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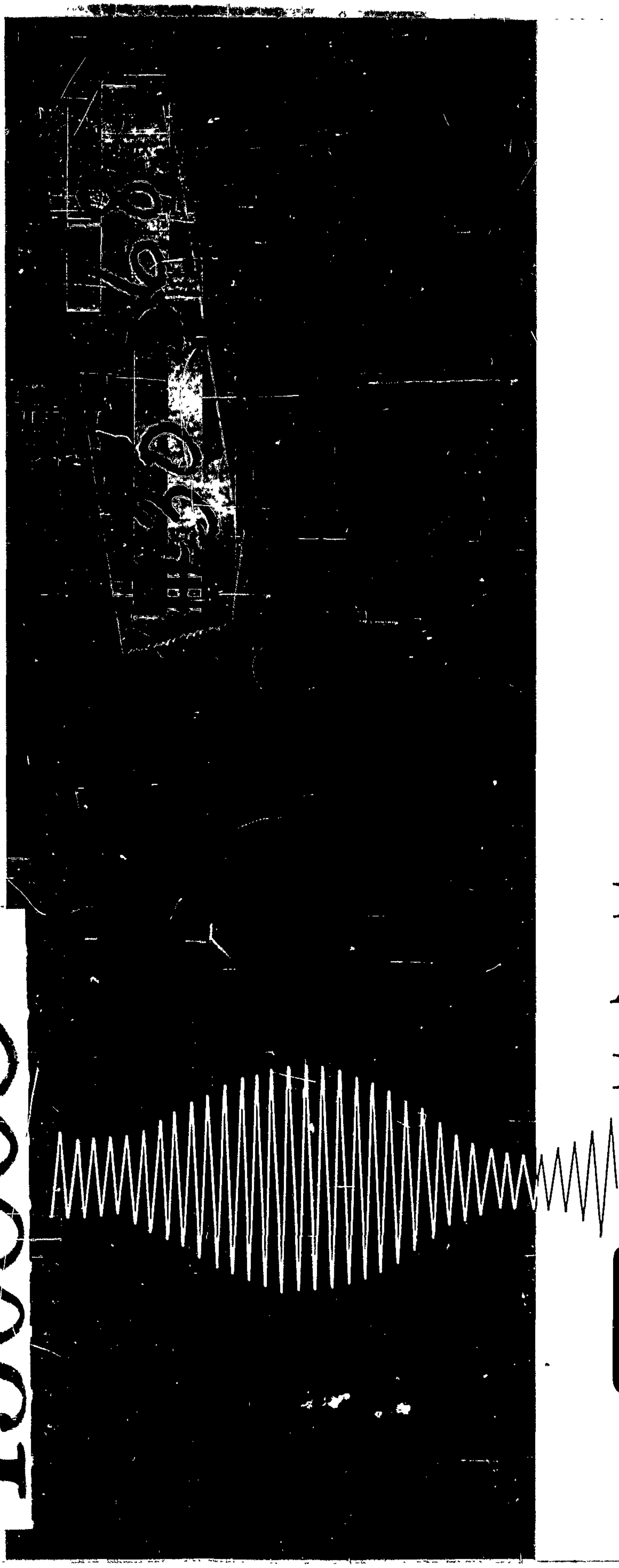



MINIATURIZED X-BAND
STRIPLINE DUPLEXER

Report No. 1
Contract No.
DA 36-039 AMC-03230 (E)

Task No. IG6-22001-A-055-04

FIRST QUARTERLY PROGRESS REPORT
1 July 1963 to 30 September 1963

U.S. Army Electronics Research
and Development Laboratory
Fort Monmouth
New Jersey

# MICROWAVE ASSOCIATES, INC.

BURLINGTON, MASSACHUSETTS

MINIATURIZED X-BAND
STRIPLINE DUPLEXER

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Technical Requirement SCL-5929 14 January 1963

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FIRST QUARTERLY PROGRESS REPORT

1 July 1963 to 30 September 1963

The object of this program is to develop a miniaturized stripline duplexer for use in a lightweight radar system.

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## SECTION I

## PURPOSE

The objective of this program is the development, construction and evaluation of a miniaturized stripline duplexer for use in a lightweight radar system. The duplexer shall be capable of operation in the X-band frequency range between 9,000 and 10,000 megacycles. The duplexer to be developed and constructed shall be designed to operate with a single microwave generator. The microwave generator shall supply both the transmitter and the local oscillator signals. During the transmit cycle, the duplexer shall provide a low-loss transmission path between the transmitter input port and the antenna port; and at the same time the duplexer shall isolate the mixer from the high power transmitter pulse. During the receive part of the cycle, the signal from the antenna shall be transmitted to the mixer circuit with low loss and at the same time the local oscillator signal incident at the transmitter input port is transmitted to the mixer with low loss.

## SECTION II

## ABSTRACT

The objectives of this development program on a miniaturized X-band stripline duplexer are discussed in relation to the present state-of-the-art. General approaches to the problem are outlined. The various major elements of the duplexer are discussed and the method of approach to the solution of each pertinent problem is analyzed.

A broadband waveguide-to-stripline transition has been developed covering the frequency range of 9,200 to 9,700 megacycles. The experimental results of this investigation are discussed and indicate that initial test results show promise for further broadbanding techniques.

An experimental fixture has been constructed for the convenient testing of limiter modules. This fixture utilizes the broadband waveguide-to-stripline transition mentioned previously. The method of approach and the expected results of this stage of limiter module development are discussed.

A test fixture has been designed to evaluate the ferrite circulator module. Various transmission line configurations and a limited number of ferrite materials have been investigated. The preliminary test results are discussed and future methods of approach are analyzed.

Studies are also underway on the development of a broadband TNC-to-stripline transition and a broadband directional coupler covering the 9,000 to 10,000 megacycle band. Preliminary experimental results show promise. A complete discussion will be given in a later report.

## SECTION III

## CONFERENCES

1. Conferences

On July 25, 1963, a meeting was held at Microwave Associates, Inc., Burlington, Massachusetts, attended by Messrs. W. Wright and R. True of the United States Army Electronics Research and Development Laboratory and R. Tenenholtz and J. Christian of Microwave Associates, Inc. The principal subject discussed was the establishment of a work schedule for the completion of major milestones in the duplexer program. Subsequent to this conference specific completion dates were assigned to these major areas as follows:

| | | |
|---|---|---|
| 1. | Limiter Module | 15 January 1964 |
| 2. | Ferrite Circulator Module | 29 February 1964 |
| 3. | Engineering Test Module | 15 April 1964 |
| 4. | Deliver last of Three (3) Prototypes | 31 July 1964 |

2. On September 10, 1963, a meeting was held at Microwave Associates. Inc., Burlington, Massachusetts, attended by Messrs. R. True of the United States Army Electronics Research and Development Laboratory and J. Christian, R. Brunton and S. Segal of Microwave Associates, Inc. The principal subjects discussed during this conference were the task organization and the specific design approaches to be pursued during the first quarter relative to the limiter module, passive components and the ferrite circulator module. Preliminary electrical tests on the wideband stripline-to-waveguide transition were discussed.

## SECTION IV

## FACTUAL DATA

1. Introduction

1.1 Program Objectives

This is the first quarterly report on a program to develop a Miniaturized Stripline X-Band Duplexer. The duplexer shall be capable of operation in the X-band frequency range between 9,000 and 10,000 megacycles. The duplexer to be developed and constructed shall be designed to operate with a single microwave generator. The microwave generator shall supply both the transmitter and the local oscillator signals. During the transmit cycle, the duplexer shall provide a low-loss transmission path between the transmitter input port and the antenna port (see Figures 1 and 2) and at the same time the duplexer shall isolate the mixer from the high power transmitter pulse. During the receive part of the cycle, the signal from the antenna entering port 2 shall be transmitted to the mixer circuit connected to ports 3 and 4 (Figures 1 and 2) with low loss and at the same time the local oscillator signal incident at port 1 is transmitted to ports 3 and 4 with low loss.

### 1.1.1 Detailed Electrical Requirements

| | |
|---|---|
| (a) Frequency Range | |
| (1) Minimum | 9200 to 9700 Mc |
| (2) Maximum | 9000 to 10,000 Mc |
| (b) Pulse Recurrence Rate (prr) | 5 kc Max. |
| (c) Duty Cycle (Du) | 0.002 Max. |
| (d) Peak Power (po) | 500 W Min. |
| (e) Average Power (Po) | 1 W Min. |
| (f) Pulse Width | |
| (1) Minimum | 0.2 $\mu$sec. |
| (2) Maximum | 1.0 $\mu$sec. |
| (g) Recovery Time | 0.5 $\mu$sec. Max. |
| (h) High Power Insertion Loss | |
| Port 1 to Port 2 | 1.0 db Max. |
| (i) High Power Spike Leakage Energy | |
| (1) Port 1 to Port 3 | 0.2 ergs Max. |
| (2) Port 1 to Port 4 | 0.2 ergs Max. |
| (j) High Power Flat Leakage Power | |
| (1) Port 1 to Port 3 | 20 mw Max. |
| (2) Port 1 to Port 4 | 20 mw Max. |
| (k) High Power Isolation | |
| Port 2 to Port 1 | 12 db Min. |
| (l) Low Level Insertion Loss | |
| (1) Port 2 to Mixer | 1.0 db Max. |
| (2) Port 1 to Mixer | 0.5 db Max. |
| (m) High Power VSWR, Port 1 | 1.4 Max. |
| (n) Life* | 500 Hours Min. |



*Based on a mixer sensitivity degradation of 2 db Max.

1.1.2 <u>Mechanical Requirements</u>

| | | |
|---|---|---|
| (a) | Weight | 10 oz. Max. |
| (b) | Size | 3 x 2 x 1 in. Max. |
| (c) | Configuration | Micro-module configuration is desired |

1.1.3 <u>Environmental</u>

The duplexer shall meet the applicable environmental requirements specified in Table I, Group I of Specification MIL-STD-446 with the exception of life requirements.

1,1.4 <u>Life Test</u>

The life of the duplexer shall be demonstrated by testing the device with 500 watts of peak power incident at port 1 and a balanced stripline mixer connected to ports 3 and 4. The device shall provide adequate mixer crystal protection for the specified time (1.1.1-n) such that tangential sensitivity of the mixer shall not degrade more than 2.0 db.

1.1.5 <u>Sample Duplexers</u>

Three (3) sample duplexers shall be constructed as a result of this development. All three devices shall be identical except for the port connectors as specified below.

(a) Duplexer No. 1: Ports 1 and 2 shall employ TNC connectors.

(b) Duplexer No. 2: Ports 1 and 2 shall employ a TNC connector and waveguide flange (UG-39/U) respectively.

(c) Duplexer No. 3: Ports 1 and 2 shall employ waveguide flanges (UG-39/U).

(d) All three duplexers shall employ connections on ports 3 and 4 that will be mutually agreed on by the contractor and contracting officers technical representative.

1.2 Technical Background

Because of size and weight limitations imposed on the duplexer, use of a gas TR approach becomes prohibitive. Therefore, other duplexing means must be seriously considered. The most obvious alternative is the employment of microwave PN junction diode duplexing techniques. This enables small size and weight characteristics to be obtained and also allows an inherent long life capability to be achieved.

1.2.1 Basic Varactor Diode Theory

In Figure (3), the varactor constructional schematic shows it to consist of a P+-N-N+ sandwich arrangement of semiconductor material, thereby creating a PN junction. Silicon materials are used for the varactors employed, the reason for this will be shown in a subsequent discussion.

At zero bias, the PN junction is at equilibrium. Holes and electrons distribute themselves so that there are essentially none at the vicinity of the junction and the density gradually increases upon proceeding into their respective regions. The region, free of electrons and holes, is called the depletion layer and is caused by material contact potential difference. If a small forward bias is now applied across the varactor (+ on the "P" side), some holes and electrons will move toward each other until a new equilibrium condition is reached. As a result the depletion layer will decrease in thickness. Conversely, a negative voltage applied across the varactor will result in a thicker depletion layer.

The net effect of these characteristics is the realization of a voltage dependent capacitor with the depletion layer representing the area between two equivalent parallel plates. The general capacitive characteristic as described is shown in the accompanying plot of Figure (3). For microwave applications, it is important that this voltage dependent capacitance characteristic be capable of responding at an extremely rapid rate. This has indeed been found to be true since holes and electrons need only move a small portion of the depletion layer width in order to change the voltage dependent capacitance appreciably.

The simple varactor equivalent circuit shown in Figure (3) consists of the depletion layer capacitance in series with a small but finite resistance, $R_s$. The latter quantity arises from the relative lightly doped "N" region and some ohmic contact effects. Generally speaking, both P+ and N+ regions will not contribute to $R_s$ due to their heavily doped characteristics.

In comparing varactor quality, a figure-of-merit expression termed cutoff frequency can be used. This is shown in Equation (2-1)

$$fc_o = \frac{1}{2\pi R_s C_o} \qquad (2\text{-}1)$$

where $fc_o$ is the zero bias cutoff frequency

$R_s$ is the zero bias varactor series resistance

$C_o$ is the depletion layer zero bias capacitance

In most varactor applications, primary concern has been limited to the region where depletion layer capacitance is predominant (negligible forward conduction). However, in varactor limiter applications, the region of forward conduction plays an equally important part. From previous varactor impedance measurement data at X-band, $R_s$ has been shown to change drastically when the varactor is subjected to high forward bias levels in the order of 10 milliamperes. This results from the injection of carriers into the "N" region thus lowering its resistance contribution to $R_s$. Typically, the change in varactor series resistance can be four to one and thus result in a lower value which will be termed $R_s$. This general action of a decreasing series resistance under forward bias is referred to as conductivity modulation.

Intuitively, one can visualize the process of conductivity modulation to be very desirable for microwave limiter applications. When subjected to relatively large power levels, the varactor will bias itself in the forward region and undergo a large impedance change. Whether or not the varactor can handle this power level depends on the amount of power dissipated by the PN junction and the voltage across it. Both characteristics depend greatly on the varactor series resistance $R_s$.

In semiconductor materials other than silicon, such as gallium arsenide, conductivity modulation does not effectively take place. Therefore, for a varactor of this type to have a comparably high power series resistance value, it must exhibit approximately four times the cutoff frequency at zero bias. This comparison well exhibits the advantage of silicon type varactors with respect to high power limiting applications.

### 1.2.2 Basic PIN Diode Theory

Another PN junction semiconductor device, similar to the varactor, is the PIN diode. However, unlike the varactor, a diode of this type incorporates a relatively thick intrinsic layer between the P+ and N+ regions as shown in Figure (4). The high resistivity and relatively low dielectric constant of this material enables the PIN diode to appear as a variable resistance as opposed to the variable reactance characteristic of the varactor. The general effective impedance variation as a function of bias is shown by the accompanying graph in Figure (4).

In the zero or reverse bias state, the PIN diode can be represented by a simple series RC circuit with the capacitance being primarily determined by the I region geometry, and the series resistance determined by the resistivity of the P+ and N+ regions. Typically, both capacitance and series resistance can be made very small causing the net junction impedance to appear as an open circuit.

In the forward bias state, that is, when appreciable current is passed through the diode, injection of holes and electrons into the I region causes it to appear as a low resistivity electron hole plasma. In actual practice, the variable resistance characteristic can be made to appear as several thousand ohms at negative bias and a fraction of an ohm under forward conduction conditions of several tens of milliamperes bias current.

Therefore, the PIN diode can be used as a variable resistance or as a two-state device by simply selecting appropriate forward and reverse bias levels.

Attractive as it may seem for microwave power control devices, the PIN diode suffers from one main disadvantage. Because of the relatively thick I region, response to a microwave signal in the X-band region is relatively slow. In the varactor, only a small distance need be traversed by electrons and holes to create an effective impedance change. However, in the PIN diode, these carriers encounter the I region and cannot penetrate a sufficient distance during a half cycle RF time period to cause any appreciable impedance state change. This difficulty can be well appreciated when one considers the distances involved to be angstroms and mils for the varactor and PIN diode respectively.

At X-band the above described disadvantage precludes use of the PIN diode as a limiter but still allows it to be used as an effective switch when controlled by an external bias source. For this type application, the PIN diode is far superior to the varactor by virtue of its high voltage breakdown I region and larger PN junction area. The latter characteristic is important when considering power dissipation characteristics.

### 1.2.3 PN Junction Diode Packaging

Normally, PN junction diodes are housed in a package convenient for handling and protection. Typically these can assume the forms as shown in Figure (5). Unfortunately, the welded pill and glass package types have associated with them parasitic reactances. These reactances are due to an inductance in series with the PN junction and a capacitance shunting this series combination. The general effect of these reactances in microwave switching or limiting applications is to reduce the bandwidth and increase dissipation loss.

These effects can be overcome to some degree by incorporating proper tuning provisions in the microwave structure housing the diode limiter or switch. However, full realization of performance of the PN junction diode without parasitics can never be completely obtained. Another approach is the construction of a packageless diode as also shown in Figure (5). In this case, the package has been completely eliminated and the bare semiconductor pellet is exposed. This type of diode construction has been successfully employed in ridge waveguide structures where the semiconductor pellet completely occupies the ridge gap. However, for the stripline type of transmission line it is doubtful that any advantage would be gained using this packageless diode. This arises from the fact that when forward biased in a stripline circuit, the semiconductor pellet and associated mounting stud appear as an effective parasitic series inductance. Though still superior to some degree over the packaged diodes, the added mechanical complexity involved does not warrant its use if packaged diodes will suffice.

### 1.3 Technical Approach

In order to achieve a design capable of satisfying Technical Requirement SCL-5929 and those requirements stated in this report, the small compact design depicted in Figure (2) will be pursued. This design approach takes full advantage of the fact that both transmitter signal and local oscillator are generated from the same source.

#### 1.3.1 Theory of Operation (Transmit Period)

During the transmission period of the system (1.0 μs Max.) power is applied incident to port 1. It passes through the stripline circulator and then splits equally and in phase quadrature between the two output arms of the 3 db hybrid. After leaving the hybrid, each high power portion is sampled by a 30 db coupler which in turn feeds two high burn out crystals used to supply bias to the PIN diodes. Therefore, after a short but finite time period, the PIN diodes are placed in a full conduction state resulting in high isolation. Any leakage power passing through the PIN stages will become incident on the varactor limiter stages and be attenuated even further. Assuming an isolation value (neglecting spike leakage) of 25 db for each stage over the frequency range of interest, a total isolation value of approximately 56 db for flat leakage will be secured. This, of course, assumes a spacing between limiter stages, $\theta$, of an odd number of quarter wavelengths.

As for spike leakage from the PIN stage, it could be expected to have a maximum value of 10 ergs. However, before passing into the mixer at port 3 (or 4) the varactor limiter would lower it to a value far less than 0.1 erg. Therefore, adequate protection is provided for the mixer. For the approach used here, the mixer would consist of one forward and one reverse crystal connected together at the I.F. output terminals.

Returning now to the majority of power incident on the PIN limiter stages, a high degree of reflection takes place. The effect of leakage power through the PIN limiter stages and power dissipated in the PIN limiter itself is to reduce reflected power by approximately 12 per cent. This would yield an arc loss value of 0.5 db. Therefore, the 88 per cent of initial transmitted power (neglecting transmission line and ferrite circulator losses) will recombine and leave through port 2, the antenna arm. Cancellation will take place in the transmitter arm since a phase quadrature power split relation is once again introduced. Should some power happen to enter this arm due to any slight nonidentical PIN limiter characteristics, it will be dissipated in the circulator load arm. Stripline circulators in the X-band region could typically be expected to provide a minimum isolation of 15 db when used as an isolator as is in this case. Should any power be reflected from a mismatched antenna, it would be reflected back by the PIN limiter stages and again be dissipated in the circulator load arm. The transmit cycle can now be considered complete.

1.3.2 Theory of Operation (Receive Period)

During the receive period, power entering the duplexer at port 1 has dropped in amplitude to a level associated with local oscillator operation.* It will split equally and in phase quadrature between the two input arms of the 3 db hybrid and pass through the limiter sections unattenuated by limiter action. This is because its amplitude is below the threshold of limiting for either the PIN or varactor limiter stage. Any received signal entering port 2 will also behave in a like manner, with the resultant LO and received signals being equally split between ports 3 and 4.

*Dependent on the type power source utilized, the output of said source may or may not shift in frequency by an amount equal to the I.F. frequency. The latter would enable zero frequency I.F. operation. In either case, duplexer operation remains unchanged.

For discussion purposes, let us assume that no limiter stages are present and above described action is taking place. If two crystal diodes are now connected to ports 3 and 4 respectively and their polarities made opposing (one forward and the other reverse), the features necessary for balanced mixer operation are present. Therefore, proper signal detection can take place and yet only a single 3 db hybrid is used in the system for both duplexing and receiving. This unique situation arises from the fact that both transmitter and local oscillator are supplied by the same source.**

## 2.0 Solid-State Limiter Module

### 2.1 Final Technical Objective

The final objective of this sub-effort is to design a semiconductor switched limiter module for incorporation into the final duplexer package.

The switched limiter module will consist of two stages of semiconductor limiting and a high burn out crystal diode detector. The first limiter stage will be a PIN diode and

**In the event that a conventional separate local oscillator were desired, an additional 3 db hybrid could be placed after the limiter stages. This would then yield a conventional balanced duplexer arrangement. Thus, the mixer would then require its own hybrid with one input arm fed by the signal and the other, the local oscillator.

will be followed with a varactor diode second stage. The crystal detector diode will be decoupled from the main line and will be located before both limiter stages. The crystal detector output pulse will be applied to the PIN and varactor diodes to drive them into forward bias during the transmitting mode thereby causing the limiting action. This type of operation is called switched limiter.

### 2.2 Intermediate Design Goals

2.2.1 Complete the design for a coaxial diode mount shunt connected to a stripline test fixture. This will be fabricated during the first quarterly period of the contract.

Measurements will be performed with this fixture during the second quarterly period.

2.2.2 Evaluate PIN and varactor diodes for use in the stripline limiter module and determine diode specifications.

Measurements will be taken using a waveguide diode mount, where the diode is inserted in series with a coaxial stub shunting the waveguide.

2.2.3 Low power measurements will be taken to determine the performance of the selected diodes under DC bias conditions. The coaxial stub used in these measurements will be similar to the mount for the stripline module.

2.2.4 Preliminary high power tests at 500 watts peak power will be performed using the waveguide limiter fixture and a directional coupler to decouple the detector crystal used to bias the limiter diodes. This test will provide information on the high power isolation and the amount of decoupling that is necessary for the detector crystal in order to provide the correct amount of coupling.

## 2.3 Accomplishments During the First Quarterly Period

### 2.3.1 Design of Initial Test Fixture

The design of a coaxial diode mount in a stripline fixture has been completed and submitted for fabrication. The completed fixture will be available the first week in November. Figure (7), a single stage semiconductor limiter, shows a pictorial view of this design. Important points are indicated on the figure and will be described in the following paragraphs.

The single stage semiconductor limiter consists of strip to coaxial to strip transmission line. A coaxial shunt stub is connected to the center coaxial section of this transmission line and a semiconductor diode will be placed in series with this stub. The stub is terminated in a folded choke which effects an RF short circuit in the stub and provides a DC open circuit for application of bias to the diode. The test fixture will provide the information required to determine the optimum method of coupling the coaxial diode mount to the stripline and will also provide information for determining the optimum stub impedance. The mount provides for variation in the length of the stub and position of the diode which will allow tuning of the diode circuit.

2.3.2 Preliminary Tests at Low Power

During this quarterly period, measurements were performed using waveguide with stub diode mounts. These mounts were modified and tuned for performance in the frequency band of 9.2 to 9.7 Gcs.

Figure (8) shows performance using two mounts with a spacing of 135$^o$ at mid-band. Figure (8) also shows the single stage waveguide mounts with coaxial stubs used in these measurements. The waveguide mounts were bolted together for the tests and the minimum spacing was 135$^o$ between centers of the diodes.

In order to obtain the data shown, both diodes were tuned individually for minimum insertion loss and maximum isolation by positioning the diode and coaxial shorting choke. After individual tuning, both diodes were biased at 25 milliamperes of forward current and the total isolation was measured. The insertion loss and VSWR were measured at 0 bias.

The data shown in Figure (8) only indicates that the diodes are particularly suitable at these frequencies, however, when the stripline mount is evaluated, some design effort is anticipated in matching the limiter stub to the line.

The two-stage mount in Figure (8) was subjected to 500 watts peak power at a duty cycle of .001. The leakage power, spike width and flat power were recorded and are shown in the following table.

| Frequency | Average Leakage Power | Spike Width | Flat Leakage Power |
|---|---|---|---|
| 9.2 Gc | .03 mw | 34 nanosec. | 20 mw |
| 9.45 | .015 mw | 34 nanosec. | 10 mw |
| 9.7 | .027 mw | 34 nanosec. | 10 mw |

The limiting was performed using a directional coupler to decouple the crystal detector 24 db down from the 500 watts peak power. The detected output was applied directly to the PIN and varactor diodes.

## 3.0 Passive Components

The following passive stripline components will be developed during the course of the duplexer program.

a) Waveguide-to-Stripline Transition

b) TNC-to Stripline Transition

c) 3 db Quadrature Hybrid

d) 30 db Directional Coupler

e) Video Detector Mount

## 3.1 Final Technical Objectives

The final technical objectives associated with each of the passive components listed above are discussed briefly as follows:

### 3.1.1 Waveguide-to-Stripline Transition

The final objective associated with this circuit element will be to achieve broadband frequency coverage from 9,000 to 10,000 megacycles with low insertion loss and VSWR. The desired VSWR maximum over this frequency range is 1.10 with an insertion loss of .1 db maximum.

### 3.1.2 TNC-tc-Stripline Transition

The final objective associated with this phase of the development program will be to achieve frequency coverage from 9,000 to 10,000 megacycles with accompanying low VSWR and insertion loss. The desired VSWR maximum over this range of frequencies is 1.2 with an insertion loss of 0.1 db maximum.

### 3.1.3 Three db Quadrature Hybrid

The following specifications pertain to the design objective associated with this component.

| | | |
|---|---|---|
| a) | Frequency Range | 9,000 - 10,000 Mc |
| b) | VSWR Maximum | 1.15:1 |
| c) | Power Split | 3.0 ± .1 db |
| d) | Isolation | 18 db Minimum |
| e) | Insertion Loss | .1 db |

### 3.1.4 30 db Directional Coupler

The following specifications pertain to the design objective associated with this component.

| | | |
|---|---|---|
| a) | Frequency Range | 9,000 - 10,000 Mc |
| b) | Coupling | 30 db (tighter or looser as may be determined) |
| c) | Coupling Flatness | ± .5 db |
| d) | VSWR (Main Line) | 1.05:1 |
| e) | Directivity | 15 db |

3.1.5 Video Detector

The following specifications pertain to the design objective associated with this component.

| | | |
|---|---|---|
| a) | Frequency Range | 9,000 - 10,000 Mc |
| b) | VSWR | 1.25:1 Maximum |
| c) | RF Suppression | 15 db |
| d) | Output Current | Compatible with limiter drive requirements |

## 3.2 Intermediate Design Goals

The intermediate design goals for this quarter and the next quarter will be to achieve limited band performance associated with the components listed in paragraph 3.0. This limited band performance will cover the frequency range from 9200 to 9700 Mc. Other specifications associated with these components shall remain as stated. Work accomplished during this quarter has been concentrated in the area of the Waveguide-to-Stripline Transition and the TNC-to-Stripline Transition.

### 3.2.1 Waveguide-to-Stripline Transition

A test fixture has been designed to evaluate the performance of a waveguide-to-stripline transition. This test fixture has been constructed in such a manner as to allow for the subsequent evaluation of other component devices such as the limiter modules, directional coupler and 3 db hybrid. A sketch of this test fixture is shown in Figure (9). The overall length of the test fixture is 6 inches and both ends are identical in that there are two waveguide transitions with an included stripline 50 ohm section. The position of short, length of the probe and dimensioning of the matching structure is identical on both ends of the fixture. Test data taken on this device was obtained utilizing a broadband waveguide matched load (mounted on one transition) whose VSWR was less than 1.01 over the frequency range of 9,000 to 10,000 megacycles. Identical changes were made in both transitions during this investigation cycle. The test results obtained on this fixture are shown in Figure (10). The VSWR plotted on this graph represents the performance of the test fixture with both transitions and included 50 ohm stripline in series with the waveguide termination. The insertion loss measured through the structure was negligible (less than 0.1db), hence, this information has not been plotted on the graph. Additional work will be conducted in the next quarter to optimize the transition over a wider band.

3.2.2 TNC-to-Stripline Transition

A test fixture has been constructed for the evaluation of TNC-to-stripline transitions. A sketch of this fixture is shown in Figure (11). This fixture has been designed to incorporate additional circuitry as required. The test fixture utilizes, as in the case of the waveguide fixture, two transitions and an included length of strip transmission line. Some preliminary test data has been taken relative to VSWR performance over the band from 8500 to 12,400 Mc. The results of these tests are shown in the graph of Figure (12). The cyclic nature of the VSWR pattern is characteristic of a double connector transition. These results indicate the corresponding phase maxima and minima of the reflection coefficients associated with each connector over the frequency band. The initial test results, although not very desirable, indicate promise when considering a single connector properly terminated. Additional work will be conducted in the next quarter to determine the actual VSWR of a single connector. One of the limiting features of this type of transition is the presence of discontinuity capacitance in the region of the actual transition from circular coaxial line to flat planar strip transmission line.

Various techniques can be employed to reduce this effect. Usually this involves some tailoring of the center conductor in the region of the transition.

## 4. Ferrite Circulator Module

### 4.1 Final Technical Objective

The final objectives in the development of the ferrite circulator module are, that it be:

a) Mechanically suitable for mounting in the finished duplexer assembly.

b) Electrically compatible with the requirements of the duplexer assembly.

The electrical requirements for the ferrite circulator are listed as follows:

| | |
|---|---|
| a) Frequency Range: | 9.0 - 10.0 Gc |
| b) VSWR: | 1.3 Maximum |
| c) Isolation: | 15 db Minimum |
| d) Insertion Loss: | .5 db Maximum |
| e) Average Power: | 1 Watt Minimum |
| f) Peak Power: | 500 Watts Minimum |

### 4.2 Technical Approach

The basic approach to be utilized in obtaining the final technical objective outlined in the preceding paragraph will be to combine various ferrite materials with several possible combinations of center conductor geometry. During the initial phase of this investigation several center conductor shim diameters will be experimentally checked with ferrite material. The following diameters of center conductor shim stock have been constructed.

a) .250 inches

b) .300 inches

c) .350 inches

d) .400 inches

e) .500 inches

Ferrite materials procured for this investigation include the following types.

4.2.1 Type 1 Ferrite Material: The type 1 ferrite utilized in the initial investigation was type G-113. This material possesses a $4\pi MS$ value of 1780 gauss and a line width ($\Delta H$) of 55 oersteds. The sample diameters used in the investigation were .500 inches.

4.2.2 Type 2 Ferrite Material: The type 2 ferrite material utilized in the investigation was type TT-1-105. This material possesses a $4\pi MS$ value of 1700 gauss and a line width ($\Delta H$) of 200 oersteds. The sample diameters used in the investigation were .500 inches.

4.3 Results Obtained This Quarter

The results obtained during this quarter utilizing the ferrite materials noted in paragraphs 4.2.1 and 4.2.2 together with the various center conductor configurations noted in paragraph 4.2 are plotted graphically in figures 13, 14 and 15.

4.3.1 The electrical data plotted in Figure (13) represents the use of type 1, ferrite material. This material (possessing $4\pi MS$:1780, $\Delta H$:55oe) was utilized in a test fixture with the various center conductor shim diameters listed in paragraph 4.2. The results of this investigation ruled out all the center conductor shim diameters with the exception of the .500 shim. The .500 shim (.002 in thickness) revealed the best electrical data utilizing the type 1. ferrite material. The data plotted in Figure (13) reveals that the operating frequency was too low and the bandwidth was too narrow due to the low linewidth value of only 55 oersteds. No additional work was conducted on this material.

4.3.2 The electrical data plotted in Figure (14) represents the use of type 2 ferrite material. This material (possessing $4\pi MS$:1700, $\Delta H$:200oe) was utilized in a test fixture with the various center conductor shim diameters listed in paragraph 4.2. The results of this investigation indicate that this type of ferrite shows promise within the frequency band of interest; 9,000 to 10,000 megacycles. The ultimate design goal on isolators is 15 db minimum isolation. The results in Figure (14) reveal that isolation at the band edges dropped to 12 db. This condition can be directly traceable to VSWR conditions existing within the structure. The insertion loss shown in

Figure (14) is excessive and further work will be required in this area. The dimensions of center conductor shim stock which revealed best performance as shown in Figure (14) were .350 inches in diameter and .002 inches thick. Based on the results obtained it was decided to investigate additional changes in center conductor configuration.

4.3.3 The electrical data plotted in Figure (15) is indicative of the results obtained after making a change in the center conductor geometry. The ferrite material utilized in this investigation was the same as that used in paragraph 4.3.2. The change made in the center conductor geometry consisted of using two identical shim stock segments each being .350 in diameter and having a combined thickness of .004 instead of one. The assumption made in the preceding paragraph concerning isolation vs. internal VSWR seems to have some basis in fact. The isolation performance at the band edges has considerably increased over the performance in Figure (14). The overall VSWR looking into the test fixture has been reduced considerably at the low end of the band. The insertion loss results shown in Figure (15) are again excessive. This fact may be explained by radiation leakage occuring in the stripline assembly. Additional work is planned for the next quarter to determine the possible solutions to the insertion loss and VSWR problems.

## SECTION V

## CONCLUSIONS

1. Experimental data indicates that a waveguide-to-stripline transition operating in the 9,000 to 10,000 megacycle band will pose no difficulty in obtaining the desired results.

2. TNC-to-Stripline transitions in the 9,000 to 10,000 Mc frequency range utilizing in-line adapters need additional engineering studies. The presence of discontinuity capacitance in the junction adequately explains the high VSWR performance in the preliminary tests.

3. Preliminary low power tests on a waveguide limiter look promising. Additional studies are needed relative to bandwidth and insertion loss.

4. Preliminary test data at low power levels on a ferrite circulator operating in the 9,000 to 10,000 Mc band look promising. Additional studies are required on the parameters effecting VSWR and insertion loss.

## SECTION VI

## PROGRAM FOR NEXT INTERVAL

1. During the next quarterly period, the single stage diode mount in the waveguide-to-stripline test fixture will be evaluated, and a final diode mount design will be completed. A first approach two-stage limiter module in the strip transmission line medium will be designed.

2. A crystal detector mount and directional coupler will be designed and evaluated. Measurement will be performed on the first two-stage limiter module with the crystal detector and coupler incorporated into the module.

3. Additional work will be conducted in broadbanding the present designs for waveguide-to-stripline and TNC-to-stripline transitions.

4. Work will continue on the development of the ferrite circulator module. Additional ferrite materials will be evaluated and engineering studies conducted on the reduction of VSWR and insertion loss. An additional test fixture shall be constructed utilizing the waveguide-to-stripline transitions.

## IDENTIFICATION OF PERSONNEL

The following personnel have performed engineering tasks associated with the development phases of this program. This report, being the first quarterly report, contains the technical resumes of those individuals listed. Subsequent reports shall include resumes of newly assigned personnel to this program.

| Personnel | Hours |
|---|---|
| James W. Christian<br>Project Manager | 40 |
| Robert Brunton<br>Project Engineer | 24 |
| Sumner Segal<br>Project Engineer | 24 |

**JAMES W. CHRISTIAN** - Project Engineer
Waveguide Systems Division

Mr. Christian graduated from Boston College in 1952 with a B.S. degree in Physics. He served two years in the United States Army as an artillery officer in Korea. He is currently active in the Army Reserve and holds the rank of Major. Mr. Christian's professional experience began in 1954 when he worked for the United States Air Force Cambridge Research Center, Airborne Antenna Laboratory; L. G. Hanscom Field, Bedford, Massachusetts. While there, he was engaged in research and development on various microwave antenna structures. His chief responsibilities included the design of multiwavelength end fire arrays and primary feeds for various parallel plate antenna lens systems. In addition, he was directly responsible for the design and development of microwave strip transmission line components and their application to antenna systems.

Mr. Christian joined the Military Electronics, Ground Support Equipment Department, Engineering Division, Laboratory for Electronics, Inc. in 1956. His primary responsibility was to introduce the design criteria and manufacturing techniques associated with photo-etched strip transmission line components to the overall effort of the Ground Support Equipment Department.
Mr. Christian was responsible for the design and development of various microwave systems and sub-systems. These efforts included the design of broadband directional couplers, balanced mixers, phase shifters, local oscillators and antenna coupling devices.

In 1958, Mr. Christian transferred to the Instrument Division of Laboratory for Electronics, Inc. where he was responsible for the design and development of various microwave instruments such as radar target simulators and ultra-stabilized microwave oscillators. In addition, Mr. Christian introduced a series of new products which constituted a line of strip transmission line microwave components. He was responsible for the engineering and manufacturing operations associated with this effort.

Mr. Christian joined the Waveguide Systems Division of Microwave Associates in 1962. His primary responsibility is directing the microwave strip transmission line components activity. In addition, he devotes his engineering experience in the areas of design, development and packaging of waveguide components and assemblies.

Sumner Segal - Project Leader

Received his B.S. in Electrical Engineering from Rutgers University in 1957.

From 1951 to 1957 Mr. Segal was employed at Sylvania Electric Products Inc., Woburn, Mass. He was involved in supervision and performance of design and life test on gas switching tubes and magnetrons. He was also involved in supervision and performance of testing on backward wave magnetrons and the design of special test components and equipment. In 1957 he was employed at Airtron Inc. for a period of eighteen months. He was project engineer on the design and fabrication of ferrite isolators, circulators, and switches.

In August 1958, he joined the Switching Devices group at Microwave Associates as a project leader responsible for the development of ferrite devices. He has concentrated primarily in the design of high power isolators, circulators, and duplexers from L band to Ku band.

Robert H. Brunton

Mr. Brunton attended Newton Junior College and Lincoln Technical Institute and received his Associates Degree in Electronics in 1958. In 1961 he obtained his BBA Degree from Northeastern University. His major was management in engineering. Since that time Mr. Brunton has taken various engineering graduate studies at Northeastern University.

Mr. Brunton was employed by Microwave Development Laboratories from 1949 to 1952. From 1952 to 1954 Mr. Brunton served with the U. S. Army.

He rejoined Microwave Development Laboratories in 1954 as a junior engineer. His work included experimental design of microwave components and packaging microwave subsystems. Mr. Brunton was project engineer and supervised production of temperature compensated wavemeters at M.D.L.

In April 1957 Mr. Brunton became employed at the Radio Corporation of America, Airborne Systems Laboratories. His duties included development of stable local oscillators, and evaluation of traveling wave tubes for both the receiver and transmitter system for a doppler radar. From November 1957 to January 1959, Mr. Brunton joined a team of R.C.A. engineers to perform systems evaluation of the U. S. Air Force GRA-5 time division digital data link ground to air communications system.

Mr. Brunton joined the AdvancedDevelopment Group at R.C.A., Burlington, January 1959. As a senior member of the technical staff, his duties consisted of design of microwave radiometers, application of parametric up-converters to phase array technique and design of solid-state microwave switching devices for modulation and attenuation in systems. He was responsible for the design and construction of two discreet electromagnetic environmental simulation systems.

During the period of January 1962 through March 1963, Mr. Brunton was employed by the Ewen Knight Corp. and Sage Laboratories. His duties involved the design and supervision of a microwave radiometer system using tunnel diodes and other solid-state components. Also, he was responsible for the development of single side band modulators, many complex microwave packages and microwave components.

In March 1963, Mr. Brunton joined Microwave Associates as a group leader in the field of solid-state microwave devices.

Mr. Brunton is an Associate Member of the IEEE and PTGMTT.

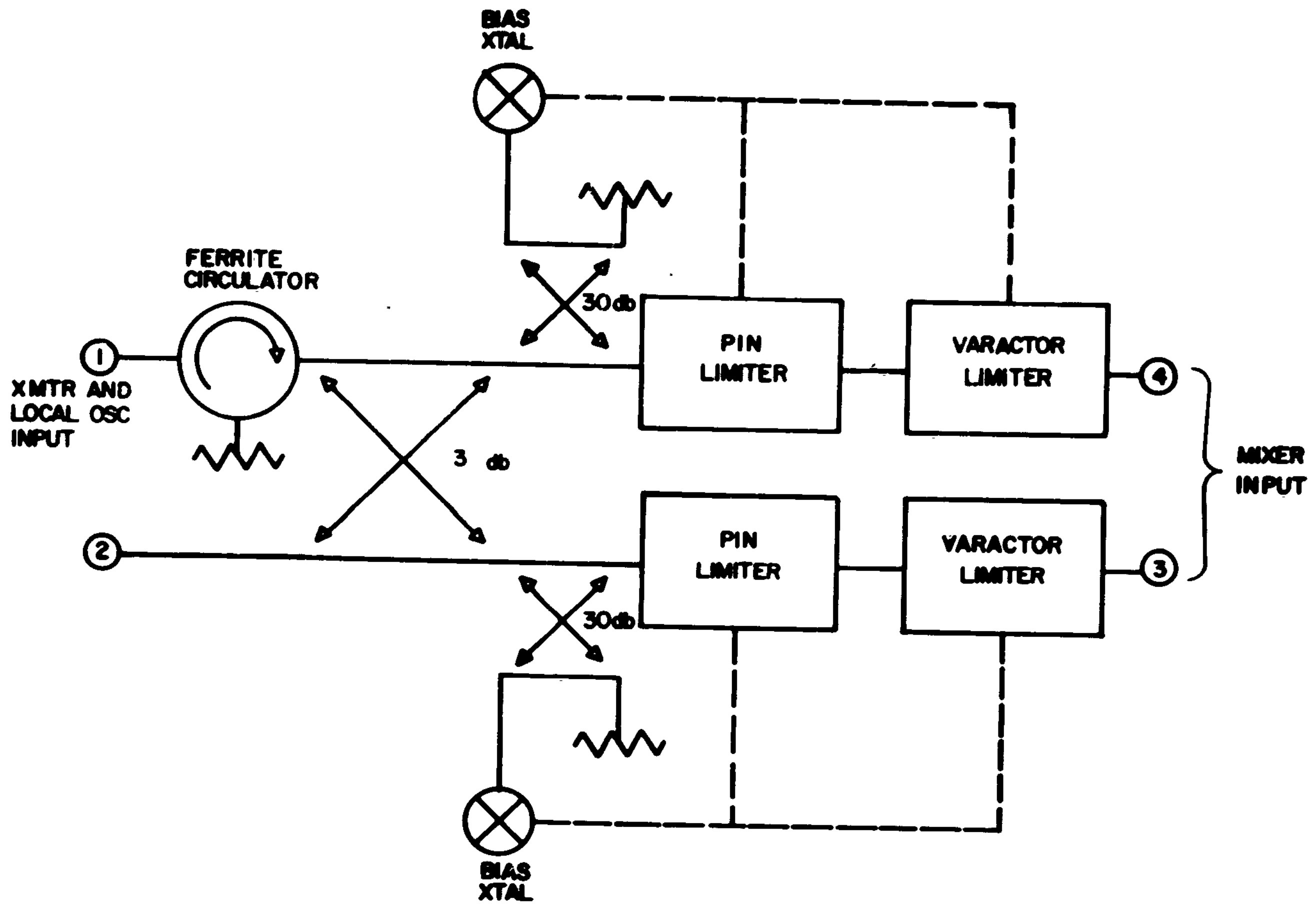



FIGURE I
SCHEMATIC OF MINIATURIZED STRIPLINE DUPLEXER

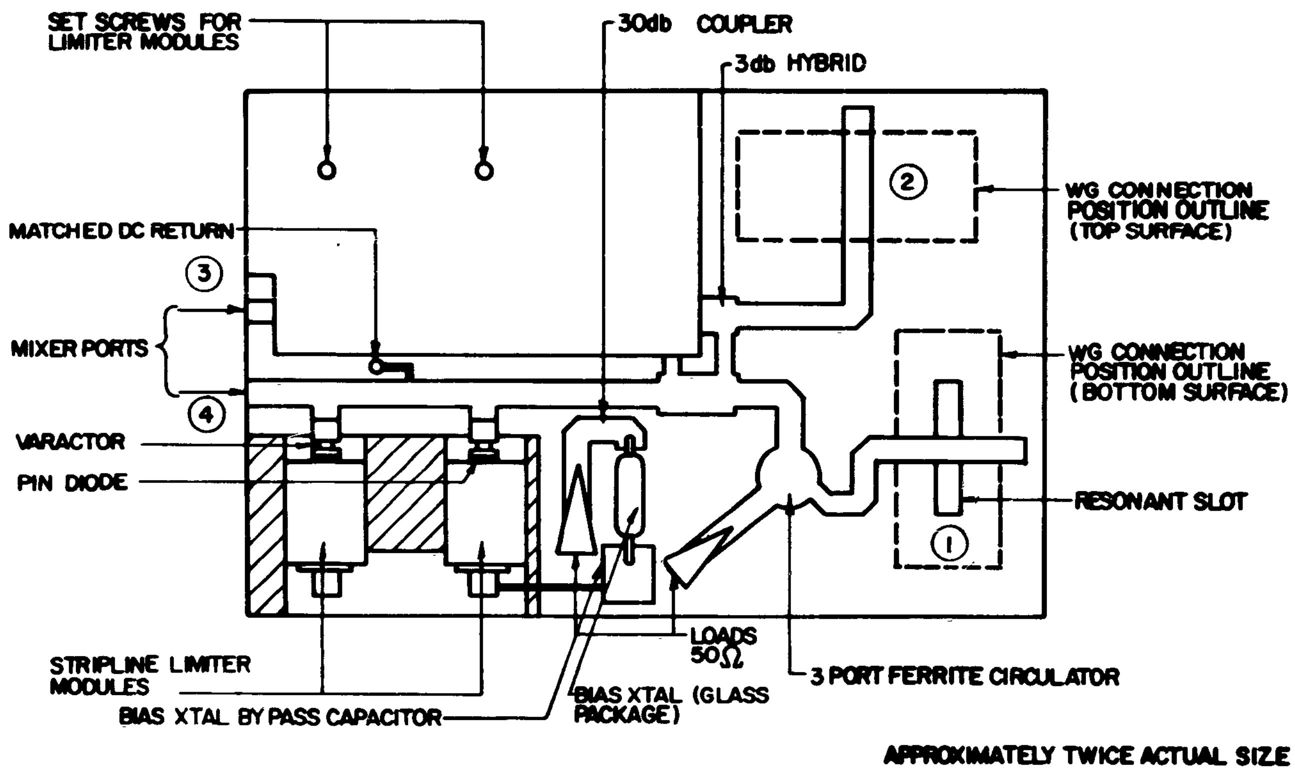



FIGURE 2
MECHANICAL LAYOUT OF PROPOSED DUPLEXER ASSEMBLY SHOWING STRIPLINE DETAILS

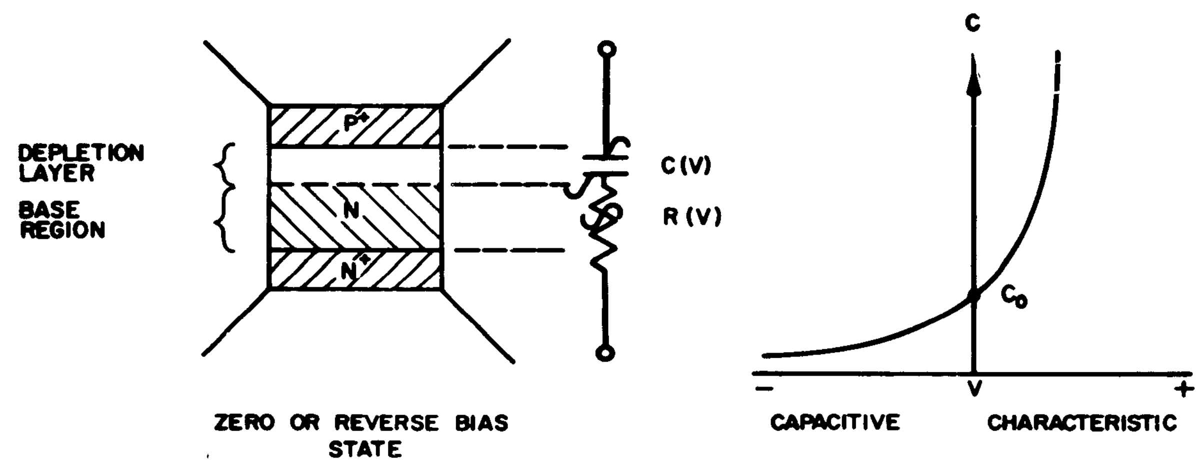



FIGURE 3
VARACTOR DIODE SCHEMATIC REPRESENTATION

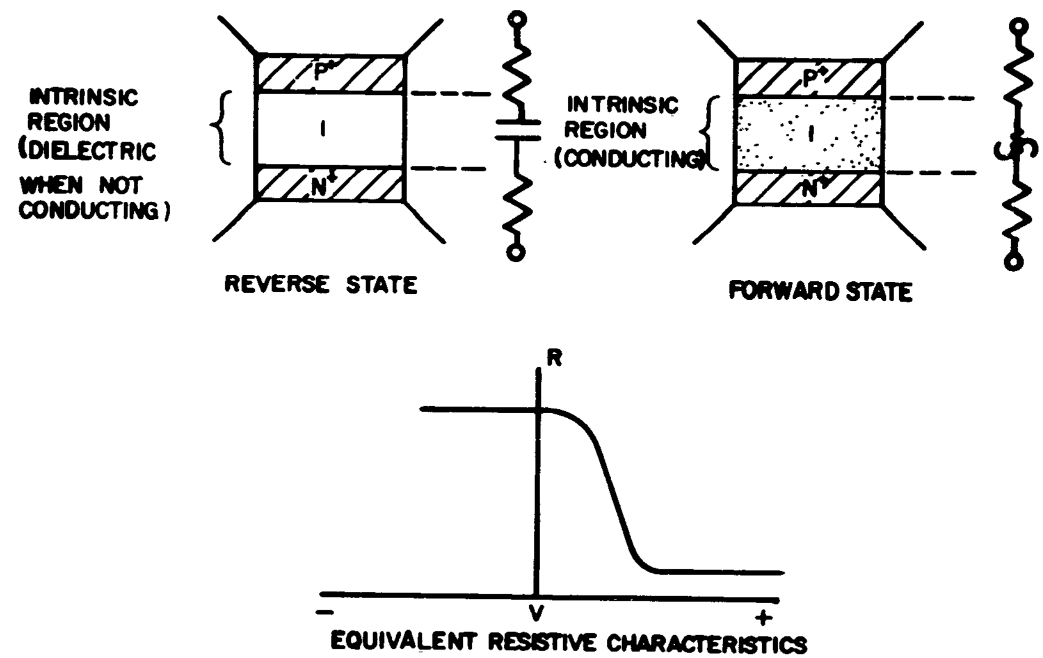



FIGURE 4
PIN DIODE SCHEMATIC REPRESENTATION

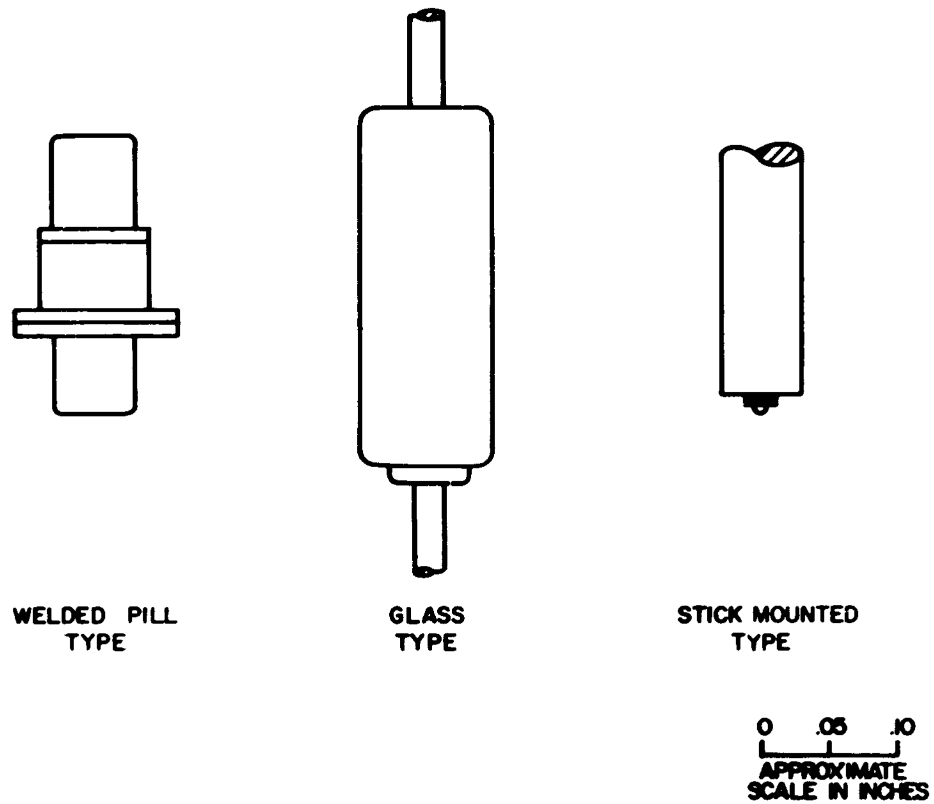



FIGURE 5
SEVERAL MICROWAVE DIODE PACKAGE CONFIGURATIONS SUITABLE
FOR X-BAND OPERATIONS

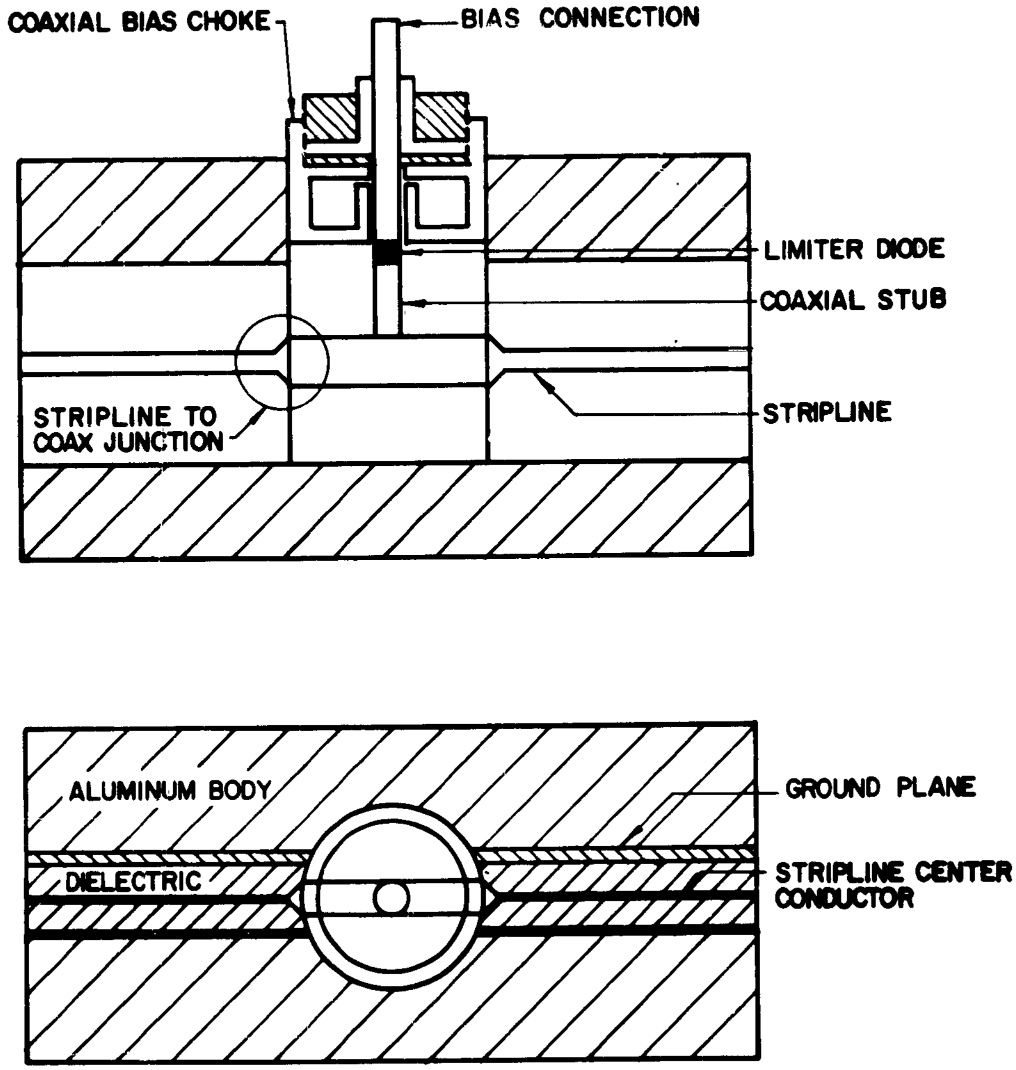



FIGURE 6
SINGLE STAGE SEMICONDUCTOR LIMITER

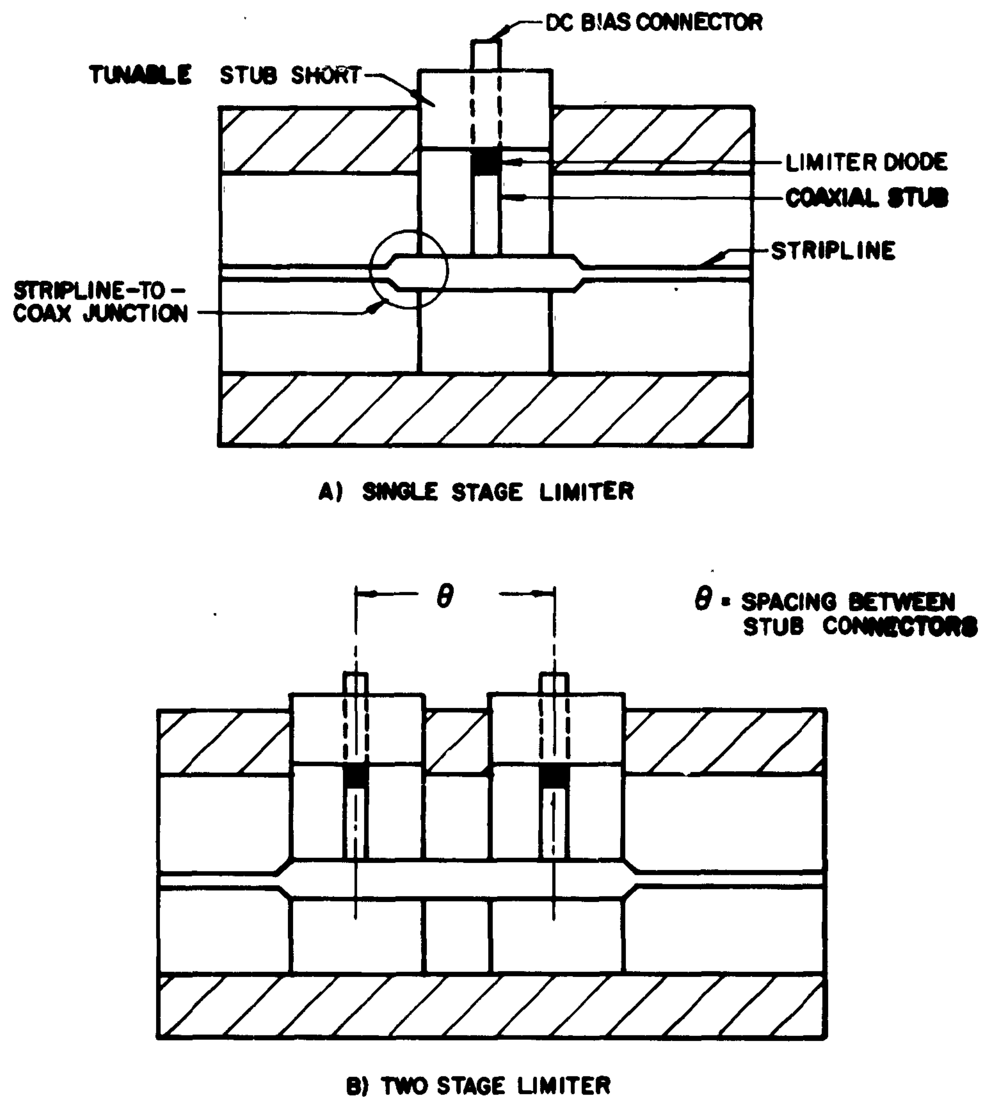
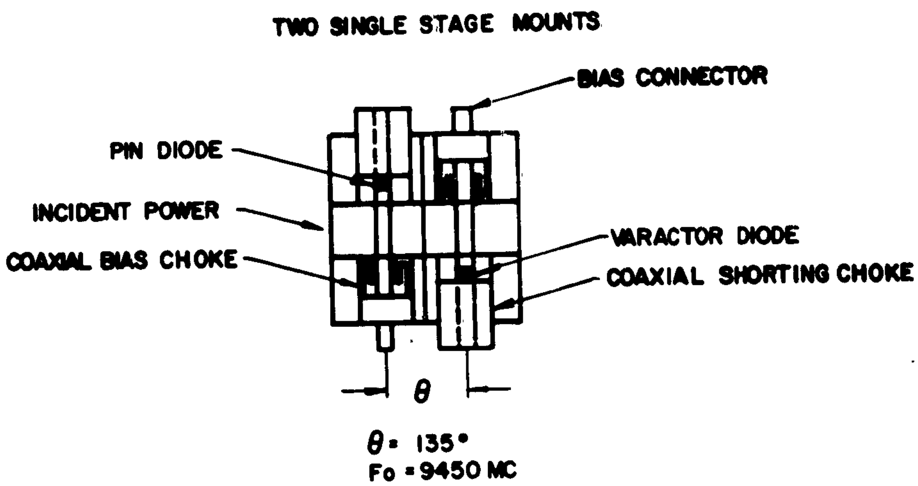



FIGURE 7
EXPERIMENTAL STRIPLINE SEMICONDUCTOR LIMITER TYPES



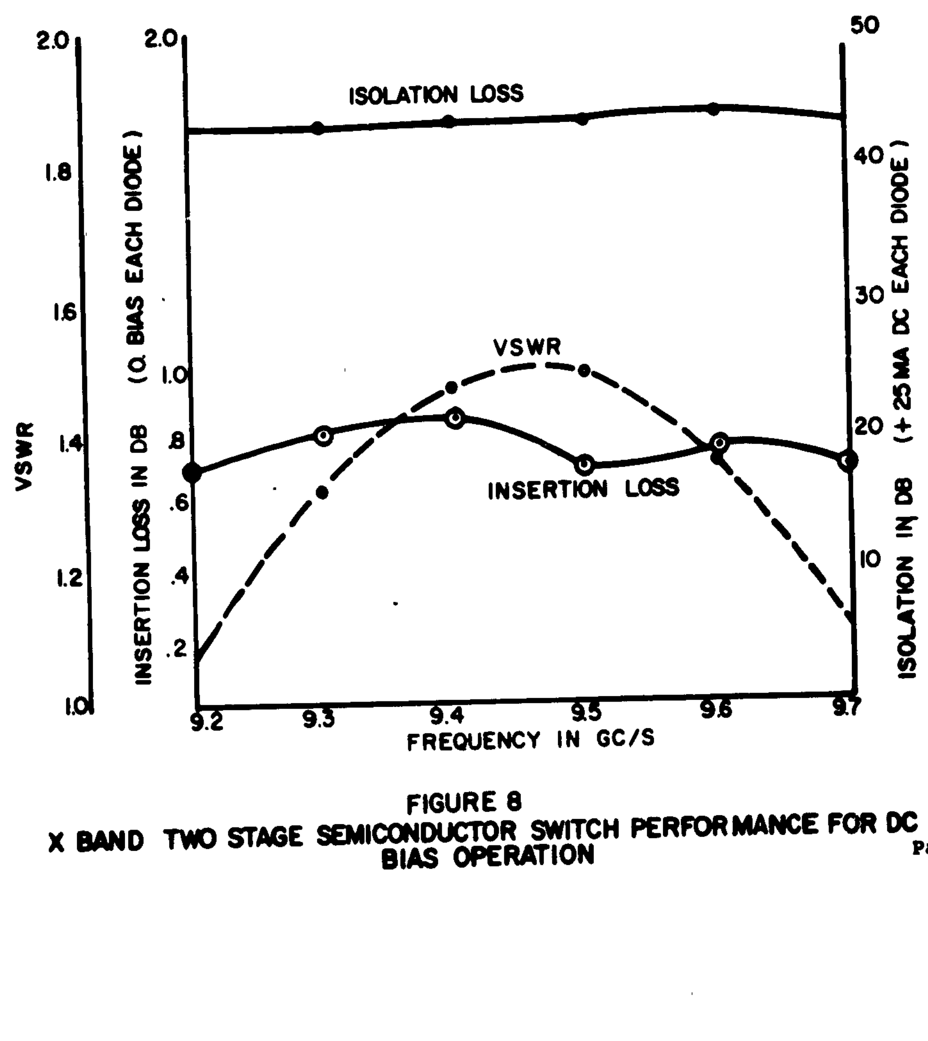




FIGURE 8
X BAND TWO STAGE SEMICONDUCTOR SWITCH PERFORMANCE FOR DC BIAS OPERATION

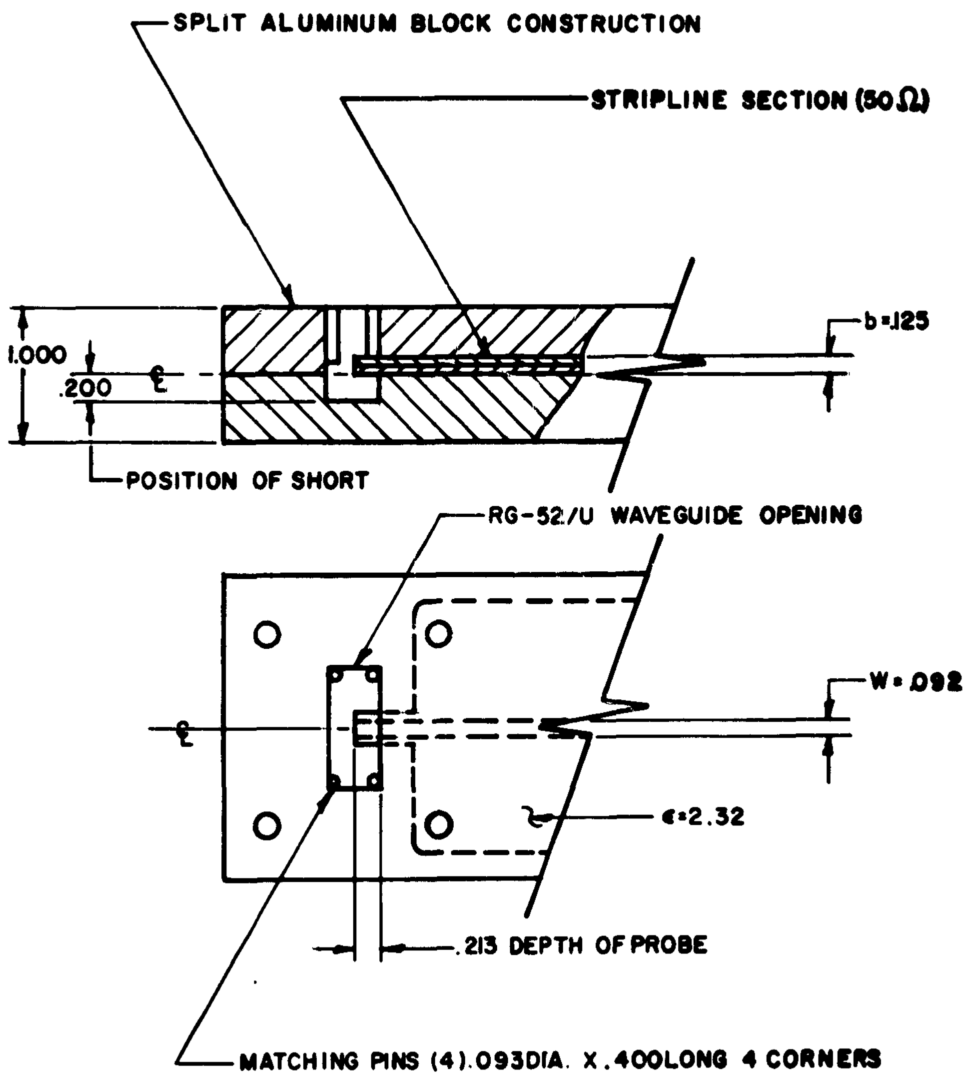



FIGURE 9

WAVEGUIDE-TO-STRIPLINE TRANSITION

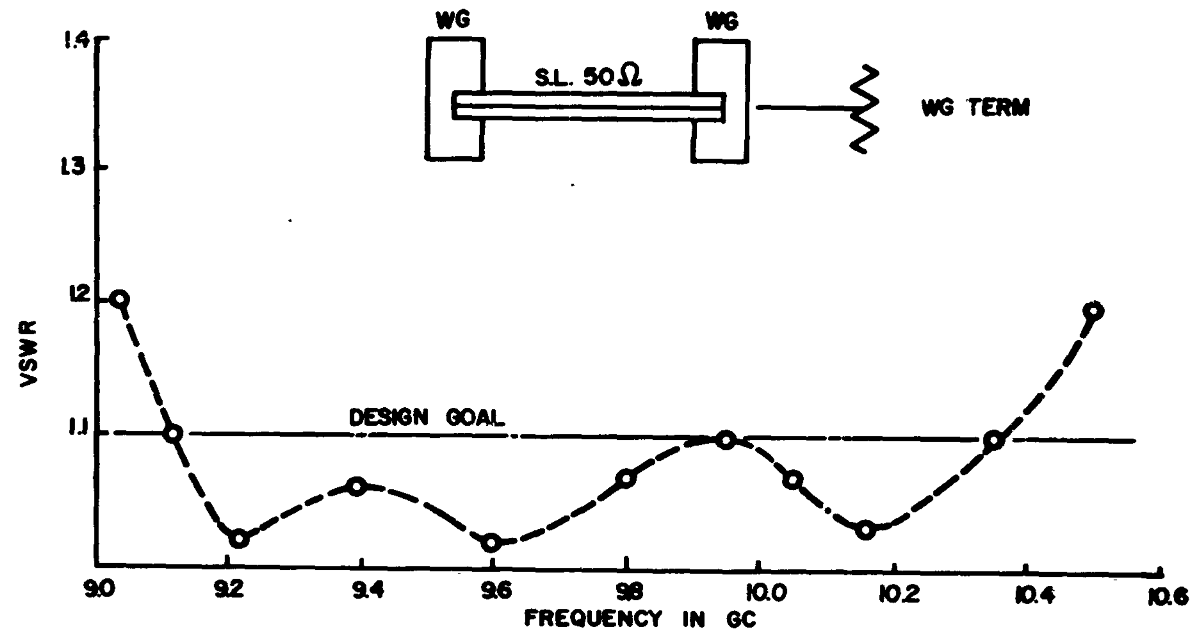



FIGURE 10
EXPERIMENTAL WAVEGUIDE—TO—STRIPLINE
TRANSITION PERFORMANCE

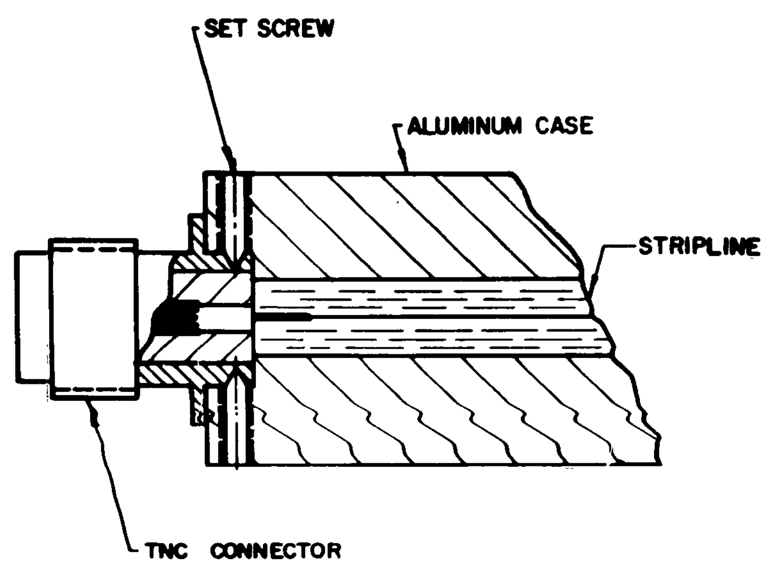



FIGURE 11
TNC-TO-STRIPLINE TRANSITION

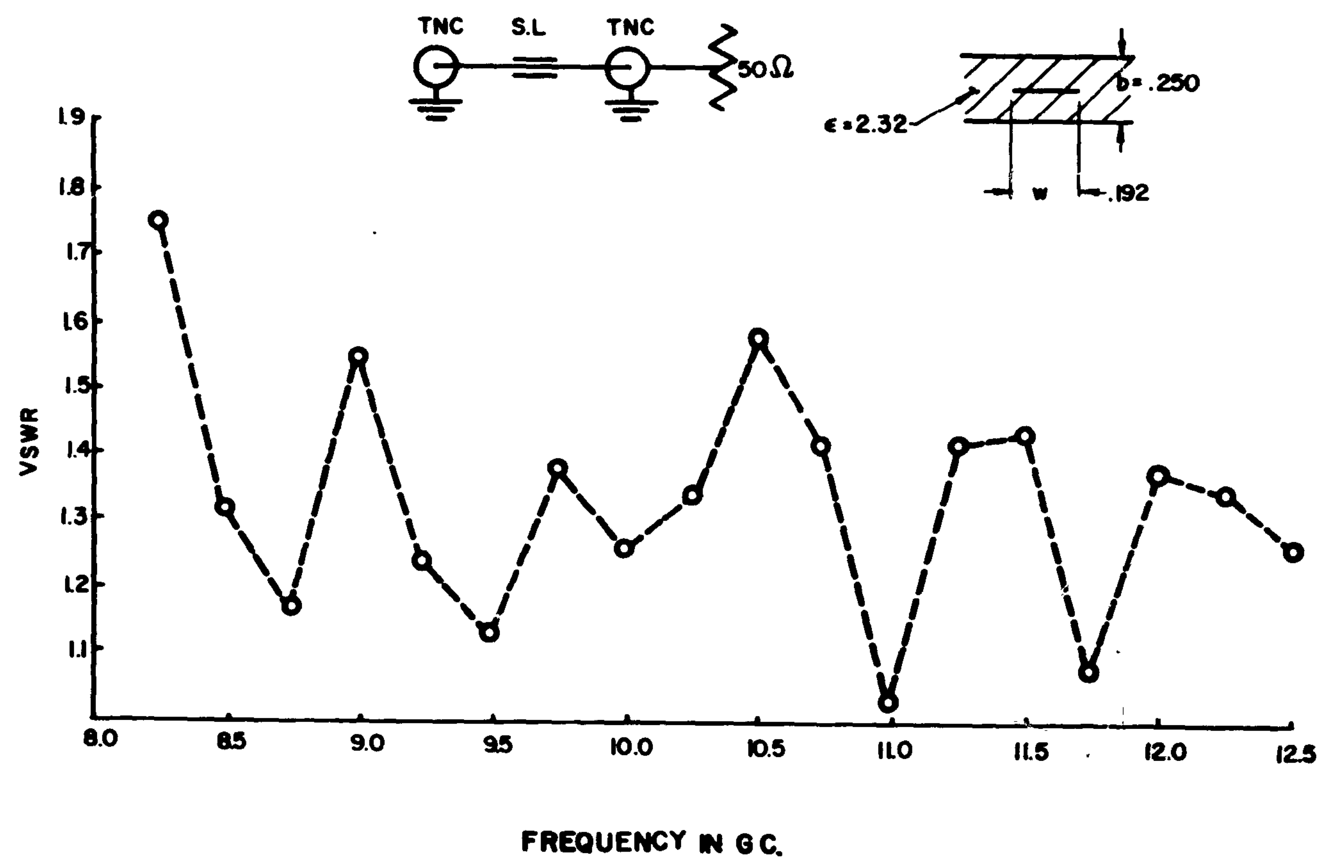



FIGURE 12

EXPERIMENTAL TNC-TO-STRIPLINE TRANSISITION PERFORMANCE GRAPH

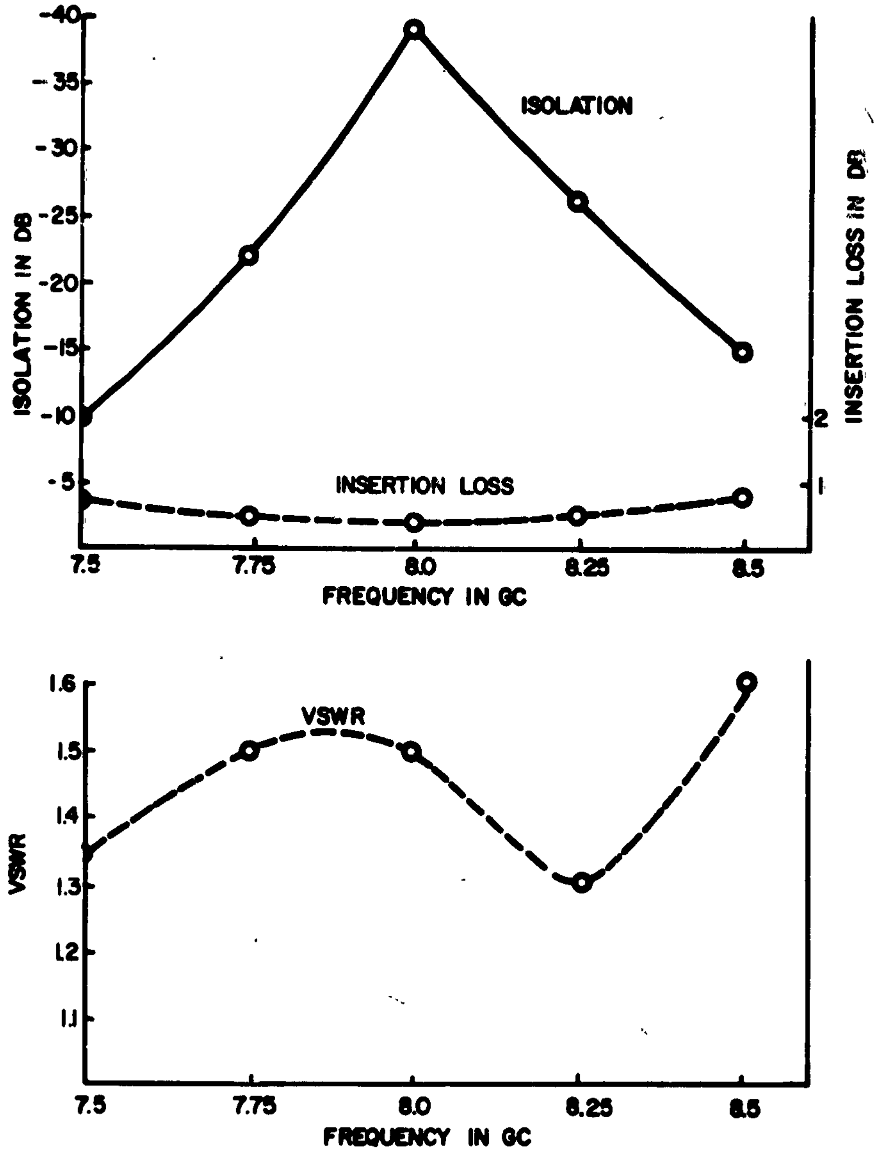



FIGURE 13
EXPERIMENTAL FERRITE CIRCULATOR
MODEL NO. 1 PERFORMANCE

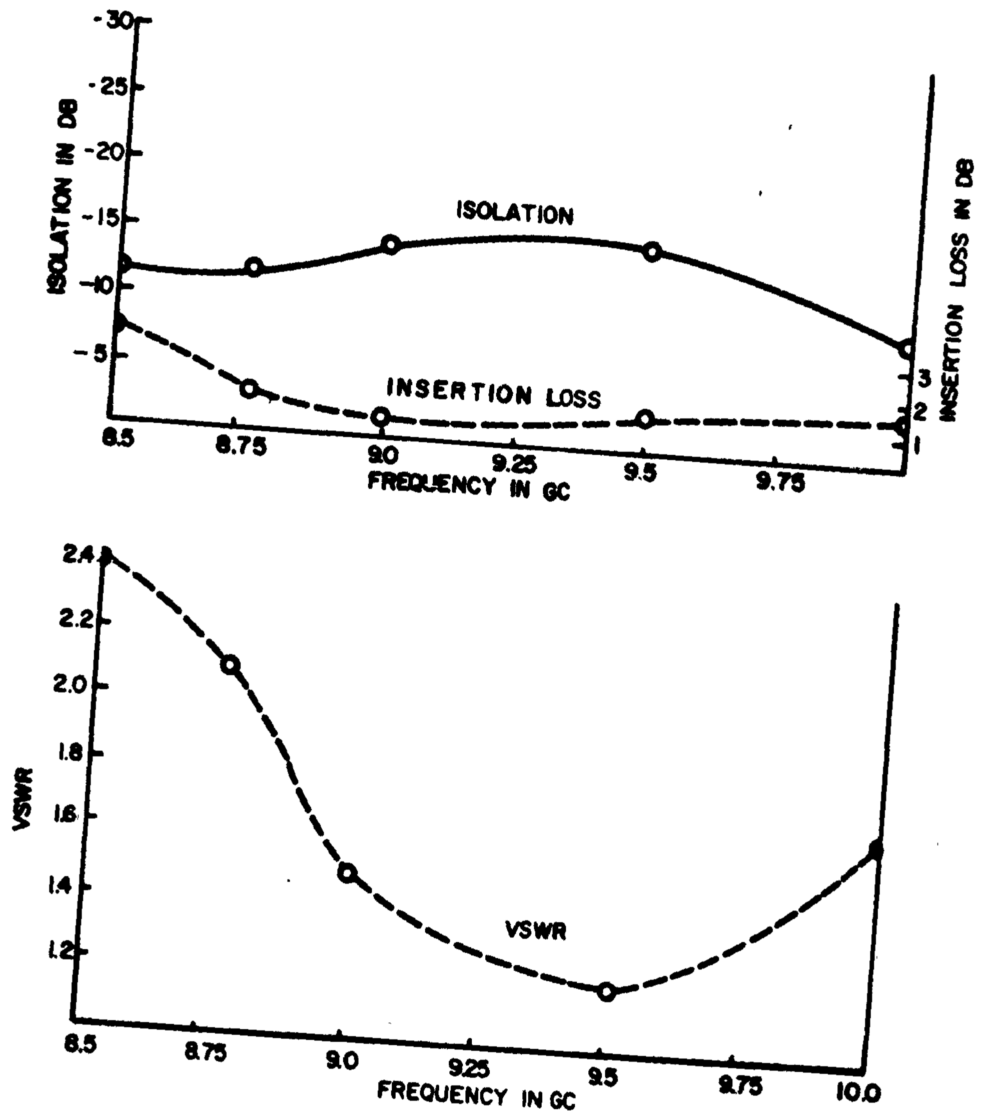
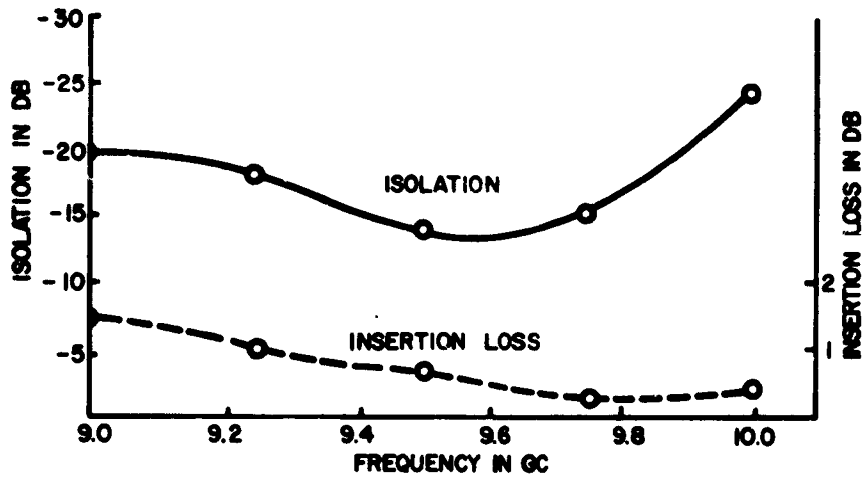



FIGURE 14
EXPERIMENTAL FERRITE CIRCULATOR
MODEL NO. 2 PERFORMANCE



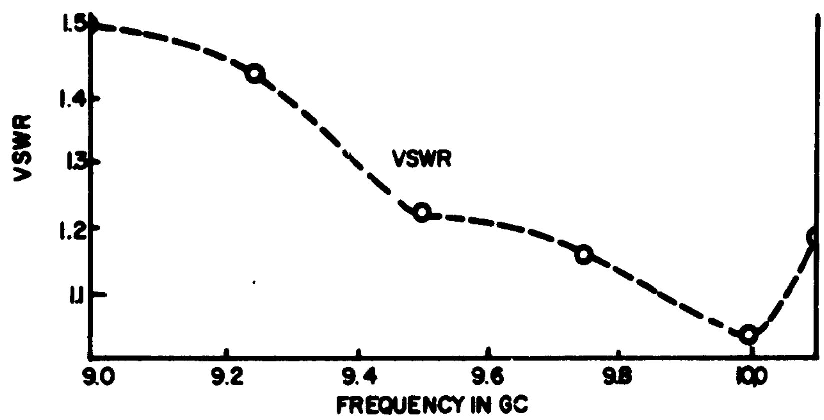




FIGURE 15
EXPERIMENTAL FERRITE CIRCULATOR
MODEL NO. 3 PERFORMANCE

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BURLINGTON, MASSACHUSETTS

MINIATURIZED X-BAND STRIPLINE DUPLEXER

J. Christian, R. Brunton, S. Segal

First Quarterly Technical Report - 1 July 1963 to 30 September 1963

48 Pages - Illus. U.S.Army Electronics Research & Development Laboratory
Contract No. DA-36-039-AMC-03230-(E)

The objectives of this development program on a miniaturized X-band stripline duplexer are discussed in relation to the present state-of-the-art. General approaches to the problem are outlined. The various major elements of the duplexer are discussed and the method of approach to the solution of each pertinent problem is analyzed.

A broadband waveguide-to-stripline transition has been developed covering the frequency range of 9200 to 9700 megacycles. The experimental results of this investigation are discussed and indicate that initial test results show promise for further broadbanding techniques.

An experimental fixture has been constructed for the convenient testing of limiter modules. This fixture utilizes the broadband waveguide-to-stripline transition mentioned previously. The method of approach and the expected results of this stage of limiter module development are discussed.

A test fixture has been designed to evaluate the ferrite circulator module. Various transmission line configurations and a limited number of ferrite materials have been investigated. The preliminary test results are discussed and future methods of approach are analyzed.

Studies are also underway on the development of a broadband TMC-to-stripline transition and a broadband directional coupler covering the 9000 to 10,000 megacycle band. Preliminary experimental results show promise
A complete discussion will be given in a later report.

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