ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

STUDY OF CIRCUIT APPLICATIONS OF
SOLID STATE DEVICES TO ECM EQUIPMENT

PROGRESS REPORT NO. 18, TASK ORDER NO. EDG-4
Period Covering July 1, 1956 to January 1, 1957

Electronic Defense Group
Department of Electrical Engineering

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ABSTRACT

The progress of the Electronic Defense Group on Task EDG-4 is reviewed for the last half of 1956. New ceramic compositions have been developed by the Solid State Devices Laboratory which have much higher Q's and better voltage breakdown characteristics than previously used compositions. Methods of prestressing or "polarizing" ferroelectric samples have been investigated. The design of a UHF FE assembly using the 416-B triode and tuning the range 350-425 mc has been carried out. A lumped-constant, electric tuned, low power oscillator circuit suitable for operation in the UHF region has been developed. The front end units of Petr Pan have been completely redesigned and repackaged. Work has continued on the measurement of the loss tangent and the dielectric constant of ferroelectric ceramics in the microwave region. An investigation of ferrite tuned cavities, filters and related problems in the microwave region is being carried on.

TASK ORDER NO. EDG-4 (Amendment No. 1)

Title: STUDY OF CIRCUIT APPLICATIONS OF SOLID STATE DEVICES TO ECM EQUIPMENT

Starting Date: 1 July 1955 Completion Date: Continuing

Purpose of Task:

To perform applied research and engineering investigations in order to familiarize SCEL engineers with possible applications of solid state materials suitable for use in improved or advanced ECM equipment.

Procedure:

1. Determine theoretically and/or experimentally the application of solid state devices to ECM equipment which offer advantage over the use of conventional circuit elements.

2. Prepare technical reports and technical memoranda presenting the results of the investigations in a form suitable for direct application by SCEL engineers to the design of equipment. It is expected that design data, charts, and formulas will be tailored to the objective of immediate reduction to practice.

3. When it is considered desirable, simple breadboard models of circuits shall be fabricated and submitted to SCEL for study, evaluation, and familiarization with novel promising techniques.

4. Consultation and guidance will be furnished by SCEL to establish priorities of application to be exploited.

Personnel:

Electronic Defense Group:	Evans Signal Laboratory
Task Engineer	Project Engineer
T. W. Butler, Jr.	Maurice S. Blum

STUDY OF CIRCUIT APPLICATIONS OF SOLID STATE DEVICES TO ECM EQUIPMENT

PROGRESS REPORT NO. 18, TASK ORDER NO. EDG-4
Period Covering July 1, 1956 to January 1, 1957

1. PURPOSE

The purpose of this report is to review the progress made by the Electronic Defense Group Task EDG-4 in the study of the circuit applications of solid state devices to ECM equipment.

2. VISITORS AND TRAVEL

August 8, 1956. Mr. F. E. Butterfield, Electronic Defense Laboratory, discussed the work of Task EDG-4 with Dr. J. A. Boyd and Mr. T. W. Butler, Jr.

August 26-30, 1956. Professor C. B. Sharpe and Mr. I. S. Friedberg visited Diamond Ordnance Fuze Laboratory, Washington, D. C.; Bell Telephone Laboratories, Murray Hill, New Jersey; and Sperry Gyroscope Company, Great Neck, Long Island, to discuss properties and investigation of techniques at microwave frequencies.

October 2, 1956. Mr. Merlin MacKenzie, Electronic Defense Laboratory, discussed the work of Task EDG-4 with EDG personnel.

October 30, 1956. Mr. C. M. Sorvaag, Electronic Defense Laboratory, discussed work in connection with Task EDG-4 with Mr. T. W. Butler, Jr.

November 5, 1956. Mr. G. S. Stanley, California Institute of Technology, discussed with Mr. T. W. Butler, Jr. the possible role of dielectric materials as tuning elements for use in radio-astronomy receiver equipment.

No reports were issued during the period.

3. FACTUAL DATA

3.1 Ferroelectric Materials

During this period, work in the area of materials studies has continued in three areas. The investigation of polarizing the ferroelectric dielectrics in order to employ the anisotropic nature of such materials in microwave measurements and applications has continued. At the same time, new dielectric materials for VHF and microwave applications have been developed and tested. These include high dielectric constant and low loss materials, which are not ferroelectric, as well as highly non-linear ferroelectric compositions. One non-linear dielectric composition (B25F1) has been chosen as a "best representative" upon which to "freeze" design of equipments based on the non-linear dielectric property (at least for the immediate future). Work is also continuing in the investigation of the ternary system, $BaSrTiO_3$, Fe_2O_3, especially in those areas where high Q is noted. Future work in substitution of Cobalt, Nickel and Manganese ions is also considered.

3.1.1 Polarizing Ferroelectric Ceramics. In order to effectively "orient" a ferroelectric sample with respect to crystal direction in a wave guide, for example, without actually applying a DC biasing field, it would be necessary to polarize the sample. Since the application of DC biasing fields in certain experiments would grossly complicate the experimental details, it has been decided to employ the method of permanent polarization as a means of effectively biasing the samples.

The polarization is commonly accomplished by cooling the ferroelectric ceramics through their Curie temperatures while applying a DC biasing field. In principle this could also be accomplished by the application of pressure during cooling through the Curie temperature (See EDG Task 4 Progress Report No. 17).

Samples to be fired under high pressure have been sent to the Carboloy Corporation, but have not as yet been returned. In the meantime an electric field method of polarizing the samples has been set up as shown in Fig. 1. This technique has been used by many manufacturers of piezoelectric ceramics.

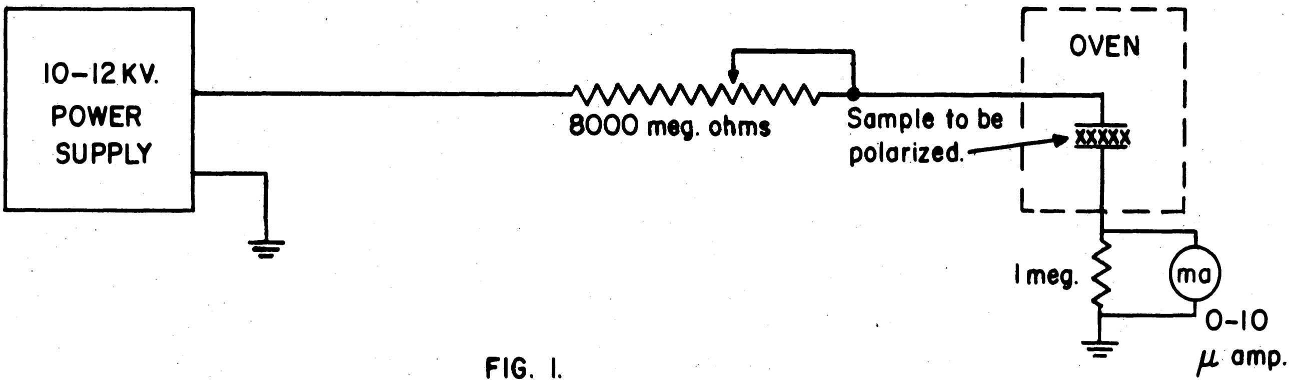

FIG. I.
SCHEMATIC ARRANGEMENT FOR METHOD OF POLARIZING SAMPLES

The experiment is arranged in such a way that a constant current is effected through the sample. Experience has shown that the best results are obtained when this current is limited to 10 micro-amperes per square inch of sample surface area. The dielectric samples have a rather low conductivity at the higher temperatures; therefore, the field across the samples must be limited to avoid dielectric breakdown.

At this time several trial runs are in progress and the data are not conclusive. It appears that, in general, for samples with peak ϵ around room temperature, the ϵ for the poled samples is about 25 % less than that of an equivalent sample. It is expected that the percentage-wise reduction in ϵ would be much greater for samples with higher Curie temperatures and this is being tested at this time. In order to apply the method of permanently polarized samples to microwave measurements and applications, it will be necessary to establish criteria for the extent to which a given sample has been polarized. These will be established during the coming period, which also should show some applications of this technique. A typical curve of ε vs T for a material such as B25F1 which has its Curie point at room temperature, is shown in Fig. 2.

3.1.2 Some New Dielectric Compositions. During the last period several new compositions have been fabricated and supplied in the form of finished circuit elements and test samples. In addition, one particular composition (i.e., B25F1 has been chosen as a best representative (temporarily, at least) of the higher Q non-linear dielectric compositions employing the Fe_2O_3 additive. It is intended to use this material specifically for the non-linear property. On the other hand, several applications have been conceived which do not demand the non-linear characteristics but do require moderately high values of ε and as high a Q as possible. In order to meet this requirement some dielectrics having these properties have been prepared. A summary of some of the more salient characteristics of representative materials, both linear with high ε, and non-linear types is given in Table I and in Fig. 3.

Table I

Some Characteristics of Representatives of Linear High ε and Non-Linear High ε Materials Made by EDG

Sample	Type		Q(100mc)	R(50v/mil) Rm.Temp.	Temp. of Max ε
B25F1	non-linear	6000	60	3.7:1	25oC
B20F1X33	linear, high ε	670	175	1:1	25°C

3.1.3 Study of $BaTiO_3$, $SrTiO_3$, Fe_2O_3 Ceramics. It has been observed that the addition of Fe_2O_3 to $BaTiO_3$-$SrTiO_3$ lowered the Curie temperature of the two component ceramics. However, when Fe_2O_3 was added to pure $BaTiO_3$, the Curie temperature remained at 120°C (the Curie temperature of $BaTiO_3$) although the original peak had been considerably flattened out by the addition of iron.[1] This led to the conjecture that iron does not enter into the composition as a solid

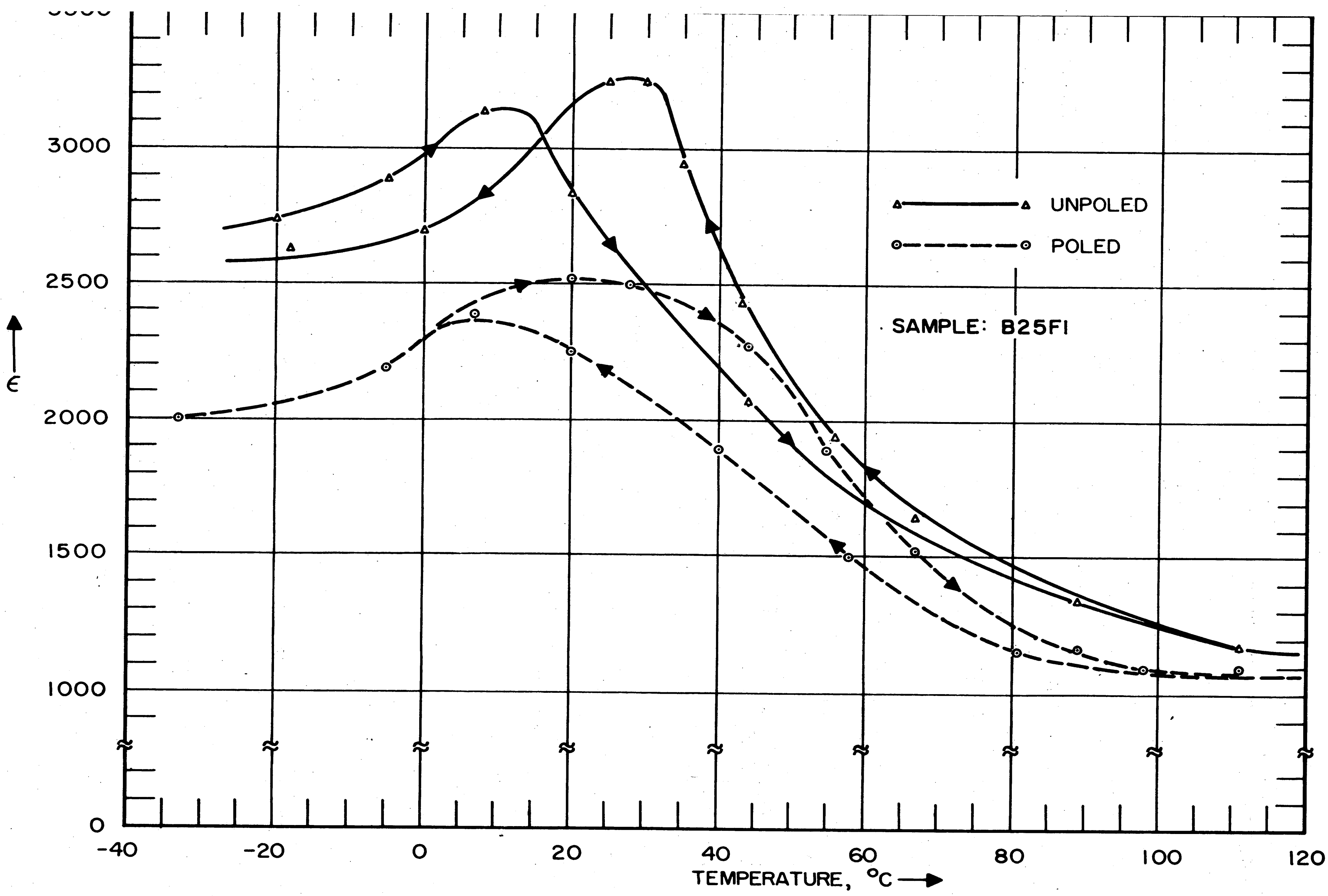

FIG. 2 EFFECT OF POLARIZING ON ϵ VS. T.

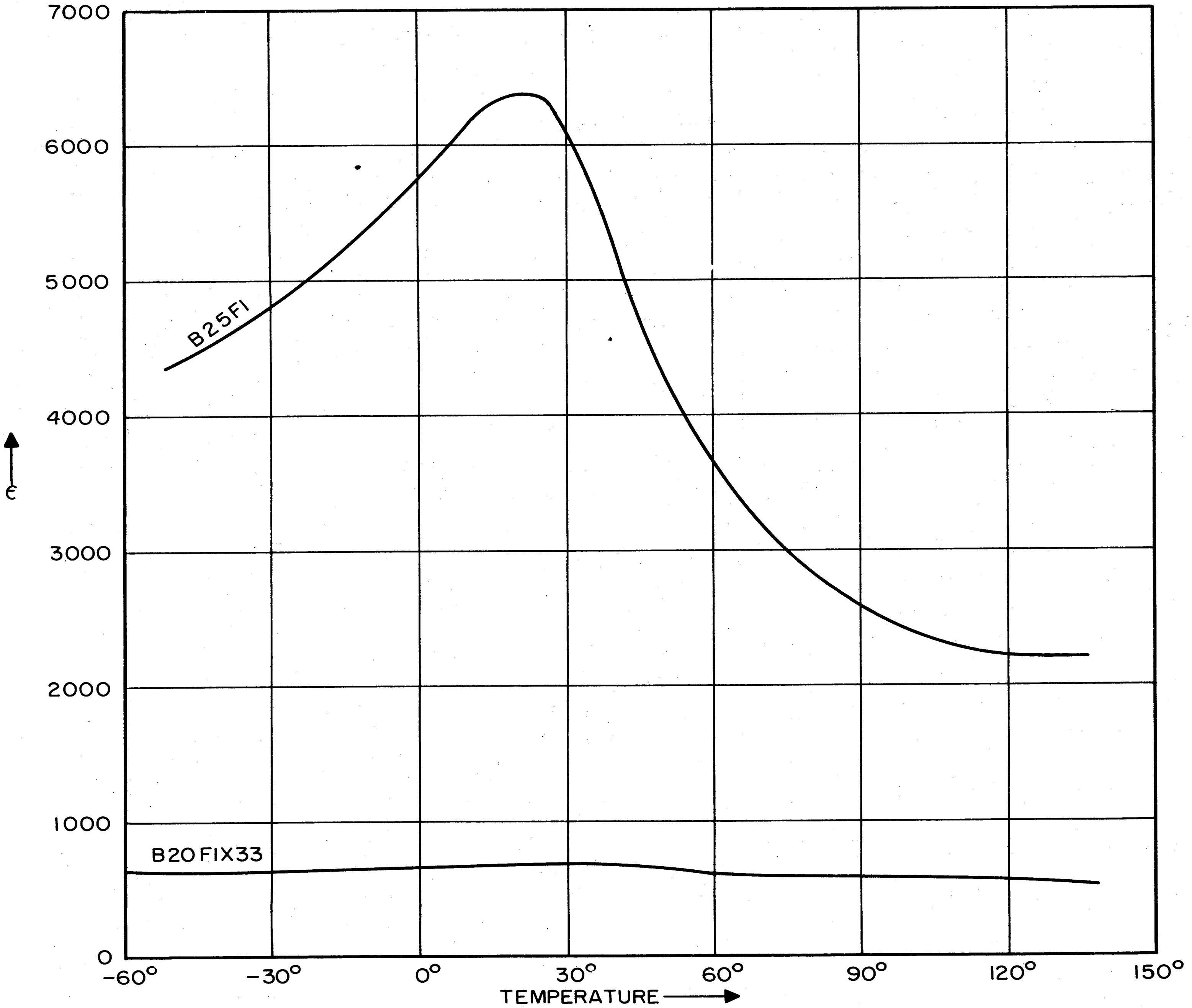

FIG. 3 ε VS. TEMPERATURE FOR TWO HIGH ε DIELECTRICS

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solution with $BaTiO_3$. The presence of $SrTiO_3$ appears to be necessary for a solid solution of all three components. In order to examine the regions in our tentative ternary diagram where there is solution of $BaTiO_3$, $SrTiO_3$ and Fe_2O_3, a series of samples along the 25°C Curie line have been examined. The results are given in Table II.

Table II

Properties of $BaTiO_3$, $SrTiO_3$, Fe_2O_3 Ceramics Close to the 25° Curie Line

Samples	Curie Temp. °C	ϵ_{max}	250 mc	Mole % Fe_2O_3 Added
B29	42	9807	53	0
B28F1	31	5231	140	0.37
B25F1	30	5340	164	0.75
B22F2	33	4600	144	1.12
B19F2	36	4300	63	1.50
B16F3	-16, 134		33	2.30
B10F3.5	-19, 137		31	2.50
B6F4	- 8, 137		25	3.00
B4F5	24, 139		21	3.40
B1F5	27, 135		23	3.80

As the % of Fe_2O_3 increases and that of $SrTiO_3$ decreases, two peaks begin to appear where there was formerly only one. It should also be noticed that high Q materials are only obtained for small additions of Fe_2O_3 (i.e., from 0.3 to 1.2 %). Another series of materials was run in which the ratio of $BaTiO_3$ to $SrTiO_3$ was held very nearly constant. Results are shown in Table III.

Table III

Addition of Fe_2O_3 to $BaTiO_3$, $SrTiO_3$ Ceramics with $\frac{BaTiO_3}{SrTiO_3} \approx$ Constant

Samples	Curie Temp.	ϵ_{max}	Q(58 mc)	Mole. % Fe_2O_3 Added
B18	77	6950	37	0
B18F1.5	20	3560	34	1.5
B18F3	-17.5	2720	58	3
B9	98	6270	34	0
B9F1	29, 120		25	1
B9F2	4, 123		19	2
B9F3	-9, 126		29	3
B4	119	3080	23	0
B4F1	32, 123		20	1
B4F2	-5, 123		17	2

From the data listed in Tables II and III, with special emphasis on the values for Curie temperatures, it appears that approximately ten times as much $SrTiO_3$ as Fe_2O_3 has to be present in order that the $BaTiO_3$ $SrTiO_3$ Fe_2O_3 ceramic form a complete solid solution.

3.1.4 Other Properties of $BaTiO_3$, $SrTiO_3$, Fe_2O_3 Ceramics.

3.1.4.1 Ageing. Ageing has a twofold effect on $BaTiO_3$, $SrTiO_3$, Fe_2O_3 materials, namely a change in color and an increase in the Q values. Over a period of months materials which were jet black after firing began to turn brown, from which it can be implied that the state of the material immediately following firing was only metastable. To illustrate the increase in Q values a list of measurements taken over a period of three months is shown in Table IV. It is seen that the Q values increase with time.

TABLE IV

Increase of Q at 50 mc and 75 mc with Time of Sample B24F1X

Date	Q at 50 mc	Q at 75 mc	Days After Firing
July 31, 1956	Firing	Date	
Aug. 2, 1956	146	95	2
Sept. 11, 1956	187	109	42
Oct. 1, 1956	211	160	62
Oct. 10, 1956	217	160	71
Oct. 23, 1956	249	196	84

3.1.4.2 Firing Under Different Atmospheric Conditions. In all samples with as little as 0.3 Mole% Fe_2O_3 addition, a jet black color is observed. This seems to indicate a chemical change (since the normal ceramic is light), such as the reduction of ferric ion to ferrous ion.

In order to find out whether the atmospheric conditions upon firing were causing this reduction, samples of $BaTiO_3$, $SrTiO_3$, both with and without the addition of Fe_2O_3, were fired in different atmospheres. In the first run, air was flushed through the furnace at a slow rate during firing, since firing in air has been the normal procedure. Further firing was conducted in oxidizing O_2 atmosphere, in an inert N_2 atmosphere, and in a somewhat reducing CO_2 atmosphere. Unfortunately, equipment was lacking for firing in a strongly reducing H_2 atmosphere.

The color as well as the dielectric behavior of the samples were compared. Contrary to what had been expected, the O_2 atmosphere did not produce lighter samples. There was almost no difference between samples fired in various atmospheres. A slightly darker ceramic was actually observed for materials fired in the air atmosphere. Also, the ϵ vs T curves gave no indication that different atmospheres had changed the properties of the ceramics.

3.1.4.3 The Dependence of Certain Ceramic Properties on the Firing Temperature for a Specific Sample.

Table V

Properties of B14F2 with Firing Temperatures

Sample Run	Firing Temp	ϵ_m	Curie Point T_c °C	Q 50 mc	Lattice Constant, A°
R3	1150	2 peaks	2 peaks	43	3.98 3.95
R4	1200	2 peaks	2 peaks	37	3.97 3.95
R5	1250	2470	-2	40	
R6	1300	3800	25		5.03 3.89
R7	1350	4350	35	40	3.94
R8	1400	2690	48	111	3.94

The way in which the reaction proceeds as the firing temperatures are increased is shown in Fig. 4. Two rather interesting effects may be noted here. First, it can be seen that as the reaction proceeds the Curie peak is shifted toward higher temperatures. Also, it can be seen from Table V that the maximum increase in Q occurs during the last 50°C increment in firing temperature (i.e., at 1400°C the Q is more than doubled over that at 1350°C).

3.2 Applications of Ferroelectric Materials

3.2.1 Voltage Tuning Program.

3.2.1.1 U.H.F. Front End Assembly (FE 11). As pointed out in the previous progress report, it is not advisable to continue designing FE units at a frequency much in excess of approximately 250 mc using presently available dielectric body materials and lumped constant design techniques, since the losses became too great for satisfactory operation of a swept receiver. However, the development of a new

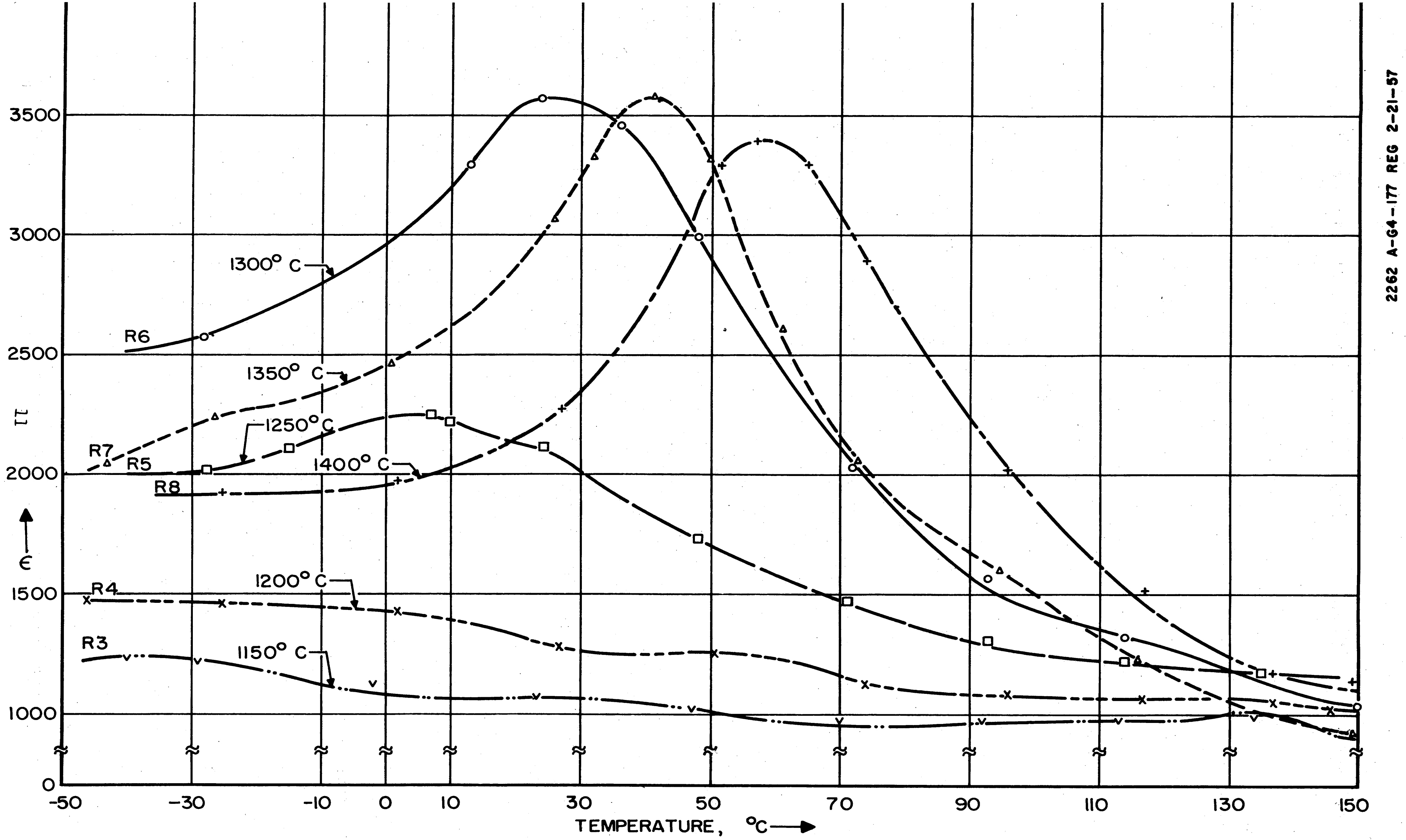


FIG. 4. ∈ VS. T CURVES OF SAMPLE B14F2 WITH INCREASING FIRING TEMPERATURES AT 2 HOURS FIRING

material which has vastly improved properties prompted the design of a UHF front end assembly (FE-11). Although capacitor tuning elements constructed from this material are not yet available, preliminary measurements were made using capacitor tuning elements constructed from commercial material but featuring low loss, low inductance leads.

The new UHF assembly (shown in the photos of Fig. 5) was designed to tune the range 350-425 mc. As shown in the schematic diagram of Fig. 6, the unit consists of two RF stages, a mixer, and a local oscillator. Grounded-grid RF stages were selected because they offered the best compromise available between good noise figure and stability. The Western Electric Type 416-B tube, which was designed for grounded-grid operation, was chosen for the various stages of the assembly. The grounded-grid amplifier is essentially a unity current-gain device with a very low input impedance and a very high output impedance. Therefore, to obtain satisfactory gain with two cascaded grounded-grid stages it is necessary to provide an impedance-matching device between stages. Impedance matching was obtained by utilizing an auto transformer type coupling circuit. The amount of step-down was adjusted empirically. The second grounded-grid stage operates through an impedance matching device into the cathode of the grounded-grid mixer stage. The tap on the input coil of the first RF amplifier was adjusted empircially for the best signal-to-noise ratio using a diode noise source. All tuned circuits can be adjusted by brass slug-tuned coils.

The mixer stage employs a 416-B triode connected in a grounded-grid circuit. Its output feeds a 20 mc IF amplifier. This type of circuit was used in an effort to standardize construction by tuilizing the same tube type for all stages of the FE assembly. The local oscillator is injected on the mixer cathode.

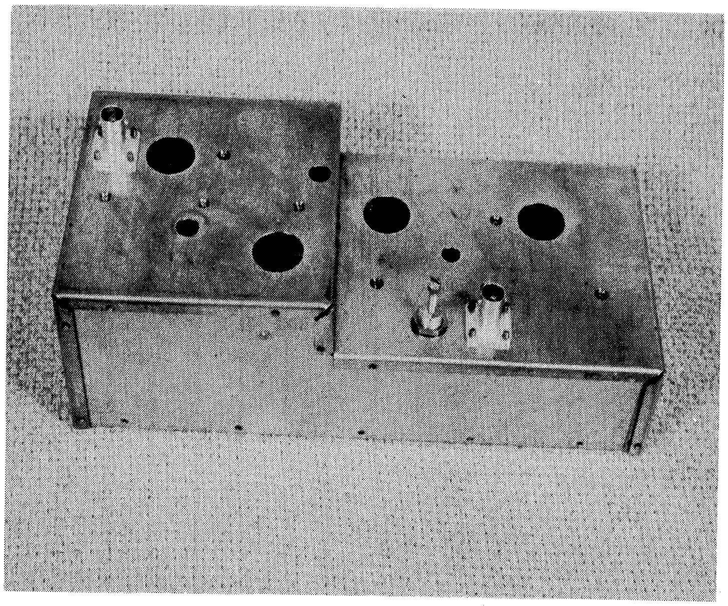


FIG. 5a

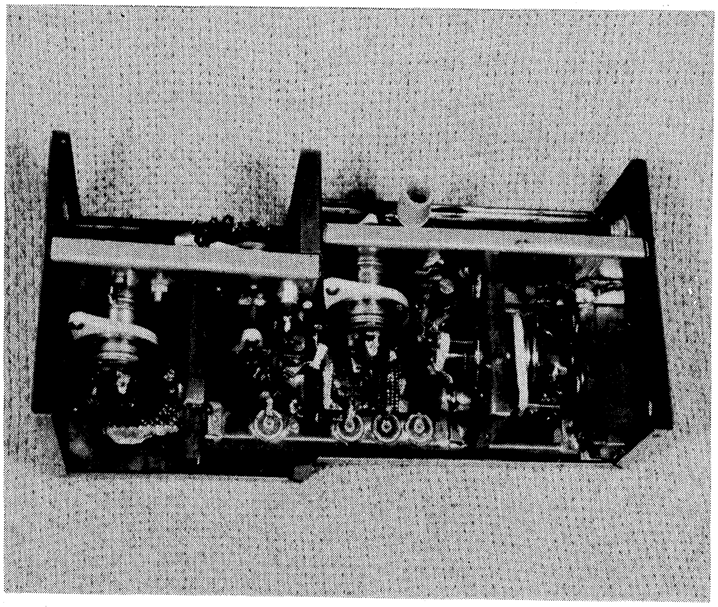
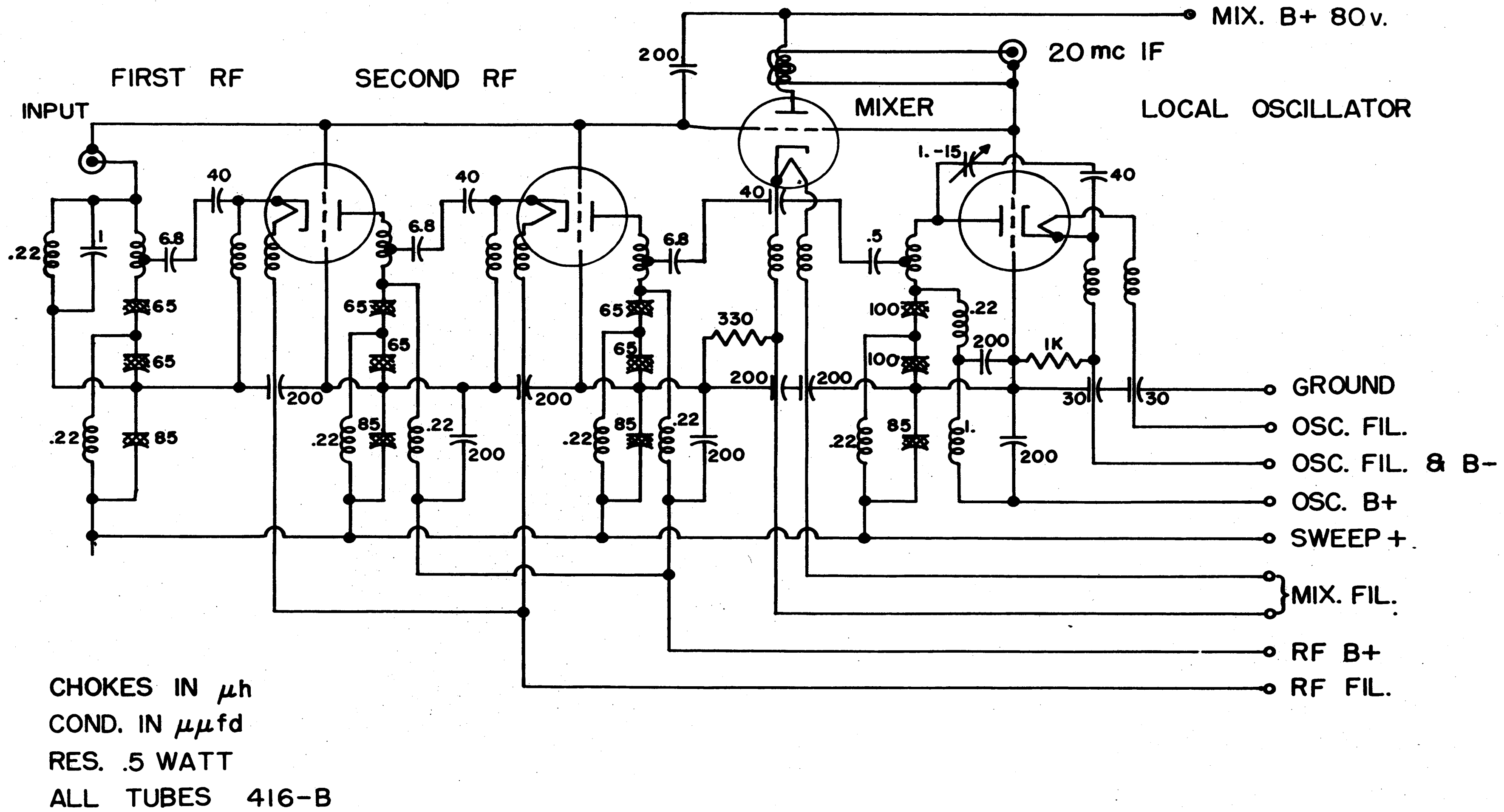


FIG. 5b

PHOTOGRAPHS OF FE-II



CHOKES IN μh
COND. IN $\mu\mu$fd
RES. .5 WATT
ALL TUBES 416-B

FIG. 6. FE-II (RECEIVER FRONT END UNIT)

TUNES 350 - 425 mc

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The amount of local oscillator excitation can be adjusted for maximum conversion gain by moving the oscillator tank coil tap and observing the IF output at a fixed RF input signal.

The local oscillator chosen for this FE assembly is a grounded-grid stage utilizing a series-tuned tank circuit. The local oscillator operates on the high frequency side of the signal. This type of operation has certain advantages in that the proximity and number of image responses are less than that obtained if the oscillator were on the low frequency side. An additional advantage is that the oscillator tuning ratio required is reduced.

The capacitor tuning elements were constructed from Aerovox Hi-Q-40 material but a new design featuring low loss, low inductance leads was used to permit their use at UHF.

Since the gain of the 416-B RF stage is high, care was taken to insure adequate decoupling and good shielding. As shown in Fig.5b the tubes are screwed into brass rings soldered to copper shields. These serve as mountings for the tubes and serve as low inductance grid returns. The 416-B has extremely close electrode spacing and, if it is allowed to become too hot due to excessive plate current or operation without forced air cooling, warping may result causing either leakage or a short as the tube cools. Forced air cooling is accomplished by means of a blower built into a compartment below the chassis. For adequate ventilation, holes are provided in the chassis as shown in Fig. 5.

Preliminary measurements on the FE assembly gave the following approximate results:

Frequency Range	347-425 mc
Voltage Gain	30 db
Image Rejection	35 db
Bandwidth	3 mc
Minimum Detectable Signal in the Noise	.3 µv

Complete measurements will be carried out when the present tuning elements are replaced by those constructed from the improved material.

3.2.1.2 UHF Electric Tuned Oscillator. A lumped-constant, electric-tuned, low-power oscillator circuit suitable for operation in the UHF region has recently bee developed. As shown in Fig. 7 the oscillator utilizes the new 416-B triode in a grounded-grid circuit. The capacitor tuning elements were constructed from Aerovo Hi-Q-40 body material and utilize low loss, low-inductance, strap-type leads.

The tuning ratio in the range 600-1200 mc is 35%* with an applied electric field of 65 volts per mil across the capacitors. Output power of approximately 10 mw into a 50 ohm load are obtainable throughout the range.

3.2.1.3 Packaged Electric Tuned Panoramic Receiver (PETR PAN). The front end units of the packaged receiver have been completely redesigned and repackaged. All units use the same type tubes and, basically, the same circuit configuration. The circuit diagram of a typical FE unit, which is designed around an RF cascode stage, a triode mixer, and a parallel-tuned Colpitts local oscillator is shown in Fig. 8. The tunable capacitors were constructed from Aerovox Hi-Q-40 material.

Table VI gives a brief summary of the performance specifications:

Table VI

Performance Specifications

Sensitivity:	two microvolts for visible signal-to-noise amplitude ratio of 2:1	
Noise Figure:	less than 10 db impedance level ~ 100 Ω	
Signal Input:	50 ohm BN connector	
Frequency Range :	FE Assembly "A"	25 - 55 mc
	FE Assembly "B"	55 - 120 mc
	FE Assembly "C"	120 - 200 mc
Scan Rate:	60 cps	
Frequency Measurement:	The marker circuit permits quick measurement of the frequency of any received signal.	
Resolution:	100 KC	

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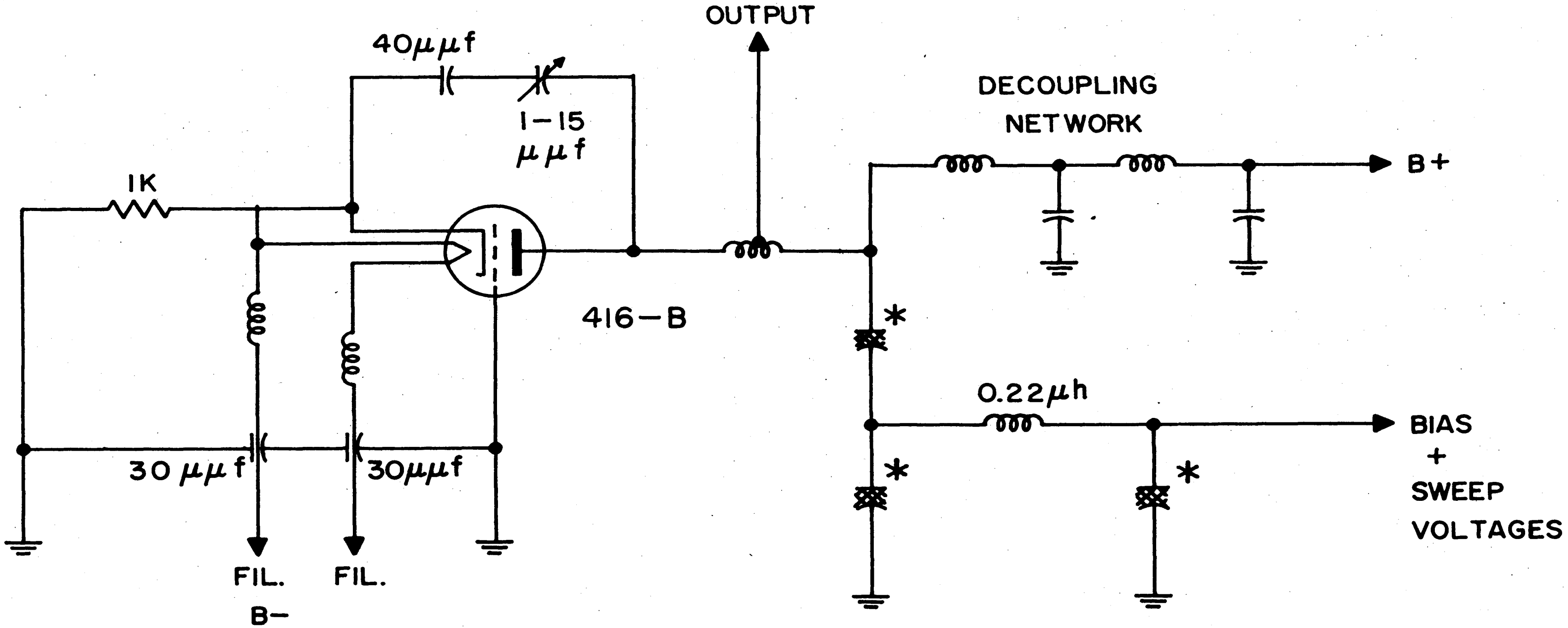
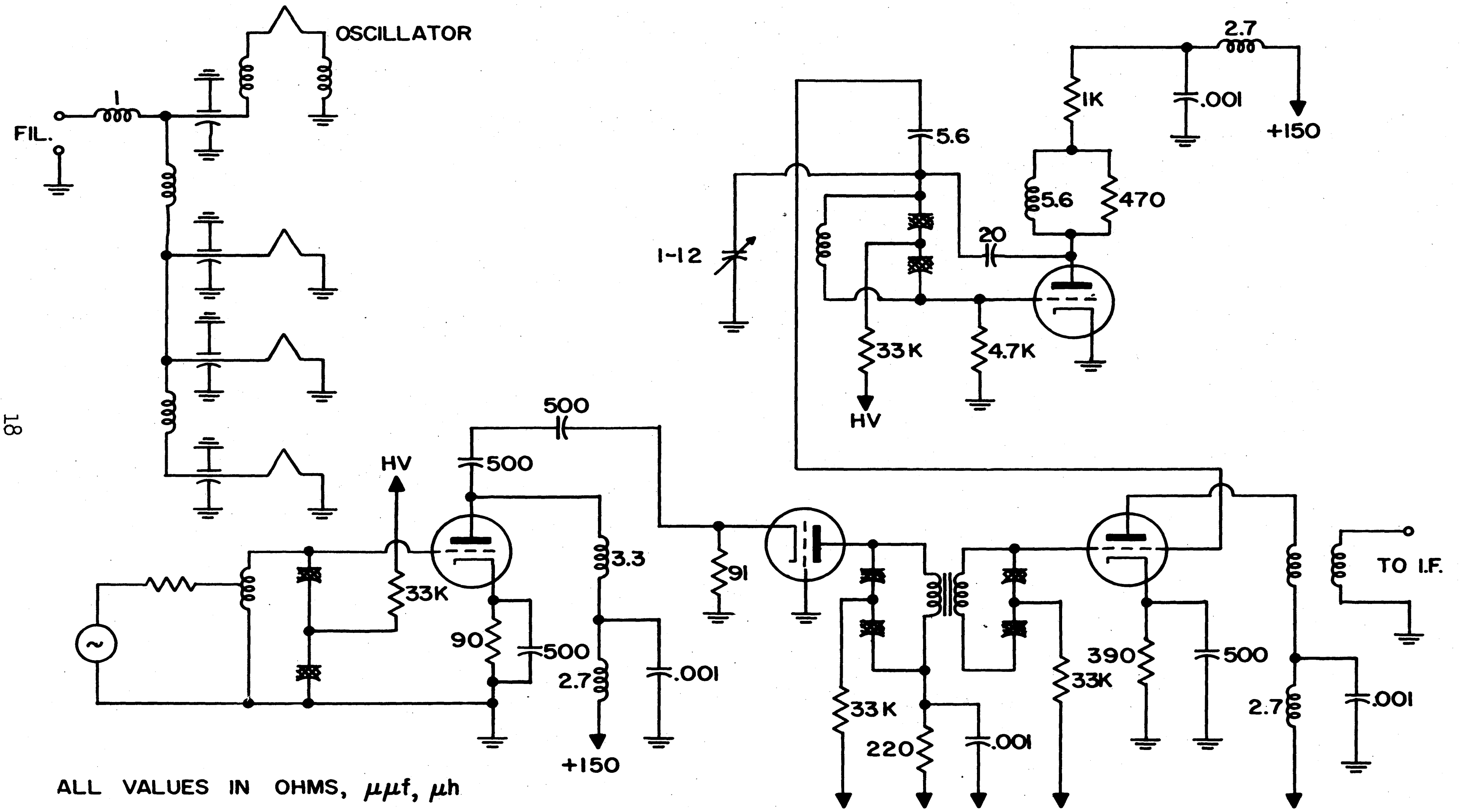
* The tuning ratio is the increase in frequency as a percent of the lowest (starting) frequency as the electric field is applied.



(* VOLTAGE TUNABLE ELEMENTS)

FIG. 7. UHF ELECTRIC TUNED LOW POWER OSCILLATOR



ALL VALUES IN OHMS, μμf, μh

ALL TUBES 417-A

1-P	4, 5, 7, 8 – g
2-NC	6 – K
3.9-FIL.	

Fig. 8
PANORAMIC RF HEAD 125 – 204 mc

The receiver work will be terminated with the completion of the final report. The report, which is essentially written, will include an evaluation of the Michigan Hi-Q material in receiver applications and some estimate as to improvements which might be anticipated due to developments in the ceramic capacitors over the short term. The report will also contain a compilation of receiver characteristics in a convenient form for comparison with other similar receivers. The receiver program should be essentially completed during the next quarter, with a consequent change in emphasis to the investigation of new devices employing ferroelectric ceramics.

3.3 Development of Microwave Devices.

3.3.1 Microwave Ferroelectrics. Work has continued on the measurement of the loss tangent and the dielectric constant of ferroelectric ceramics. This effort is part of the Task 4 program to exploit the use of ferroelectrics in the UHF and microwave region. At the present time there is very little reliable information on the characteristics of these materials in this frequency range. Powles and Jackson[2] and Davis and Rubin[3] have measured ϵ' and tan δ for barium titanate at x-band and s-band, respectively. Their methods make use of quarter-wavelength matching sections. The Powles and Jackson technique depends on having two ceramic matching sections of appropriate dielectric constant for each sample at each frequency. Davis and Rubin, while using a similar matching scheme, assumed the mismatch was negligible over a range of tan δ and ϵ' variations. This simplified their method but left an undetermined error in their experiment. The basic problem in measuring the ferroelectrics or any high -ϵ material is that it is very difficult to devise an experiment which can accurately distinguish between very large values of ϵ' (in the order of (500-3000) when the standing wave ratio is correspondingly high. In essence, the dielectric sample acts much like a conductor, and, unless considerable care is taken in matching, practically all the incident energy is reflected. Bady[4] has devised a method which does not depend on matching the sample, but his method also suffers from the difficulty of making very high standing wave ratio measurements.

Two methods of measuring the characteristics of high-ϵ materials are currently under investigation. One method makes use of a microwave bridge to measure phase shift and attenuation through the sample. Matching is accomplished by the use of slide-screw tuners, or E-H tuners, on each side of the sample. The method depends upon the rapid convergence of an iterative process which compensates for the dependence of the phase measurement upon the attenuation. The experiment has been set up using x-band components for convenience, although the technique is applicable throughout the microwave region. A technical report describing the method in detail will be prepared in the near future.

A second method of measurement is under investigation for use in the 500-4000 mc range. This method utilizes coaxial components and a dielectric matching section. Unlike the Powles and Jackson method, the same matching section is used for a relatively wide frequency range. The mismatch and attendent reflections are taken into account by a simple graphical procedure using the Smith chart. The advantage this method offers is in the simplicity of the physical layout. In addition, there is the possibility of polarizing the samples by means of an electric field.

3.3.2 Microwave Ferrites. Research in Task 4 in the microwave applications of ferrites is primarily concerned with an investigation of ferrite tuned cavities, filters, and related problems. The application of ferrites to the tuning of cavity filters and klystrons is now well known. Tuning ranges of 1.0:1.10 or 1.15 are readily obtainable using pieces of ferrite which are small relative to the cavity volume. Increasing the range of the applied magnetic field beyond certain limits leads to rapid deterioration in the Q of the ferrite loaded cavity. A substantial improvement in tuning range versus Q over what has been obtained does not appear likely without a much better understanding of the fields inside the ferrite medium as a function of the cavity geometry and the type of cavity coupling.

The approach taken by this task has been to investigate both theoretically and experimentally some of the basic aspects of the problem with the immediate view of improving the tuning range and Q of the ferrite-tuned devices. Problems which logically fall under consideration are:

a) The nature of the fields inside, and in the vicinity of, ferrite media in wave guides and cavities.

b) The importance of the ferrite dielectric constant in determining the tuning characteristics.

c) The nature and importance of mode coupling in ferrite loaded devices.

3.3.2.1 Cavity Tuning. Figure 9 illustrates an experiment which was devised to

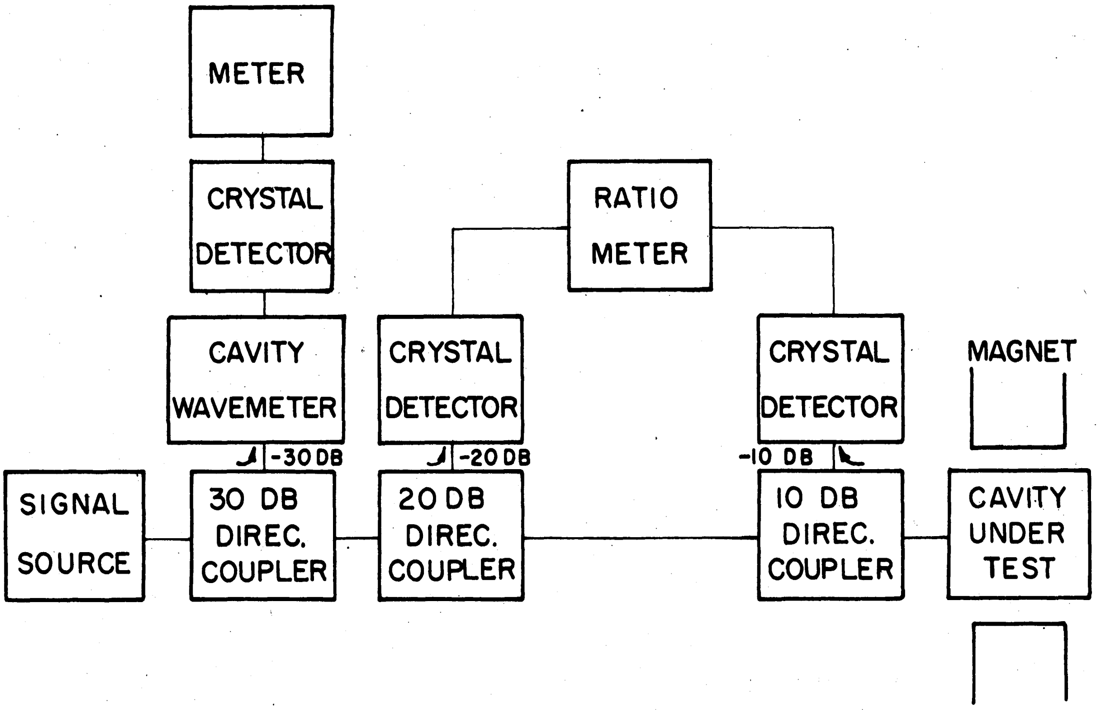


FIG. 9 - TEST SETUP FOR CAVITY TUNING EXPERIMENT

investigate some aspects of the cavity tuning problem. The ferrite is placed at the end of the cavity which, in turn, is coupled to the waveguide by an iris with a circular aperture. The magnetic field is applied in a direction parallel to the E vector of the incident wave. For a given applied field, the frequency of the signal source is varied until resonance is indicated by the ratio meter as a reduced reflection coefficient. The resonant frequency and bandwidth is indicated by the wavemeter. From the reflection coefficient, resonant frequency, and bandwidth the loaded and unloaded cavity Q is calculated.[5] A typical curve is presented in Fig. 10. The sample used is 0.090" thick and the tuning range from 0 to 1750 oersteds (with this field the Q_o has dropped to about 250) is

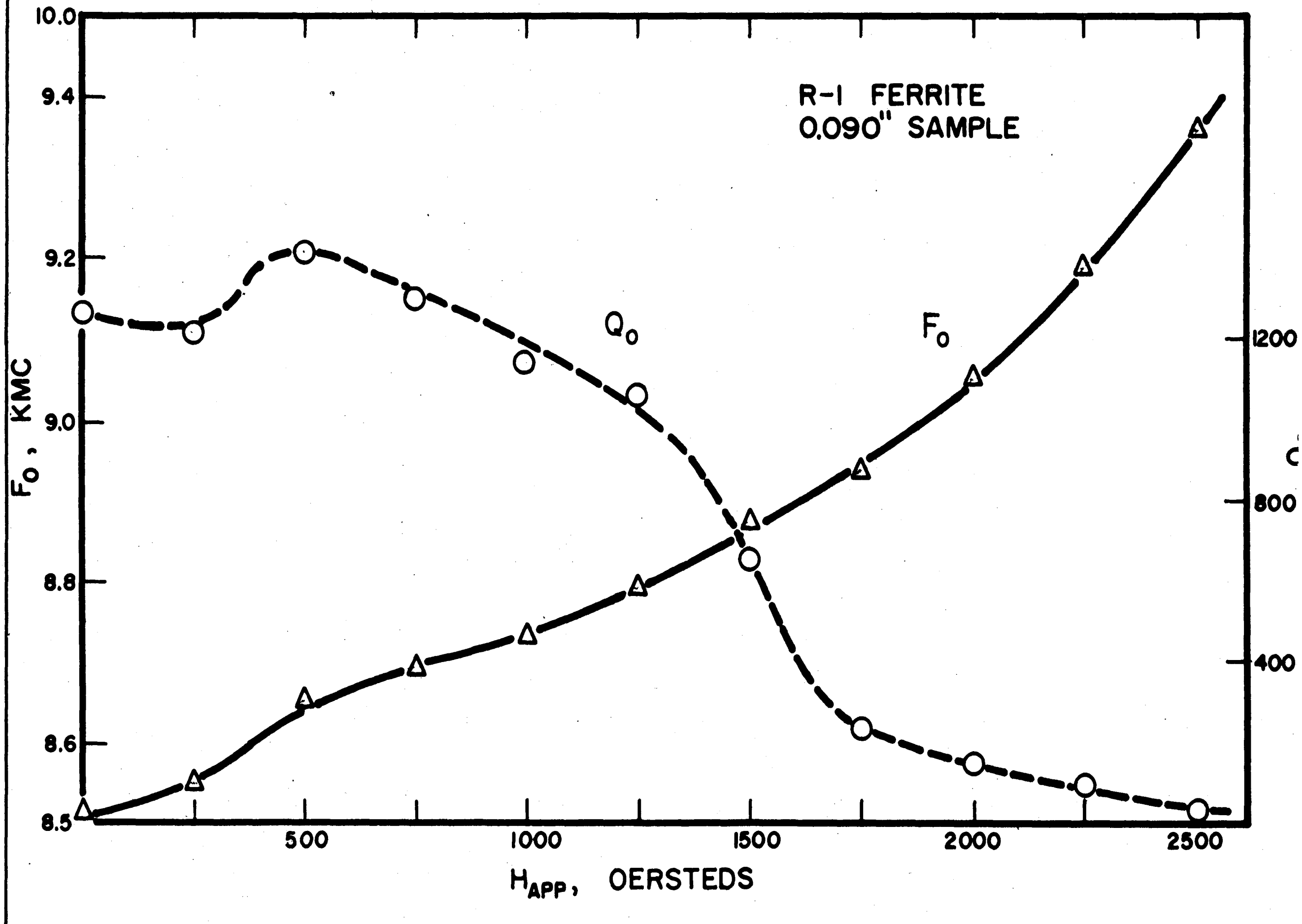


FIG. 10-TYPICAL FREQUENCY VS Q PLOT FROM CAVITY INVESTIGATION

approximately 450 mc. Samples varying in thickness from .040" to .090" have also been employed, but no general conclusions have be drawn at this time.

Multiple cavity resonances have been observed in this experiment, which is substantiated by the work of others. The explanation for this phenomena has not as yet been found. It is possible that the theoretical problem discussed in the next section will shed some light on this rather important characteristic of ferrite tuned cavities.

In order to provide data which are subject to more direct interpretation, a modification of the cavity experiment is under way. This experiment will measure directly the impedance presented to the waveguide by the ferrite as a function of the applied magnetic field. The data obtained can also be used to verify the results of the analytical study discussed below.

3.3.2.2 Theory. A theoretical problem of basic interest is illustrated in Fig. 11. The ferrite which fills the rectangular guide is magnetized in the y-direction. The incident TE_{10} wave is converted at the air-ferrite interface into an infinite set of reflected and transmitted modes, the relative magnitudes of which depend on H_{dc} as well as the frequency and the parameters of the ferrite. Although this boundary-value problem would appear to be straightforward, its solution up till now has not been found. However, definite progress has been made at EDG in obtaining a solution during the last interval and the results are now being evaluated. A technical report presenting the solution in terms of the electric and magnetic fields at the interface and the equivalent circuit will be issued in the near future..

3.3.2.3 Faraday Rotation. It was pointed out in Progress Report No. 6 that a plane polarized wave undergoes what is known as Faraday rotation as it propagates through a ferrite magnetized in the direction of propagation. The measurement of this phenomenon can be used to provide a rough evaluation of ferrite materials. The experiment can also provide an indication of the behavior of ferrites which might be expected in various cylindrical geometries. An accurate determination

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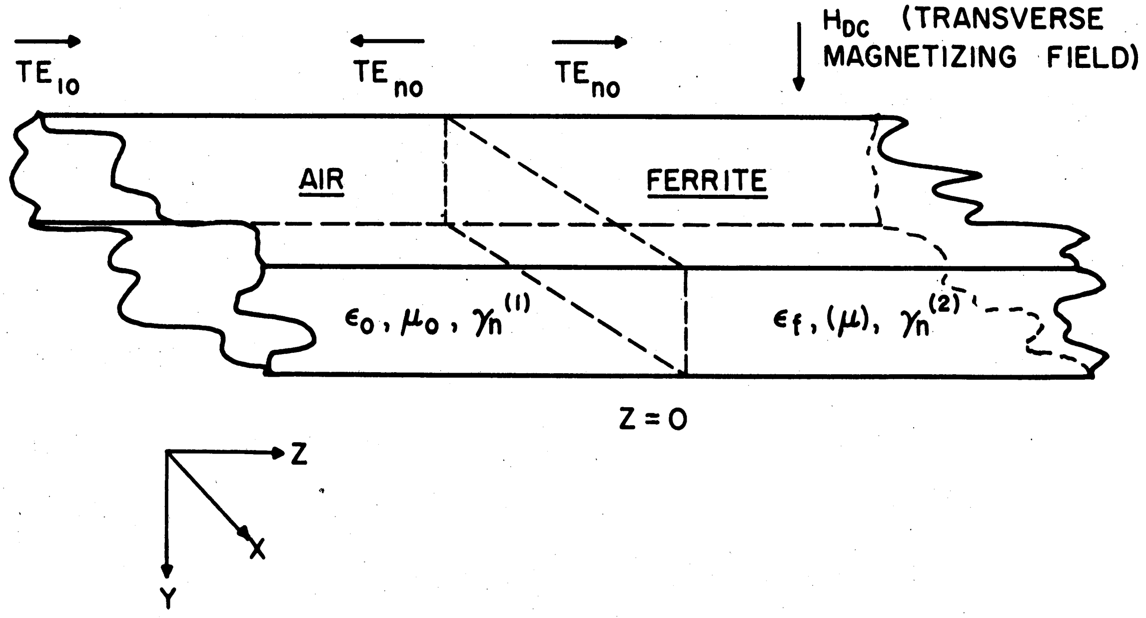

FIG. 11. REFLECTION FROM A FERRITE IN A RECTANGULAR WAVE GUIDE

of the Faraday rotation angle can be made by making phase shift measurements on each of the two circularly polarized modes separately. In the last interval two quarter-wave plates were designed and constructed. These plates transform a plane polarized wave into an elliptically polarized wave with maximum ellipticity of 1.22 over the frequency range 8-10 kmc. This maximum value of ellipticity corresponds to a ratio of desired to undesired polarization of 20 db or greater.

Figure 12 demonstrates the use of these plates in the measurement of

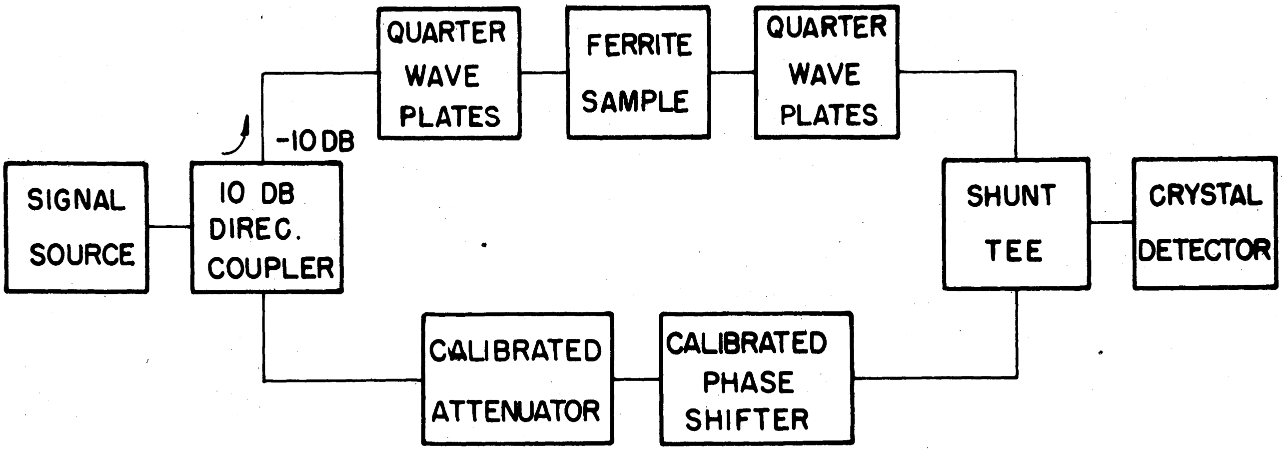

FIG. 12- TEST SETUP FOR FARRADAY ROTATION EXPERIMENT

Faraday rotation and attenuation by a ferrite rod. With no magnetic field applied to the ferrite, the calibrated attenuator and phase shifter are adjusted for a null at the crystal detector. The magnetic field is then applied and varied. For any given value of field, the calibrated attenuator and phase shifter are readjusted to maintain a null at the crystal detector. The change of attenuation and phase shift measures the loss and the Faraday rotation in the ferrite. This can be repeated for different frequencies. This work is inactive at the present time.

4. CONCLUSIONS

The objectives for the period have been met and all phases of the work appear to be progressing satisfactorily.

5. PROGRAM FOR THE NEXT INTERVAL

a) Continue improvement of Michigan High-Q ferroelectric material.

b) Complete report on Petr-Pan.

c) Continue investigation of distributed constant circuits in the range 100 and 1000 mc using ferroelectric ceramics.

d) Continue study of microwave applications of ferroelectric ceramics.

e) Continue investigation of ferrite tuned cavities, filters and related problems in the microwave region.

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