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ABSTRACT

The development of a contact transducer system is described. The transducer, based upon the mass-loaded shear tube principle, is housed in a 1.0-inch diameter brass case. Its sensitivity is approximately +2dB referred to one microvolt per micro-g excitation. A special filter-amplifier having continuously variable low-and high-pass filters was also designed and constructed. This transducer and this filter-amplifier unit were incorporated into a kit along with the necessary accessories.

A comparison was made between the results of the Harvard Phonetically Balanced Word List and the Fairbanks Rhyme Test methods of measuring the intelligibility of speech which has passed through an acoustical or electronic system. This comparison, while limited because of a time deadline, indicated that both tests were capable of detecting trends in the system under test, even though individual scores did not correlate exactly. Further study in the correlation of these two tests is indicated.

I. OBJECTIVES

The objectives of this program are to provide improved techniques and equipment for the purposes of gathering and processing field data. Special audio frequency transducers and electronic techniques are being developed and utilized in providing data collecting equipment and supporting instrumentation.

II. INTRODUCTION

The basic purpose of the research program reported here is to study indirect methods of obtaining acoustical surveillance data and to study the applications and limitations of such methods. Primary attention is being given to contact transducers which sense vibrational information in the structural components of the target room.

The advantage of a contact transducer over a pinhole microphone is the absence of the pinhole, which greatly increases the security of a clandestine installation. However, because the contact transducer is sensitive to vibration, vibratory sources other than the desired acoustical information contribute to the over-all transducer output. Examples of sources of noise which can affect a contact transducer are air conditioning machinery, pumps and other building equipment, people walking and talking in other areas, slamming doors, water running, and wind blowing against the exterior walls of the building. The signal-to-noise ratio can usually be improved in a given installation by providing electrical wave filtering in the amplifier system used with the transducer.

The research work reported here is intended to study the application of contact transducers to thick concrete walls with emphasis on the measurement of signal intelligibility and on the effects of various sources of noise, and to develop the shear tube concept in contact transducers. This report summarizes the work performed in the first three quarters of the program, and details the work performed in the final quarter of the program.

III. ACCOMPLISHMENTS

A. Summary of Work Performed in Previous Quarters

Detailed accounts of the work performed in each of the prior three quarters are contained in the respective quarterly progress reports. The contents of those reports are reviewed briefly here.

During the first quarter[1*] of this program two units of a new shear tube contact transducer housed in a 0.875-inch diameter case were constructed and delivered to the Sponsor, in addition to two units of a special transducer preamplifier. This preamplifier was intended to provide the necessary interface between the recently developed contact transducers and an existing radio transmitter unit used by the Sponsor. The preamplifier was self-powered and packaged to be compatible with the existing transmitter unit.

A comparison of the intelligibility characteristics of four types of contact transducers used under identical conditions was initiated. The data for the comparison were obtained in a field situation where the acoustical conditions could be controlled to some extent. Standard intelligibility words carried in unrelated, nonsense sentences were used as the source material for the tests. Various noise conditions were imposed. The outputs of the various transducers were recorded on magnetic tape in the field. Then these tapes were played back in the laboratory to a special listener panel consisting of several people who made written records of what they heard from the tapes. The written records were scored against a master key word list. Because of an accident which occurred in the field, parts of the original data were lost. Thus, this comparison was not completed during the first quarter.

During the second quarter[2] of the program, the lost portions of the field data were re-recorded and the resultant tapes were processed by the listener panel. Comparison of the many intelligibility scores thus obtained did not indicate any single transducer as being best in all situations; however, in many cases, the shear tube unit mounted in a deep hole in the wall showed superior intelligibility scores.

The effects of the size of the seismic mass on the

*See References, Section V

characteristics of a shear tube transducer were studied. As expected, increased mass resulted in a lower resonant frequency and in increased sensitivity. A diminishing returns situation was also noted with respect to these effects. That is, equal increments in mass produced rapidly diminishing increments in sensitivity. Various forms of damping were tried as a means of reducing the magnitude and sharpness of the transducer resonance. A silicone oil was found to produce the best results.

The third quarter[3] of the program was concerned primarily with the design of a new filter-amplifier unit which would be compatible with the shear tube transducers. The preamplifier circuit was breadboarded and tested. Design of a variable cut-off frequency active filter was performed. Five units of the 1.0-inch diameter shear tube transducer were started, the intention being to include these in special kits. However, it was decided to deliver three of the transducers early, so a special power supply adapter was constructed for each of these transducers to facilitate connection of the transducer to existing filter-amplifier equipment.

B. Special Tasks

Two special tasks were performed during the life of this program. Each of these tasks was reported in detail in a Special Report. Brief summaries of these two reports are presented here.

1. Study of Transducer Applications[4]

This study was intended to compare the characteristics under similar operating conditions of a pinhole microphone, a microphone used as a contact transducer, and a true contact transducer. RCA "Universal" microphones with 0.85-inch magnetic structure were used for the two microphone installations. A 1.0-inch diameter shear tube transducer was used as a true contact transducer. Frequency response and absolute sensitivity of each installation were measured. In addition, intelligibility test data were recorded under various noise conditions. These intelligibility data were processed through the special listener panel in the usual manner.

This study revealed that the pinhole microphone was the most sensitive unit and its effectiveness was reduced only by airborne noise. The true contact transducer ranked second in sensitivity, but its effectiveness was reduced by both airborne and structure-borne noises. The microphone used as a contact transducer had extremely poor sensitivity.

2. Study of Room Acoustics[5]

This study was directed toward finding methods of predicting the acoustical properties of a room by indirect means and of estimating the performance of a pinhole microphone or contact transducer installation by indirect means. In this task, a small, highly reverberant conference room was studied in detail. Its acoustical properties were determined by measurement of steady state frequency response, by measurement of reverberation time and decay characteristics using impulsive excitation of the room, and by measuring the speech intelligibility characteristics by word tests. An analysis of the effects of room acoustics on the intelligibility of speech was performed.

It was concluded that small variations in the placement of a microphone can make large changes in the transfer function between an acoustical source and the microphone. In addition, the position of the acoustical source has an effect on the response of the system. Best results would probably be obtained by mounting the microphone in a wall or other surface having high acoustical absorption. The mounting of a contact transducer is less critical since the wall upon which the device is mounted tends to average the acoustical signal over its entire area, and this produces smoother response. While laborious calculations might yield a prediction of the response and effectiveness of a microphone installation, no simple method for accomplishing this was discovered.

C. Filter-Amplifier Unit

The design of the new filter-amplifier unit was completed this quarter. The final schematic circuit diagram of the unit is presented in Figure 1. Input to the device is through a coaxial connector. Either a straight high impedance input or a low impedance input having provision for powering a preamplifier in the transducer can be selected by the "EXT-INT PREAMP" switch. The amplifier input stage is a low I_{DSS} field effect transistor operating at zero gate bias, having a dynamic drain load. This configuration utilizes a large fraction of the maximum available gain of the input device, thereby minimizing the noise contributions of other circuit elements. Two bipolar transistor amplifier stages having opposite polarities of transistors complete the forward gain path of the amplifier. A load resistor in the collector circuit of transistor Q4 provides negative DC feedback to the base of the dynamic load transistor Q2. Filtering is provided in this feedback path to prevent degeneration at the midband frequencies. This circuit provides a high

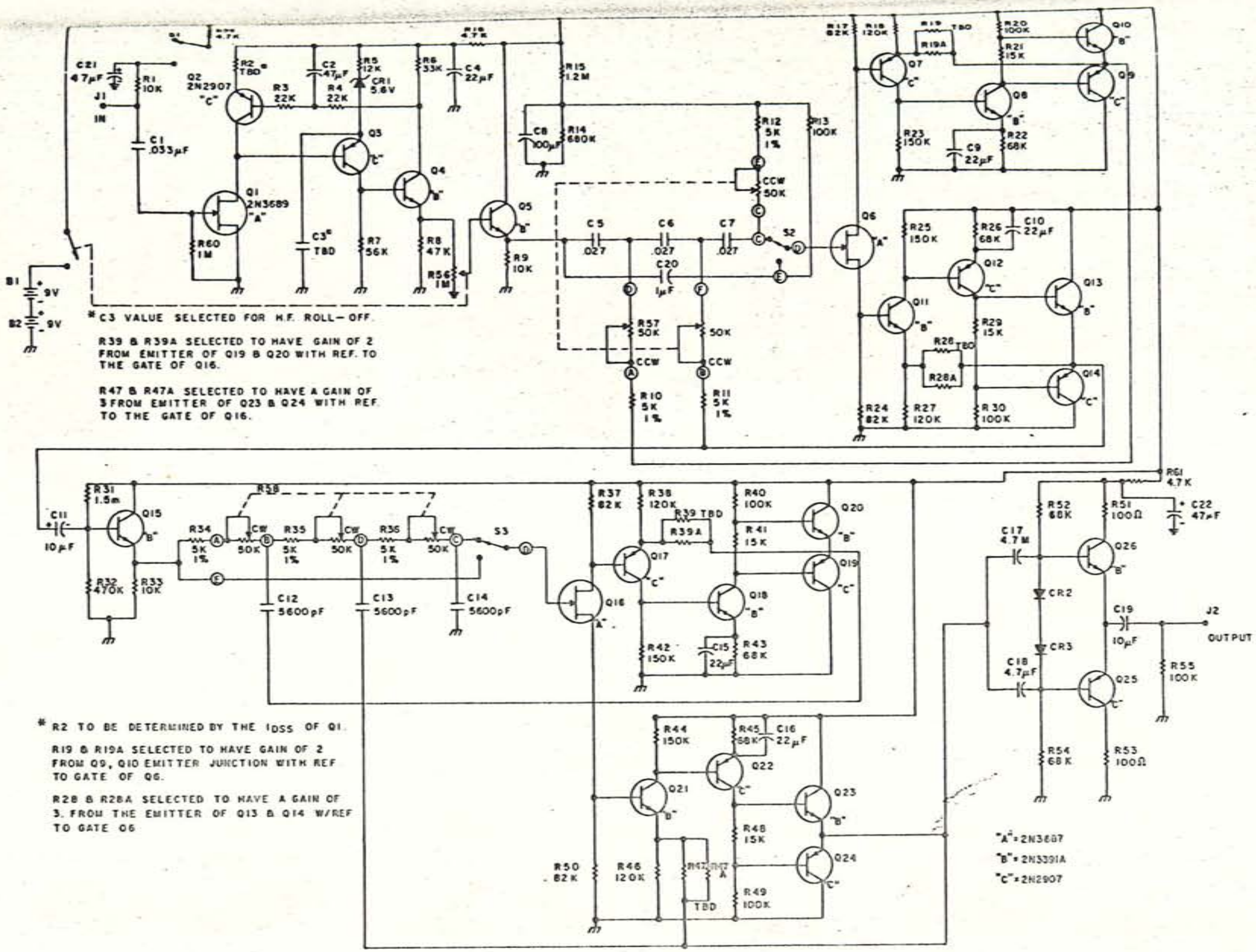

FIGURE I

MODEL 2117A FILTER-AMPLIFIER SCHEMATIC CIRCUIT DIAGRAM degree of DC stability with a consequent stability in operating characteristics. The output of this amplifier circuit drives the input of the first filter section through an emitter follower and a gain control.

Both filters are similar in configuration. Only the capacitors and resistors in the frequency sensitive portions of the circuit are interchanged to provide for the opposite responses of the two filter circuits. Minor differences in the "filter in-out" switch circuitry are present to prevent large transients from being generated by transferring these switches.

The signal enters the filter through a 3-section resistance-capacitance filter of appropriate configuration. The signal passes through the three sections of this filter into a field effect transistor split-load phase inverter. The outputs of the phase inverter drive 3-stage transistor amplifiers having high undegenerated gain and low output impedance. These amplifiers are provided with negative feedback such that the gain of the in-phase signal amplifier is 3, and the gain of the inverted signal amplifier is 2. The output of the in-phase signal amplifier is fed back to the second shunt element of the resistance-capacitance filter, the output of the inverted signal amplifier is fed back to the first shunt element of the resistance-capacitance filter, and the third shunt element of the resistance-capacitance filter is grounded. This configuration produces optimally flat, or Butterworth, filter frequency response.

The resistive elements of the resistance-capacitance filter circuits are composed of a variable resistor of 50 kilohms in series with a fixed resistor of 5 kilohms. The three variable elements within a particular filter circuit are ganged, so that the 3-dB down corner frequency of the filter can be continuously tuned through approximately a decade range.

The output of the high-pass filter circuit drives the input of the low-pass filter circuit. The output of the low-pass filter feeds a complementary symmetry earphone driver. The filter-amplifier unit is designed to drive a pair of 2000-ohm earphone drivers, series connected. The earphones supplied with the unit are of this type.

Typical performance characteristics of this new filter-amplifier unit (designated Model 2117A) are listed in Table I. The ranges of the parameters shown in the table are the extremes of the measured characteristics of five units. The tuning ranges are nominal and small variations from unit to unit can be expected.

TABLE I

PERFORMANCE CHARACTERISTICS OF
MODEL 2117A FILTER-AMPLIFIER UNITS

Gain	76.9 to 80.0	dB
Equivalent Input Noise (Wide Band)	1.23 to 3.44	μV RMS
Maximum Undistorted Output Signal	2.5 to 2.8	V RMS
Maximum Input Signal	0.7 to 1.0	m V RMS
Current Drain (With Transducer Connected)	4.35 to 4.45	m A DC
Tuning Range of High-Pass Filter (Nominal)	100 to 1000	Hz
Tuning Range of Low-Pass Filter (Nominal)	500 to 5000	Hz
Ultimate Slope of Filters (Nominal)	18	dB/Octave
Lower 3-dB Point (Wide Band Setting)	8 to 10	Hz
Upper 3-dB Point (Wide Band Setting)	14.0 to 16.5	kHz

The filter-amplifier units are packaged in anodized two-piece drawn aluminum boxes. The electronic circuitry is constructed on an etched circuit board. All controls and input-output connectors are available on the front panel of the box. A photograph of the Model 2117A Filter-Amplifier unit is presented in Figure 2, and a photograph of the rear of the unit with the cover removed, thus exposing the etched circuit board, is presented in Figure 3. The Model 2117A Filter Amplifier is powered by an integral power supply consisting of two batteries. These batteries are standard 9-volt transistor radio batteries of a widely available type. They are connected in series in the circuit to provide an 18-volt supply.

The curves of Figures 4 and 5 illustrate the frequency response characteristics of the filter sections. The curves of Figure 4 show the frequency response of the filter-amplifier unit with only the high frequency pass filter in the circuit. The two curves represent the responses obtained with the tuning control at its two extremes of rotation. Similarly, the curves of Figure 5 are for the two extremes of rotation of the appropriate tuning control with only the low frequency pass filter in the circuit. There are slight differences in the shapes of the curves plotted for the two extremes of rotation of the tuning controls; these differences result from changes in the gain of the filter feedback amplifier circuits caused by the change in electrical loading on these amplifiers.

D. 1.0-Inch Diameter Shear Tube Transducer

Five units of the shear tube contact transducer housed in a 1.0-inch diameter oil-filled case were completed during this quarter. Three of these units were delivered to the Sponsor, while two units were retained for future delivery.

These units contained a 0.5-inch diameter by 0.5-inch long by 0.125-inch wall thickness lead zirconate titanate piezoelectric shear tube element. This element was supported by a post passing through the center hole of the shear tube as shown in Figure 6. A Mallory-1000 seismic mass was bonded to the outer wall of the shear tube element. The case cover, which was equipped with suitable air-tight seals, held a one-stage field effect transistor preamplifier, the schematic diagram of which is presented in Figure 7. A Microdot coaxial connector was provided for making electrical connection to the preamplifier. A neoprene washer under the base of the shear tube element provided for damping; additional damping was provided by vacuum filling of the voids

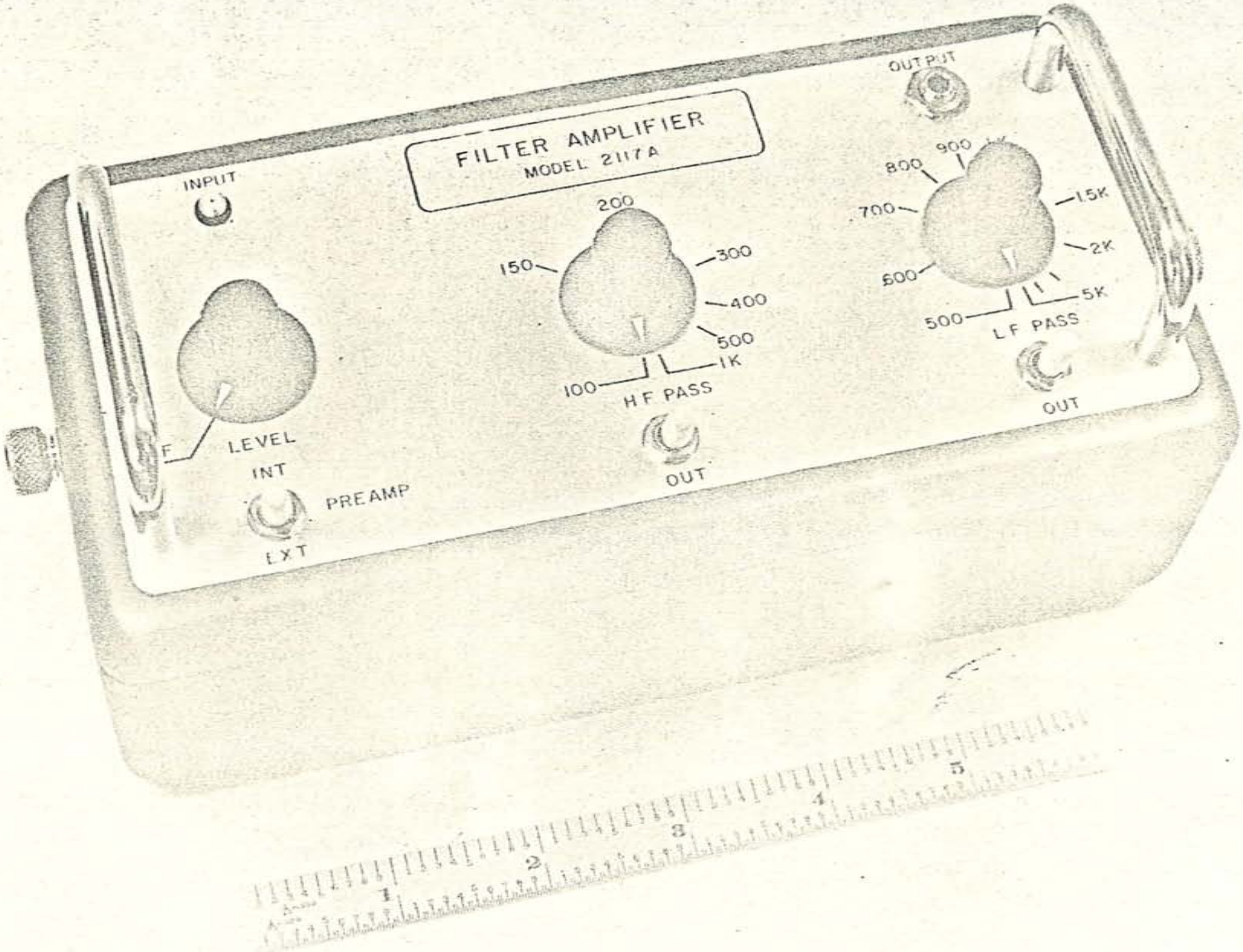

FIGURE 2. PHOTOGRAPH OF MODEL 2117A FILTER-AMPLIFIER UNIT

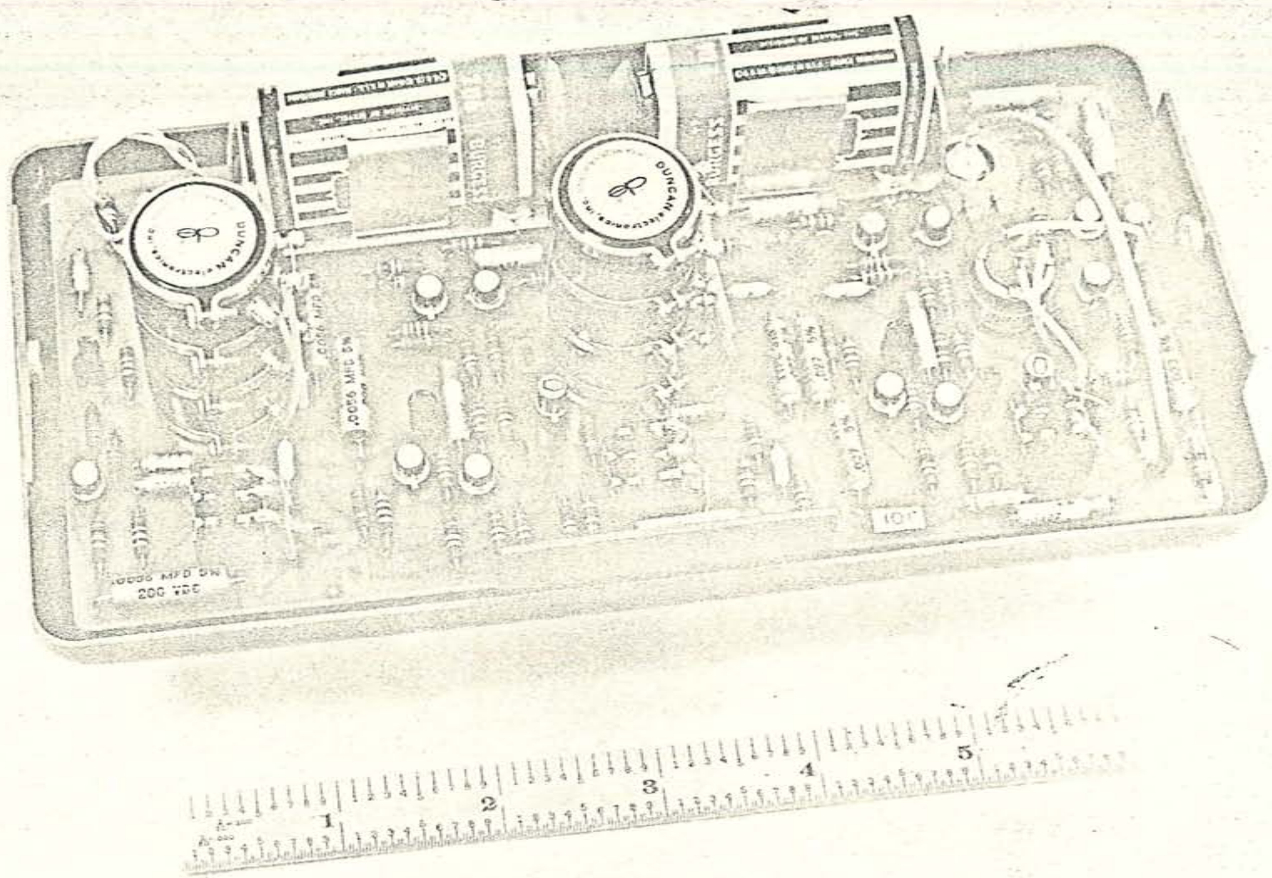

FIGURE 3. PHOTOGRAPH OF MODEL 2117A FILTER-AMPLIFIER WITH COVER REMOVED

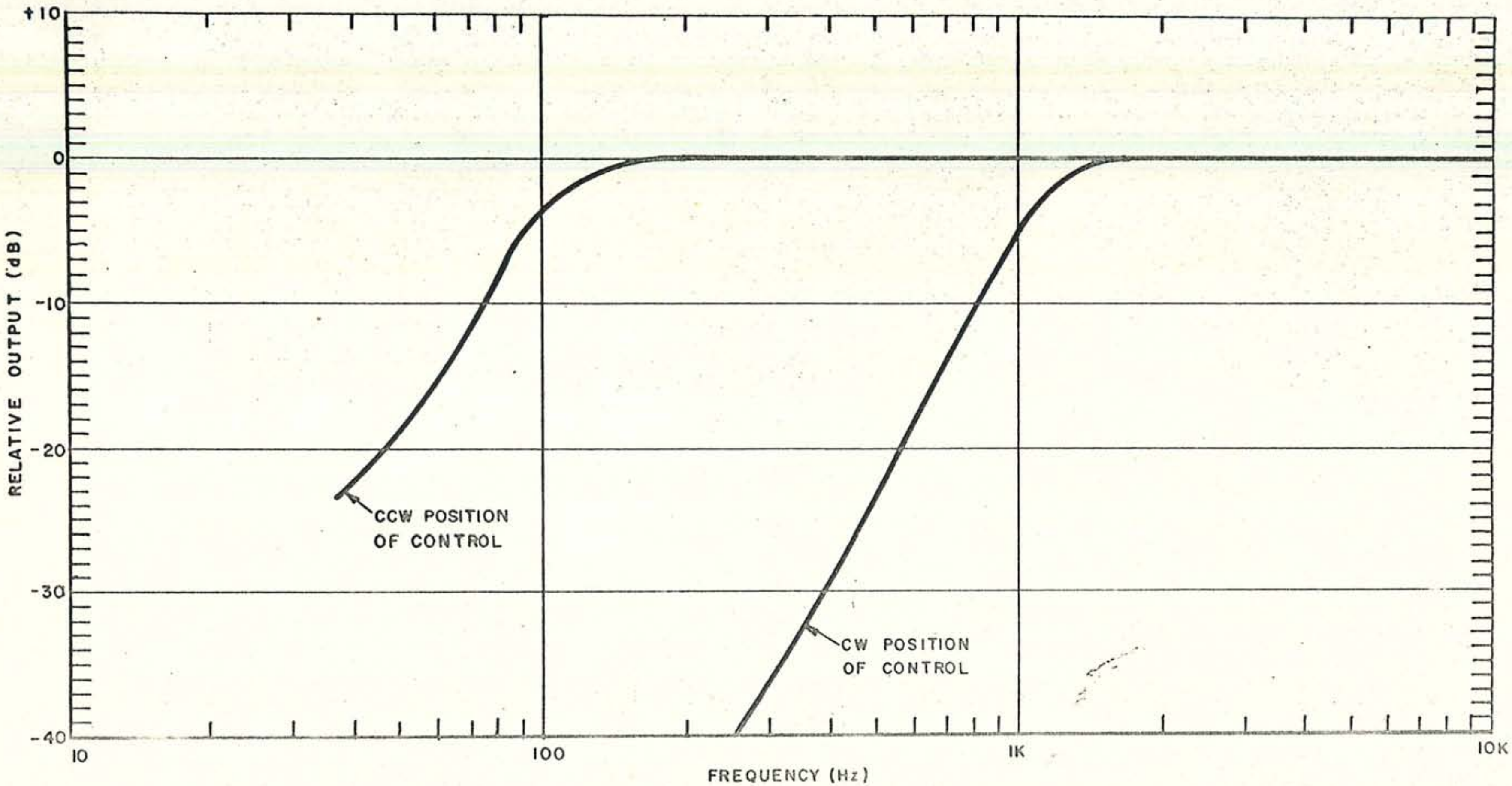

FIGURE 4

FREQUENCY RESPONSE OF HIGH FREQUENCY PASS FILTER

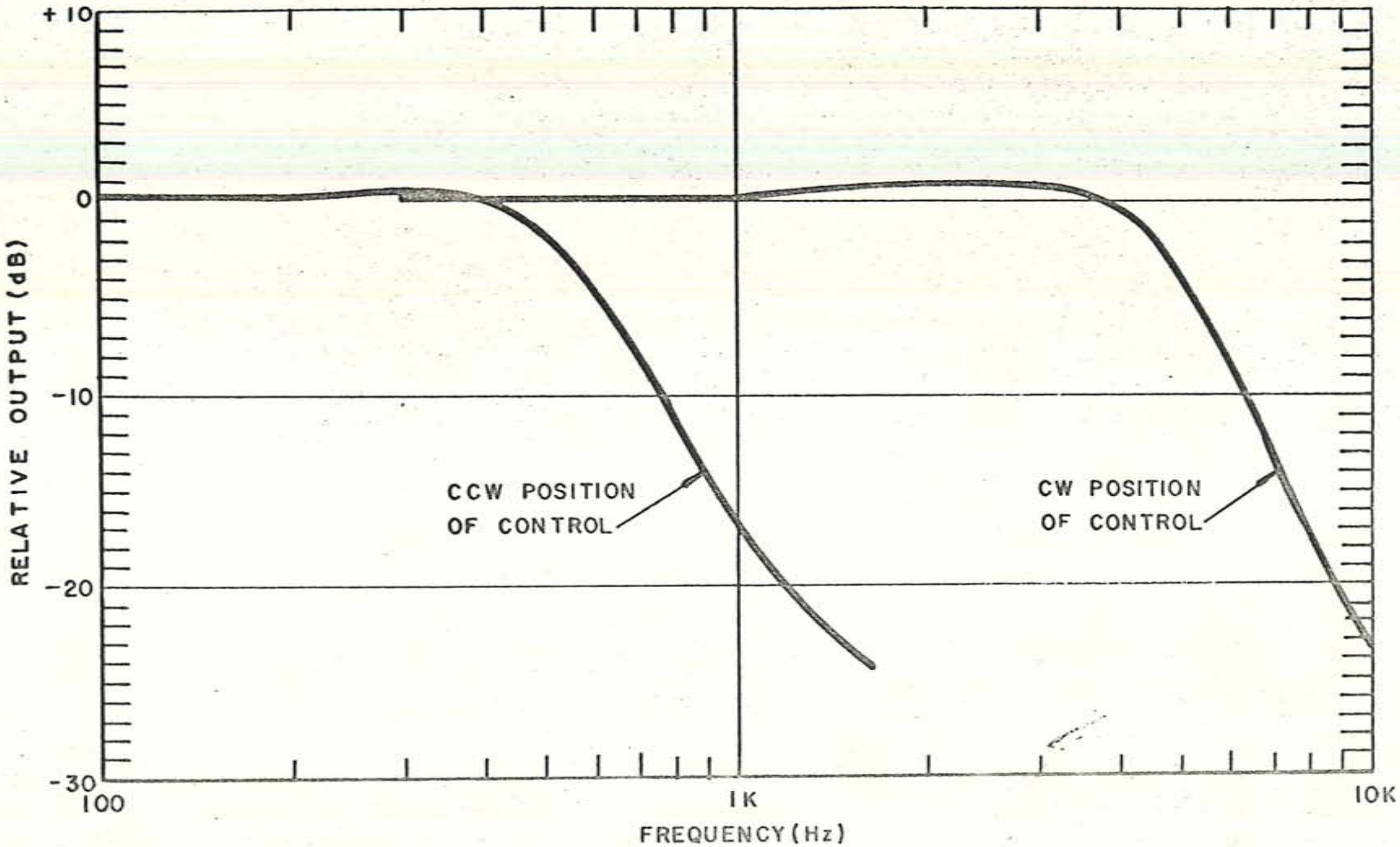

FIGURE 5

FREQUENCY RESPONSE OF LOW FREQUENCY PASS FILTER

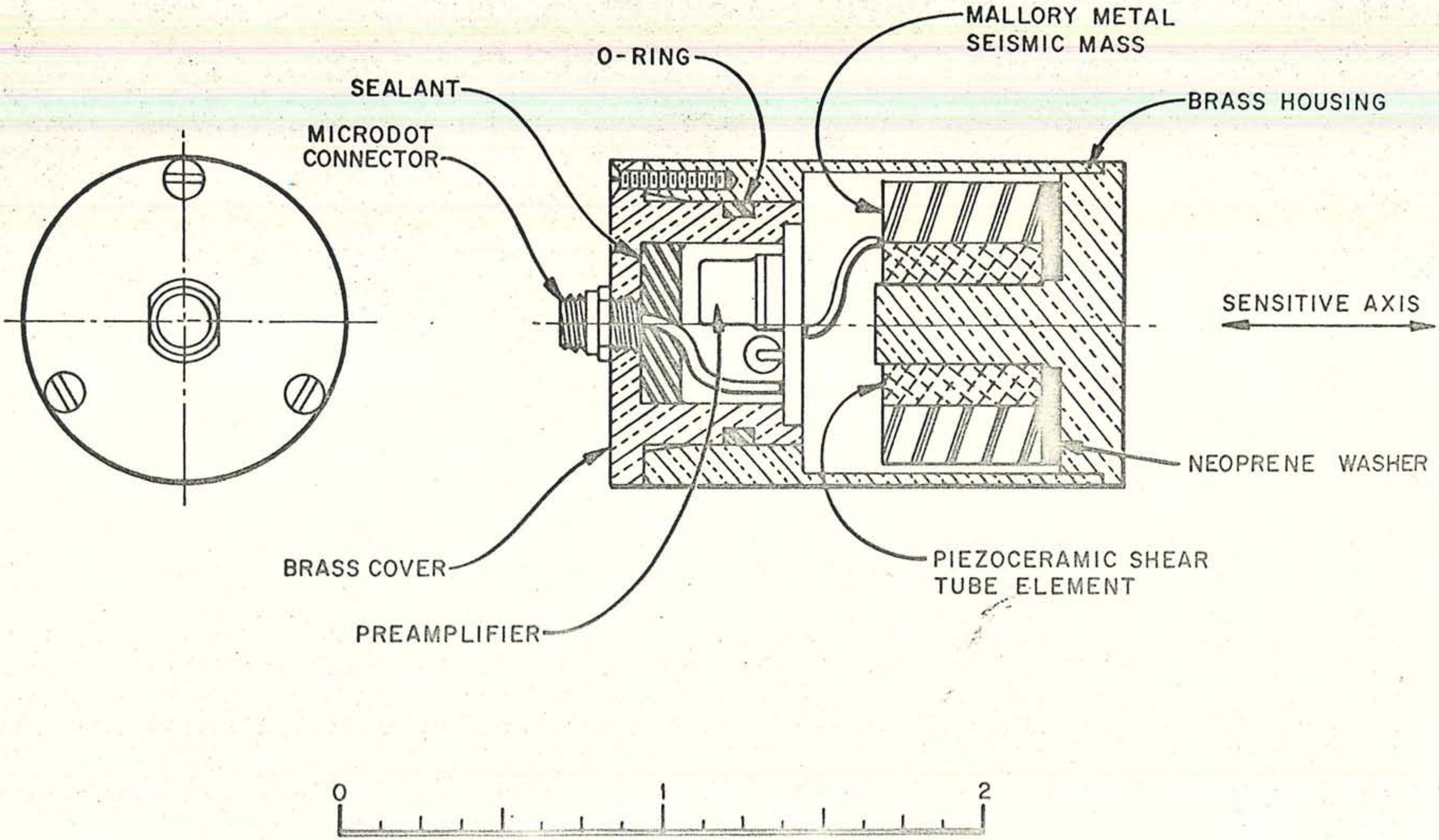

FIGURE 6

CROSS-SECTIONAL VIEW OF 1.0-INCH DIAMETER SHEAR TUBE TRANSDUCER.

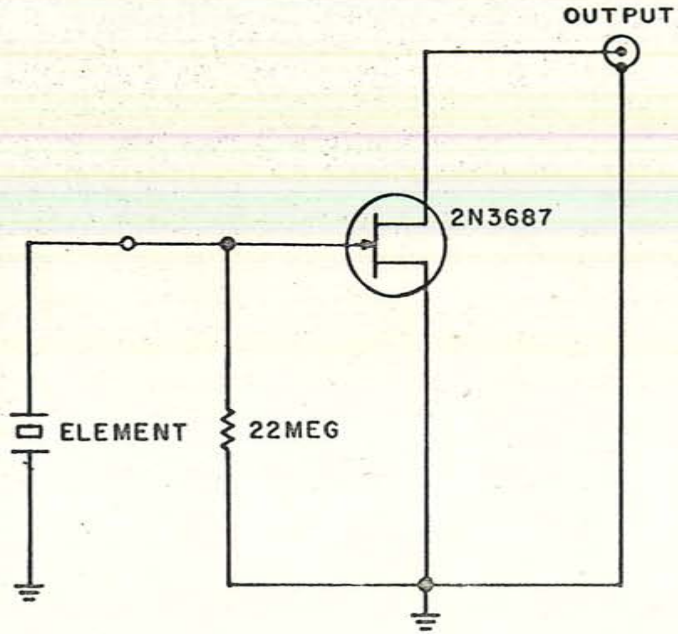

FIGURE 7

SCHEMATIC CIRCUIT DIAGRAM OF TRANSDUCER

in the case with General Electric SF-1080 silicond fluid. A typical frequency response curve for the 1.0-inch diameter shear tube transducer is shown in Figure 8.

E. Kits

A kit containing a 1.0-inch diameter, oil-filled shear tube transducer, an interconnecting cable, a Model 2117A Filter-Amplifier, and an earphone set was assembled. This kit was enclosed in a standard attache case. The interior of the case was fitted with a polyfoam insert which was provided with suitable compartments for each of the kit components. The contents of the kit comprised a compatible transducer-filter-amplifier system. A photograph of the kit showing its contents is presented in Figure 9.

Five such kits were prepared during the last quarter of this project, and these five kits were delivered to the Sponsor at the close of the project. Three of the kits were delivered without transducers and interconnecting cables; the three transducers and interconnecting cables delivered earlier this final quarter were intended to be incorporated into these incomplete kits.

F. Intelligibility Tests

It has been common practice in the past to subject transducers, amplifiers and other acoustical apparatus to tests which were designed to determine the effect of such apparatus on the intelligibility of speech signals being handled by the equipment. The test which has been used exclusively on this and related projects was the Harvard Phonetically Balanced Word List. These words were inserted as the last words in unrelated, nonsense sentences. Such sentences were recorded on magnetic tape and played back through the acoustical system under test. The output of the system being tested was itself recorded on magnetic tape and these tapes were played back to a special listener panel. Panel members were required to make written records of the last words in the sentences as they heard them. The written answer forms thus completed were checked and scored. The resulting numbers represented percent intelligibility scores for the equipment under test.

However, because of the necessity of writing entire words on the answer form, because of the relatively long time involved in

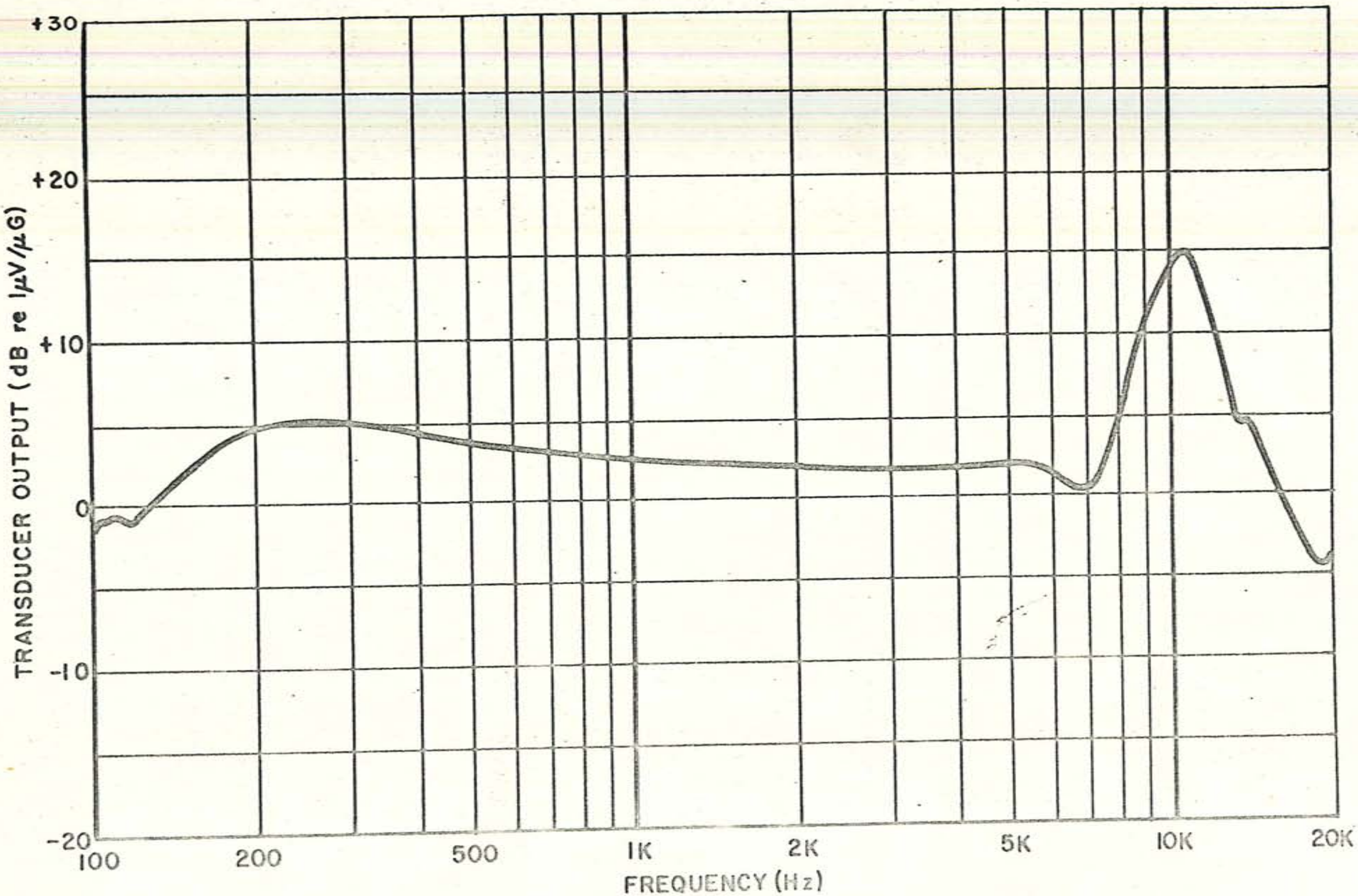

FIGURE 8.

FREQUENCY RESPONSE OF 1.0-INCH DIAMETER SHEAR TUBE TRANSDUCER FILLED WITH GE SF-1080 SILICONE FLUID.

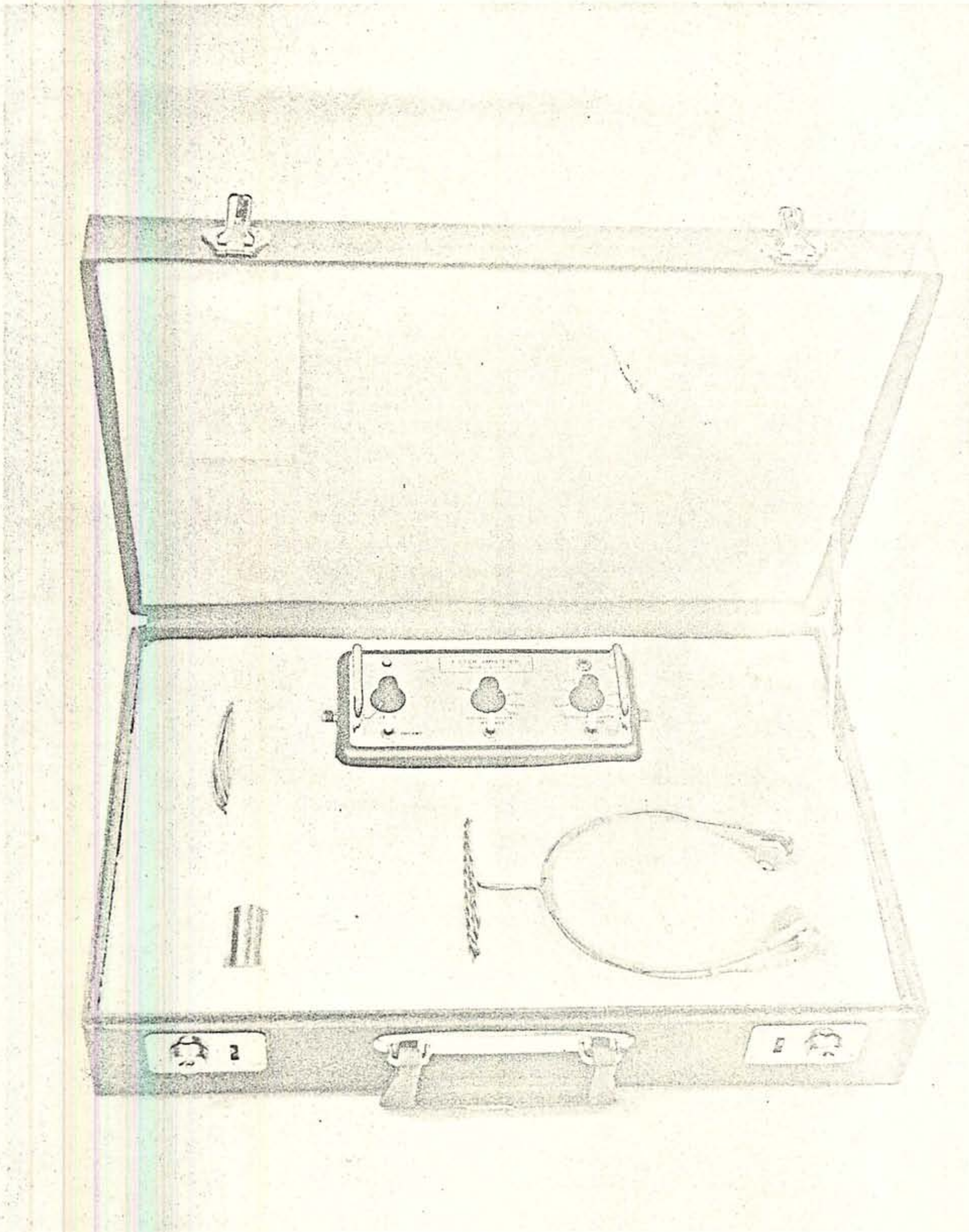

FIGURE 9. PHOTOGRAPH OF KIT

speaking even a short sentence, and because of the questions which arose during the grading process, this type of test was cumbersome and time consuming. As a result, a search was made for another type of intelligibility test which would yield similar results, but be faster.

A possible candidate for this was the Fairbanks Rhyme Test[6]. This test consisted of five groups of fifty words each so selected and arranged that the word in a particular sequential position in any of the five groups always had the same ending; only the first letters were different. The answer form for this test consisted of a list of the word endings with blanks printed in place of the first letters. The words were recorded on magnetic tape at a rate of one word every two seconds; no carrier sentences were used. This source tape was used in the same manner as the source tapes for the Harvard Word List, except that the panel members were required to make written records of only the first letters of the words as they heard them. This test is fast and easy to grade. It permits larger statistical samples to be gathered in the same length of time. In addition, the test is suitable for computer grading and analysis.

In order to obtain a comparison between the two types of intelligibility tests and to gather intelligibility data on the Model 2117A Filter-Amplifier system, both of these intelligibility tests were used in a field test program.

A block diagram of the apparatus is shown in Figure 10. The Acoustic Test Building was used as the test location. This is a cinder block building located in a relatively remote area. This building is divided into two rooms by a 30-inch thick concrete wall. The north room of the building contained an acoustical driver which provided acoustical excitation of the north face of the test wall. A General Radio Model 1560-P5 Sound Level Microphone equipped with a General Radio Model 1560-P40 Preamplifier was placed near the wall to monitor the sound pressure level.

Two 1.0-inch diameter shear tube contact transducers were mounted on the south face of the test wall. Each was followed by a suitable filter-amplifier unit set for a bandpass of 250 Hz to 3 kHz. One transducer fed a Model 2117A Filter-Amplifier while the other transducer fed a Model 1905A Filter-Amplifier. The latter unit was designed and constructed on an earlier project. The outputs of these two filter-amplifier units were connected to the two inputs of an Ampex

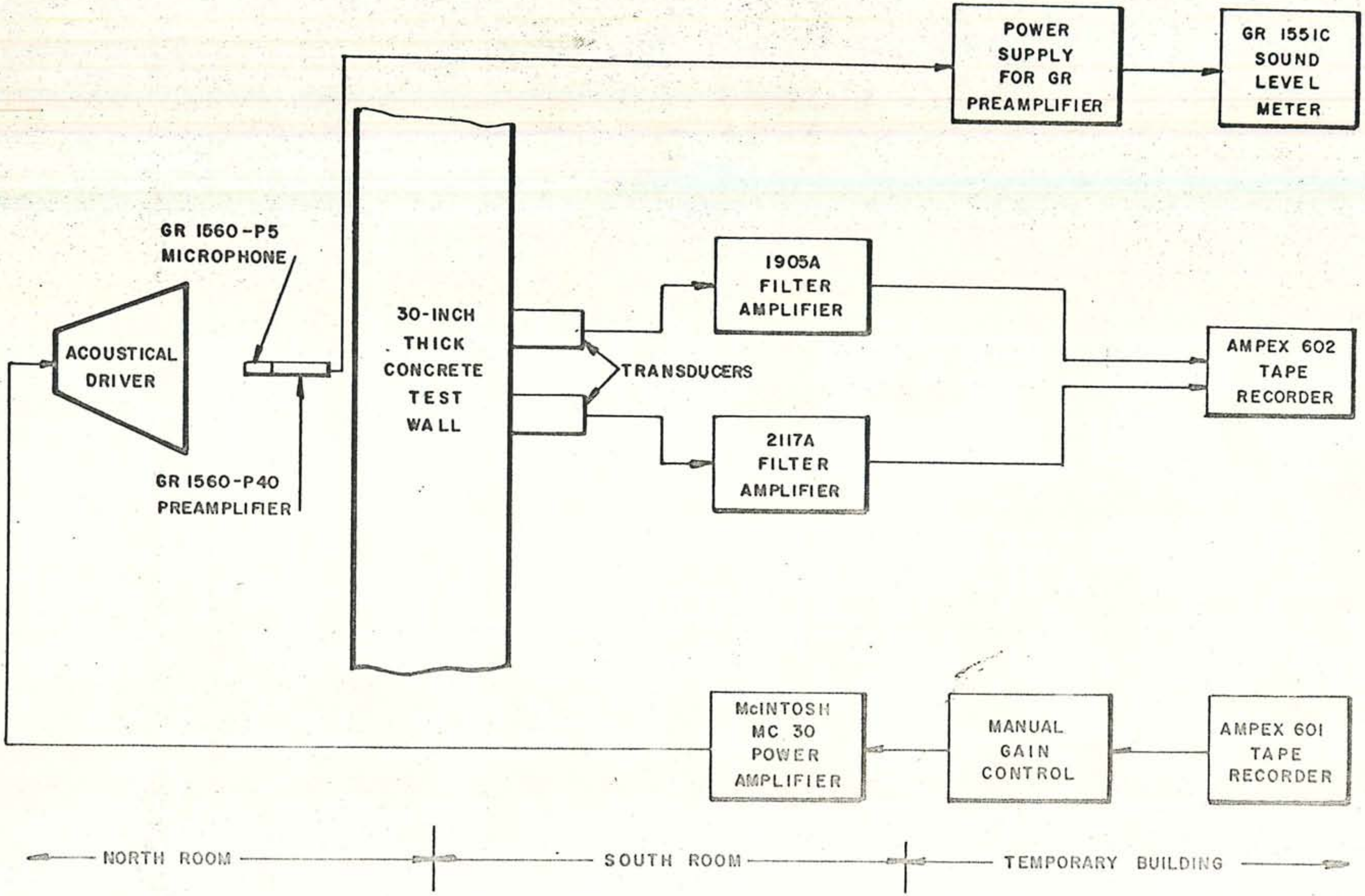

FIGURE 10

BLOCK DIAGRAM OF APPARATUS FOR RECORDING INTELLIGIBILTY TEST DATA

Model 602 Two-Channel Tape Recorder. The recorder and other equipment requiring frequent operator attention were located in a temporary building south of the Acoustic Test Building. This was to avoid interference caused by equipment noises and operator movements.

The General Radio Preamplifier was connected through a power supply box to the body of a General Radio Model 1551-C Sound Level Meter set for fast response, "C" weighting. This meter body was also located in the temporary building.

The intelligibility test source tapes were played on an Ampex Model 601 Tape Recorder through a manual gain control to a Mc Intosh Model MC-30 Audio Power Amplifier. This amplifier drove the acoustic driver.

The intelligibility data tapes were prepared by establishing a specific sound pressure level in the north room and playing several sequences of the source tapes while simultaneously recording the outputs of the two filter-amplifier units. Sound levels of 80, 70, 65, 60 and 55 dB referred to 0.0002 microbar were used. One set of data was recorded with no intentionally introduced noise, and a second set of data was recorded with the room air conditioning unit in the north room in operation.

These data tapes were played back to a listener panel consisting of six women. They wrote the words or letters which they heard on special answer forms provided for this purpose. The answer sheets were then compared to master key lists and the percentage of correct words or letters determined. The results of these tests are presented in Table II.

Examination of the figures presented in Table II indicates that the intelligibility scores from the Fairbanks Rhyme Test were consistently higher than those from the Harvard Word List. The pattern set by these figures, however, is consistent. The percent intelligibility scores decline with declining sound pressure level in all cases. In addition, for intelligibility levels above approximately 50 percent, the scores from both tests are higher for the Model 1905A Filter-Amplifier than those for the Model 2117A Filter-Amplifier. However, below this division point the Model 2117A has superior scores. This indicates that both tests are defining the same trend in the intelligibility characteristics.

TABLE II

PERCENT WORD INTELLIGIBILITY SCORES

A. No Noise, 250-3000 Hz Bandwidth

Filter-Amplifier		2117A	2117A	1905A	1905A
Test Used		Harvard	Fairbanks	Harvard	Fairbanks
Sound Pressure Level (dB re 0.0002 μbar)	80	79.1	92.1	90.0	96.6
	70	70.3	83.0	75.6	86.3
	65	66.4	67.7	70.9	75.8
	60	33.8	50.3	23.2	49.4
	55	16.0	41.9	5.3	32.3

B. Air Conditioning Operating, 250-3000 Hz Bandwidth

Filter-Amplifier		2117A	2117A	1905A	1905A
Test Used		Harvard	Fairbanks	Harvard	Fairbanks
Sound Pressure Level (dB re 0.0002 μbar)	80	83.6	94.2	91.0	96.2
	70	57.2	76.6	64.1	83.0
	65	32.4	54.3	25.1	47.4

The actual values of percent word intelligibility are affected by the reading of the sound pressure level meter during the recording process. For the Harvard test in which short sentences are spoken, an average sound pressure level can be set with moderate accuracy. However, in the case of the Fairbanks test in which only isolated, one-syllable words are spoken, only a peak reading of the sound pressure level meter can be made. Correlation of these two methods of establishing the sound pressure level would require more testing which was beyond the scope of the present program. Thus, on the basis of the tests performed here, it is not possible to categorically state that one of the tests is better than the other as far as accuracy is concerned. However, both tests indicated the same trends, and the Fairbanks test is much faster and easier to use. In addition, the special listener panel members preferred the Fairbanks test because it was less monotonous. The advantage of using the Fairbanks test as opposed to the Harvard test is that a greater statistical sample can be gathered in a shorter time and at less expense. For these reasons, it is recommended that further studies along these lines be conducted to establish a correlation between methods of reading the sound level meter.

IV. CONCLUSIONS AND RECOMMENDATIONS

During this program a new 1.0-inch diameter shear tube transducer was designed and built. This unit had better sensitivity and slightly narrower bandwidth than the 0.875-inch diameter unit developed in a previous program.

A comparison among four types of contact transducers was made. It was found that no single unit was best under all conditions, but in the majority of cases a shear tube transducer mounted in a deep hole in the target wall gave the best results.

A new filter-amplifier which was compatible with the shear tube transducers was designed and constructed. Kits containing a transducer, a filter-amplifier unit, and the required accessories were assembled and delivered to the Sponsor.

Two types of intelligibility tests were compared, but because of limited time, conclusive results were not obtained. However, it was noted that the scores from both tests conformed to the same patterns, indicating that a study should be made to isolate and find methods of controlling the variables which resulted in the individual intelligibility scores being unequal.