\right) - \sin \left(\frac{2 \omega R_o}{C}\right)$$

$$\sin \left(\frac{2\omega\Delta R \sin \omega_m t}{C}\right) . \qquad (13)$$

A relatively complicated quadrature system must be used to find the displacement amplitude, ΔR, precisely. However, under appropriate conditions the displacement can be found approximately with a single channel device. If the argument, $\frac{2\omega R_o}{C}$, is chosen to be an odd multiple of $\pi/2$ and if $\frac{2\omega\Delta R}{C}$ is small, then equation (13) becomes

$$V_I' = \frac{AB\omega\Delta R}{C} \sin \omega_m t . \qquad (14)$$

A time domain display of the waveform may be qualitatively done to determine whether the waveform is sinusoidal and the conditions described above are at least approximately met. In Tables 1 and 2, data are presented. Clearly, the amplitude ratios correspond roughly to the pressure ratios. Errors

TABLE 1

PRESSURE AND AMPLITUDE EXPERIMENTAL DATA

FOR SMALL PRESSURE VARIATIONS

HEIGHT OF WATER COLUMN (cm)	PRESSURE RATIO	VIBRATION AMPLITUDE (Relative Units)	INVERSE AMPLITUDE RATIO	ERROR (%)
3.7	---	1.9	---	---
3.9	1.054	1.7	1.118	6.0
4.7	1.270	1.2	1.583	24.6
5.5	1.486	0.8	2.375	59.8
6.1	1.649	0.6	3.167	92.1

TABLE 2

PRESSURE AND AMPLITUDE EXPERIMENTAL DATA

FOR LARGE PRESSURE VARIATIONS

HEIGHT OF WATER COLUMN (cm)	PRESSURE RATIO	VIBRATION AMPLITUDE (Relative Units)	INVERSE AMPLITUDE RATIO	ERROR (%)
8.8	---	1.4	---	---
13.5	1.534	0.7	2.000	30.4
17.1	1.943	0.9	1.555	20.0
23.0	2.614	1.1	1.273	51.3
24.8	2.818	1.8	0.778	78.3
31.6	3.591	1.5	0.993	74.0

are introduced by the approximations discussed above and by the membrane bulging and thus, changing the cross-section of the target as well as the single channel sensitivity (the cosine of the phase angle is more sensitive to small displacements when the cosine approaches zero than when it approaches one). A practical system would require a quadrature system perhaps interfaced to a computer to obtain the displacements and hence the pressure accurately.

IV. SUMMARY AND CONCLUSIONS

Non-contact pressure measurements using interferometry and a method of producing small surface vibrations without contact appear to be feasible. To be practical, such a system will need quadrature channels and a computer to obtain precise measurements of the displacements and thus the pressure. A larger study to do this will be proposed to NIH in the near future.

REFERENCES

1. Grant, W. M., "Tonography: Past, Present, and Future", Ophthalmology (Rochester), Vol. 85, March, 1978.

2. Gelatt, K. N., Gunn, G. G., and Barrie, K. P., "Tonometry in Glaucomatous Globes", Invest Ophthalmol Vis Sci, Vol. 20, No. 5, May, 1981.

3. Paton, D. and Craig, J. D., "Glaucomas: Diagnosis and Management", Clinical Symposia, Vol. 28, No. 2, 1976.

4. Starrels, M. E., "The Measurement of Intraocular Pressure", Internal Ophthalmology Clinics, ed. by G. Spaeth, Vol. 19, No. 1, Little and Brown, Boston, 1979.

5. Draeger, J. and Jessen, K., "Tonometry and Tonography", Chapter 6 of Glaucoma-Comtemporary International Concepts, ed. by J.Bellows, Masson, New York, 1979.