THE DESIGN AND CALIBRATION OF A UNIVERSAL MMIC TEST FIXTURE

James A. Benet

Rockwell International
Collins Communication Systems Division
Anaheim, California

ABSTRACT

A universal test fixture suitable for performing repeatable, nondestructive microwave tests for characterizing various sized monolithic microwave integrated circuit (MMIC) chips has been developed at Rockwell International. The fixture, which encloses the MMIC chip, is designed to accommodate multiple RF inputs and outputs as well as up to 36 independent isolated bias connections. A method for calibrating the fixture on an automatic network analyzer (ANA) without the use of known precision calibration standards was also developed. A description of the fixture and the calibration method is presented in this paper.

INTRODUCTION

Advances in microwave gallium arsenide (GaAs) technology has lead to the emergence of monolithic microwave integrated circuits (MMIC) to solve the problem of mass producing low cost, high reliable microwave circuits. The MMIC combines many active (GaAs) devices with appropriate passive circuit elements to produce a single chip under one square centimeter in size which performs the electrical tasks equivalent to several microstrip circuits occupying ten to twenty times the area.

A problem arises with regard to testing and characterizing these devices. A method or technique needed to be developed to accurately measure the microwave performance without destroying the chip (for reuse). To solve this problem a project was initiated to develop an appropriate MMIC test fixture.

DESIGN AND FABRICATION

Design Objectives

The fundamental design goal was to develop a fixture system to perform accurate, nondestructive RF tests on a wide variety of chips which differ both functionally and physically. The fixture must allow for quick connections and disconnections of the MMIC. The fixture also must accommodate a large number of bias inputs without necessitating bonding during the testing process. Multiple RF input/output connections, as well as the multiple bias connections, must also be provided. Provisions for monitoring bias voltages is another desirable feature. Metal walls completely enclosing the input/output circuits and the MMIC chip must be provided to maintain RF shielding and reduce external noise inputs to the device under test. Since a subcarrier would be required, it must be designed such that it could be produced inexpensively. Finally, since the overall objective is to obtain accurate RF measurements, the fixture must provide a means by which it can be calibrated on an automatic network analyzer (ANA). Hence, the development of calibration pieces and appropriate measurement software must be included in the design objectives.

MMIC Subcarrier

To achieve nondestructive testing of the fragile MMIC chips and to avoid the necessity of making bonding connections during tests, the MMIC chip is bonded to a .062 inch thick, copper subcarrier which is made from a copper-backed dielectric (or PC) board. The subcarrier is shown in Figure 1. The dielectric material, which is .010 inch thick, is machined away in the center section of the subcarrier where the MMIC device is mounted. Bias lines are etched on the PC board sections which extend out on each side of the center section. These microstrip lines fan out to a pattern of 18 metallized pads which are .040 inch square. Small tabs extend outward in the center section along the measurement axis to interface with the fixture. The entire subcarrier is gold-plated to prevent copper oxidation.

The subcarrier is designed to accommodate MMIC chips of various sizes from .5 x .5 x .125 mm up to 10 x 8 x .625 mm with up to 36 independent isolated bias input. Leader microstrip substrates can be placed in front and in back of the MMIC device to accommodate very small chips or to convert the MMIC to a beam lead device. Small SiO chip capacitors are bonded to the subcarrier between the MMIC chip and the PC board to provide RF isolation on the bias lines.

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The overall size of the subcarrier is 1.8 x .84 inches; however, this size can be reduced considerably after the testing is completed by merely shearing off the leader tabs and most of the PC board sections. The final dimensions could be as small as 2 mm long by 5 mm wide depending on the size of the chip and the bias capacitors. In the testing configuration the length of subcarrier with respect to the RF path is .4 inch or less. Although the size of the PC board sections with the bias pads is always fixed, the center section length is "customized" to fit the length of the particular MMIC chip which is being tested.

To produce the subcarrier inexpensively, the bias line pattern is repeated sixty times on a 16 by 10 inch panel. The entire panel is then etched and the individual PC boards are cut from the panel using an automatic (computerized) routing machine. The tabs and grooves are machined in for each size by stacking and machining the boards in lots of ten or more. Produced in this manner, the subcarriers can be built inexpensively.

The design of the subcarrier does not severely restrict the configuration in which the MMIC chip is packaged. For example, the chip can be built on a thin metal base and bonded or epoxied to the subcarrier. Alternatively, the subcarrier could be made part of a ceramic package to house the MMIC chip. The chip could also be built on a post or pill package and inserted into the subcarrier through a hole drilled in the center of the subcarrier. Furthermore, the subcarrier itself could be modified to use a thicker metal base or to change the width of the center groove in the dielectric, if necessary.

Test Fixture

An assembly drawing depicting the various components of the test fixture is shown in Figure 2. The fixture is built on a dove-tail assembly with a fixed center block and two end blocks which move in and out in unison by rotating a right- and left-hand threaded drive rod. Microstrip housings, which are open on the inside end, are spring-mounted on the end blocks and overhang them enough to come together midway at the center block. At this end, the bottom floor of the microstrip housing is thin (.031 inch) and a notch in the floor is cut away to expose the bottom surface of a .015 inch thick alumina microstrip substrate. When the MMIC subcarrier is set in place, the tabs on the subcarrier slip into the notches in the microstrip housing and the tops of the tabs make pressure contact with the bottom surface of the microstrip substrates to achieve the ground continuity. Four springs, located in the spring-mounted block, are used in mounting each microstrip housing to the movable end blocks so as to exert a sufficient amount of downward pressure on the substrate to assure an adequate ground contact to the subcarrier tabs. The two inside springs exert a downward force while the two outside springs exert an upward force. This forces the ground contact on the tabs to be made at the very end of the microstrip substrate. A tapered wedge, which is located between the end block and the spring mount block, is used to tilt the microstrip housing up at the inside end to allow the subcarrier to be inserted easily. The foam spring cushion in the beam lead pressure lid is used to exert pressure to hold the MMIC beam lead down on the microstrip center conductor.

The microwave path through the test fixture is completely enclosed with the use of three kinds of lid covers. The microstrip housing lid covers most of the microstrip housing near the connector end. The beam lead pressure lid covers the remaining microstrip at the open (inside) end of the housing. A top lid cover fits over the MMIC chip and rests on top of the other two lids. This cover is built with side walls in the center to provide extra shielding around the test device. The side walls come down to .025 inch above the dielectric material on the subcarrier. Four spring-loaded lid clamp assemblies, which are attached to the microstrip housing assemblies, exert sufficient pressure on the covers to maintain proper shielding.

The fixture is designed for considerable flexibility to handle a variety of potential testing requirements. For example, circuits requiring multiple RF inputs and outputs can be readily tested by using the two auxiliary connectors on each microstrip housing. The microstrip substrate inside the housing can easily be changed to a three-conductor pattern for this application. In addition, microstrip couplers can be incorporated in the substrate to monitor power or to inject additional signals into the MMIC circuit. Special filters, diplexers, bias chokes, by-pass capacitors, or attenuators could also be made on the microstrip circuits. The response of these circuits would be removed during the calibration procedure. If desired, the entire microstrip housings could easily be replaced with a microstrip-to-waveguide transition for making measurements above 18 GHz.

Bias Interface

To provide bias to the MMIC chip, wire bonds are made from the MMIC chip to the SiO chip capacitors and then to the PC board on the subcarrier. The bias lines fan out to the .040 inch square bias pads on the sides of the subcarrier. A set of 18 spring-loaded pins, closely spaced in a phenolic block, produce a positive pressure contact to the bias pads on the subcarrier. Two dowel pins on each side of the center section of the fixture position the bias block assembly directly over the bias pads on the subcarrier and two clamps swing over to hold the bias block down. Each pin is soldered on the top of the bias block assembly to a wire in a nineteen lead, wire harness that has a connector on the other end. The extra wire goes to the fixture base to establish the ground reference. The connector attaches to a bias interface box which consists of 36 pairs of banana jacks and 36 SPDT switches. These switches provide a convenient way to change the voltage between two states on any bias pad, which is particularly useful in testing multibit phase shifters or devices requiring bias on/off switches. The bias voltages can be monitored at the bias interface box or directly on the subcarrier PC board by using a small probe.

FIXTURE CALIBRATION

Calibration Approach

Since the overall objective is to characterize MMIC chips (in particular with accurate S-parameter measurements), the calibration approach was derived for measurements on an automatic network analyzer (ANA). The software was written for measurements on a Hewlett Packard 8542B ANA, but it is applicable for any ANA model or system. The basic approach taken was to calibrate the fixture as part of the overall ANA system calibration, instead of characterizing the fixture separately from the ANA. The procedure used for calibration is described in the following paragraphs.

The twelve-term error model, outlined in Hewlett Packard Application Note 221A, forms the basis of the calibration. Since the equations for the forward and reverse parameters are identical in form, the notation used here will be given only for the forward direction. The equations for the reverse direction can be obtained by replacing S_{11} and S_{21} with S_{22} and S_{12}, respectively. The forward error terms become reverse terms. The equations for the measured reflection and transmission (Γ_m and T_m, respectively) are as follows:

$$\Gamma_m = E_D + \frac{E_R S_{11} - E_R E_L \,(S_{11}S_{22} - S_{12}S_{21})}{(1 - E_s S_{11})(1 - E_L S_{22}) - E_s E_L S_{12} S_{21}} \quad (1)$$

$$T_m = E_x + \frac{E_T S_{21}}{(1 - E_s S_{11})(1 - E_L S_{22}) - E_s E_L S_{12} S_{21}} \quad (2)$$

To determine the six error coefficients, reflection measurements are taken on a short and on an open, and both transmission and reflection measurements are taken on five offset transmission lines. Although five offsets are used, only three offsets are actually required to determine the error terms; however, the additional measurements are used to improve the accuracy by making use of a least error square fit of the data points. For the reflection measurements of the short and the open, S_{12} and S_{21} are assumed to be zero. For the short $S_{11} = -1$ and for the open $S_{11} = 1$. The measured reflection equation, (1), is reduced for the short and the open to:

$$\Gamma_{ms} = E_D - E_R/(1 + E_s) \quad (3)$$

$$\Gamma_{mo} = E_D + E_R/(1 - E_s) \quad . \quad (4)$$

For the reflection of the offset through transmission lines, $S_{11} = S_{22} = 0$ and $S_{12} = S_{21} = e^{\gamma}$, where γ is $\alpha l + j\beta l$. The reflection equations for the offsets reduce to:

$$\Gamma_{mT} = E_D + E_R E_L e^{2\gamma}/(1 - E_s E_L e^{2\gamma}) \quad . \quad (5)$$

The same assumptions are made for the transmission equation for offsets. Under these conditions equation (2) reduces to:

$$T_m = E_x + E_T e^{\gamma}/(1 - E_s E_L e^{2\gamma}) \quad . \quad (6)$$

Except for the open, the remaining calibration pieces are shown in Figure 4. These pieces are mounted on a gold-plated, .062 inch thick, copper subcarrier with interfacing tabs similar to the MMIC subcarriers. The short is a rectangular bar, .1 inch long with a cross-section of .015 by .015 inch. Beam leads are bonded to the top of the bar to interface with the microstrip center conductors in the microstrip housing. The offsets are made similarly, except that microstrip transmission lines on .015 inch alumina substrates replace the shorting bar. The offsets are made in incremental step sizes from .1 to .5 inch in length. No calibration piece is used to obtain the open. The housings are positioned slightly over the center section of the fixture with the wedge pushed back to raise the open end of the microstrip housing above the center section. Since both the center conductor and the ground plane of the microstrip are opened, the fringing capacitance is negligible.

The procedure used in the calibration is to make all the measurements first, store them, and then solve the equations to obtain the error coefficients. The effort term, E_D, is first determined from equation (5). The product of $E_s E_L$ is assumed to be very small compared to unity since these are source and load reflection error terms. If these terms are neglected initially, equation (5) will trace out a circle as a function of increasing offset lengths. The center of the circle is the E_D error term. The $E_s E_L$ product puts a small amount of distortion in the trace of the circle; but since the center of the circle is determined from a least-error equare fit of all five points, the resulting error in determining E_D is negligible. Since E_D is now known, E_R and E_s can be determined from Eqs. (3) and (4) for the reflections of the short and open, respectively.

To determine the remaining error terms, it is necessary to first determine the complex propagation constant, γ, for the incremental offsets. This is accomplished by averaging the ratio of the transmission equations, Eq. (6), of offset number n + 1 to offset number n. This technique assumes E_X and $E_S E_L$ are mathematically negligible, which turns out to be a valid assumption. In any case, the averaging technique will diminish the error caused by this assumption. The E_L error term can now be determined from the reflection equations of the offset transmission lines using equation (5). Since this equation is repeated for each of the five offsets, the unknown error term, E_L, is determined using a least-error square fit of all the data points. The remaining two terms, E_X and E_T, are determined in a similar fashion by evaluating the transmission equations, Eq. (6), using the least-error square fit for the set of all five offsets.

The mathematics in the calibration approach may appear to be somewhat cumbersome; however, the technique is significant because it allows the error coefficients to be determined accurately from a few simple, insertable calibration pieces.

Measurement Software

The calibration and measurement software allow for the measurement of up to 101 frequency points. These points do not have to be spaced at equal intervals apart because a frequency file is stored in the software. Based on a single measurement run of the four S-parameters, up to twelve pages of corrected data can be printed or displayed at the discretion of the user. (The corrected S-parameters are obtained directly from the measured data using the equations given in Application Note 221A.) The first two pages of output data provide listings of the S-parameters in a magnitude and phase format for page one and in dB magnitude format in page two. Data pages three through six present the data in a Smith Chart or polar graphics form for each of the four parameters. The Smith Chart for the reflection measurements can be presented either as an impedance chart or can admittance chart. Pages seven through ten present a frequency plot of the magnitude in dB of each S-parameter. Automatic horizontal and vertical scaling is used in the plots. Plots of the forward group delay and maximum available gain are presented on the last two pages.

One convenient feature of the measurement software is that the input/output reference plane can be rotated by specifying the rotation length in inches of microstrip. Since the propagation constants of the microstrip lines were determined in the calibration software, this data is used for obtaining accurate line rotations independent of line loss or dispersion as these effects have already been included in the measured data.

TEST RESULTS

To obtain a proper evaluation of the fixture and the system calibration approach each must be evaluated separately. The fixture was first evaluated on the automatic network analyzer for reflections in the frequency domain and the results were convoluted into the time (or distance) domain to determine the source of the reflections. The system was then evaluated using the developed calibration software to determine if calibration routine was successful in removing the fixture reflection errors.

Fixture Results

The overall fixture VSWR is shown in Figure 5. A .4 inch microstrip transmission was measured. These reflections were convoluted into the time domain to determine their origins and the results are displayed in Figure 6. The results indicated that there was a problem associated with the output SMA connector interface. The interface was later repaired to correct the problem. The reflections around subcarrier were converted back into the frequency domain to produce the plot shown in Figure 7. This plot represents the interactions between the VSWR of the subcarrier interfaces between the two housings. The maximum VSWR is 1.6 to 1 which is equivalent to a maximum reflection coefficient of .117 at each interface.

The biggest contribution to this reflection was caused by misalignment of the center conductors of the microstrip transmission lines. Before these conductors were realigned, the fixture was calibrated using the correction software to determine if these errors could be removed by the software.

System Software

After calibrating the fixture with the ANA using the developed software, .4 inch offset was remeasured with the reference planes rotated in by .2 inch. The return loss data is shown in Figure 8. It can be seen that the reflections have been significantly reduced to demonstrate the validity of the calibration approach. Also, the transmission phase angle is near zero degrees which validates the rotation technique.

Further testing on actual MMIC chips is now in progress; however, insufficient data has been obtained at the time of this writing for inclusion in this paper.

CONCLUSIONS

A universal MMIC test fixture has been developed which has several unique features. It can accommodate various chip sizes, it can be calibrated on an automatic network analyzer using just microstrip type calibration pieces, it has provisions for multiple RF inputs and outputs, and it has provisions for use of up to

36 independent bias lines. Furthermore, no bonding is required during tests and the device under test can be enclosed on all sides. The fixture has the flexibility that it can be easily modified for special or unusual chip devices or testing requirements.

In addition to the hardware, software for calibrating and measuring MMIC chips in the fixture in an automatic network analyzer has also been developed. The software removes the measurement errors contributed by the fixture.

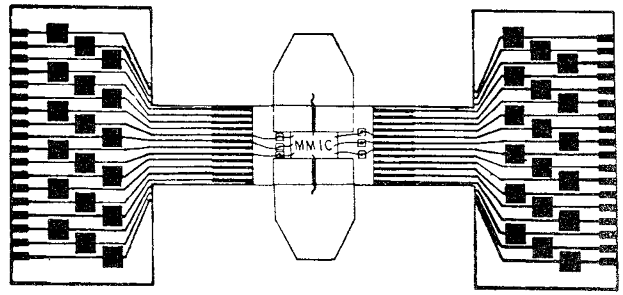

Figure 1. MMIC Subcarrier

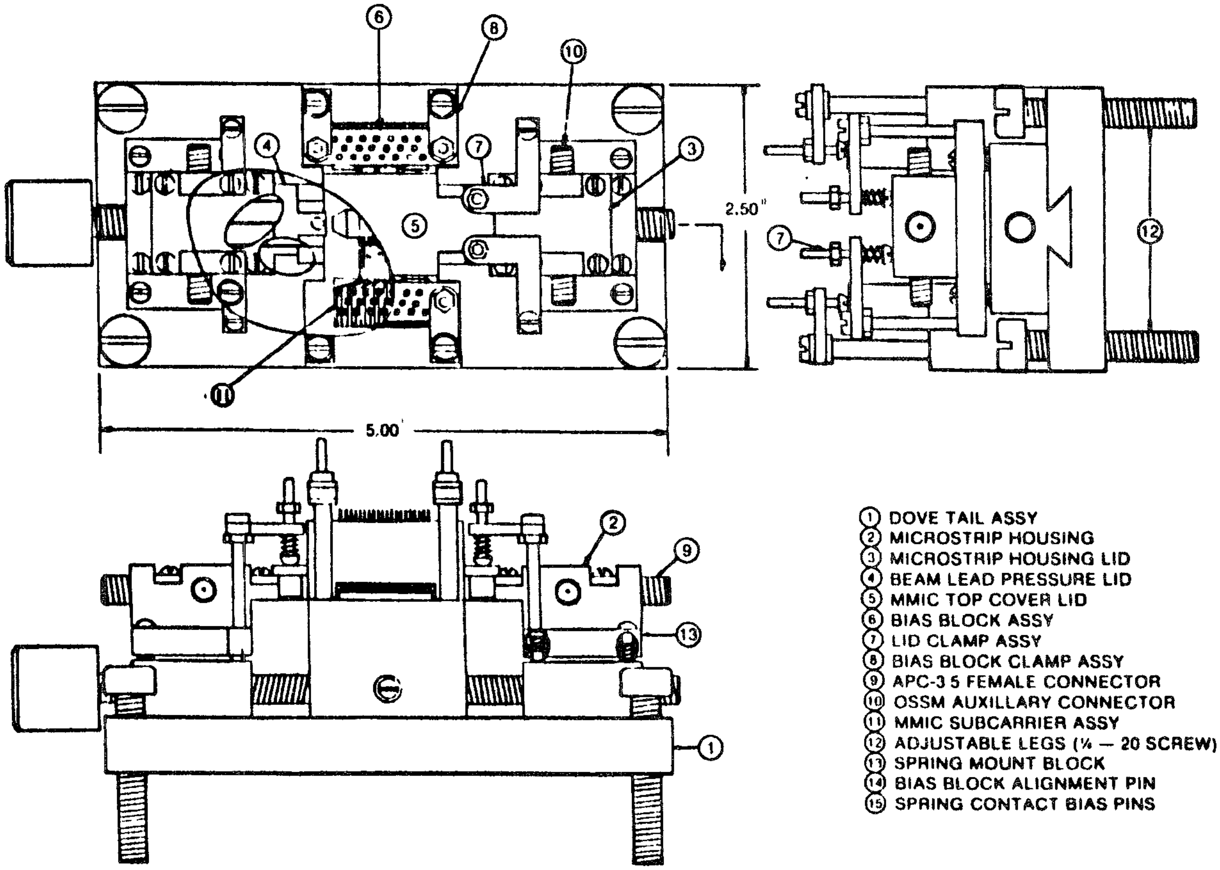

Figure 2. Test Fixture Assembly Drawing

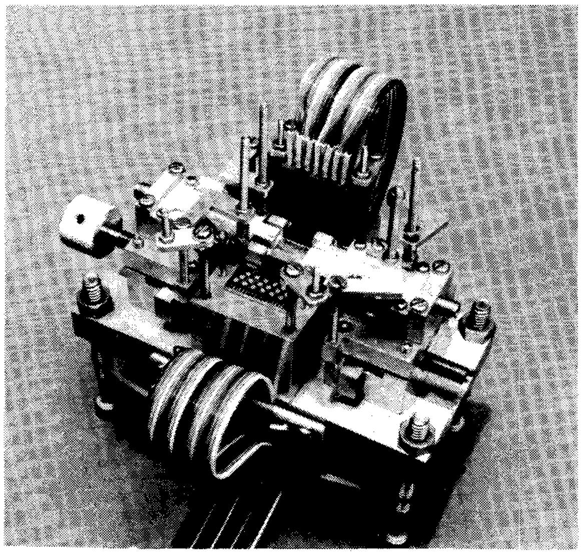

Figure 3. MMIC Test Fixture

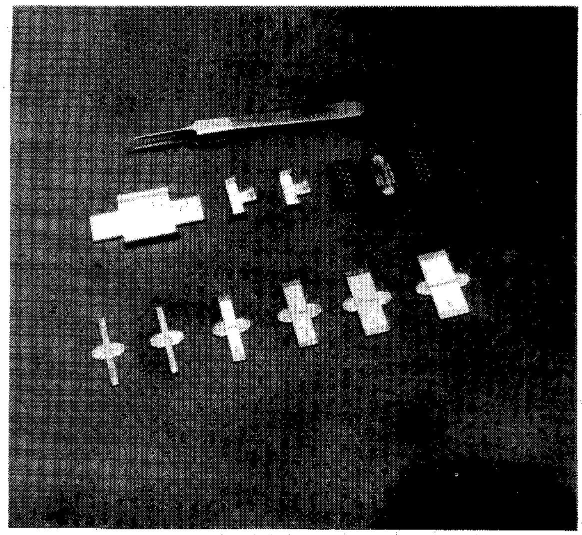

Figure 4. Calibration Pieces With Top Cover, BL Pressure Lid, and Subcarrier

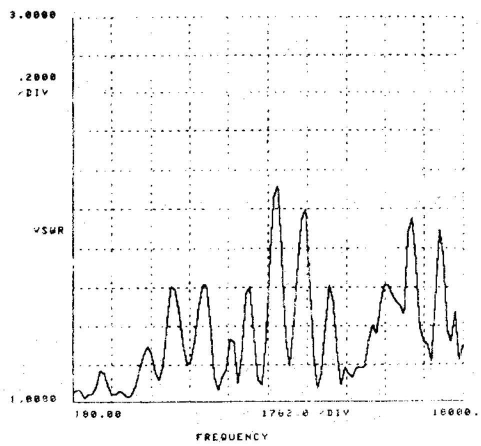

Figure 5. Overall Fixture VSWR

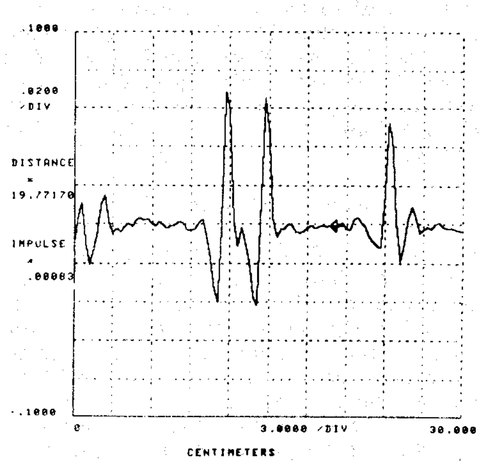

Figure 6. Fixture Time Domain Reflections

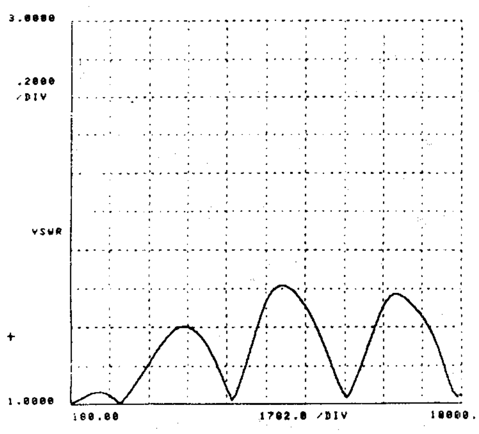

Figure 7. VSWR Without Connectors

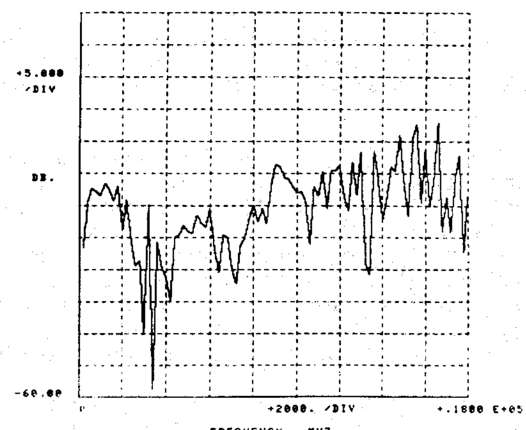

Figure 8. Return Loss Using Calibration Routine