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TECHNICAL REPORT ECOM-2588

L-BAND AMPLIFIER DESIGN FROM TWO-PORT PARAMETERS

V. GELNOVATCH

G. E. HAMBLETON

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L-BAND AMPLIFIER DESIGN FROM TWO-PORT PARAMETERS

by

V. Gelnovatch
G. E. Hambleton

April 1965

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U. S. ARMY ELECTRONICS LABORATORIES
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Abstract

Transistors now possess the capability to operate in the L-band region. This report describes an amplifier design using y-parameters measured at the design frequency and the fabrication of a laboratory amplifier model. Design calculations and performance data are presented.

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L-BAND AMPLIFIER DESIGN FROM TWO-PORT PARAMETERS

INTRODUCTION

Transistors have recently become available with useful gains in the L-band region.[1,2] The design of circuits around these devices has been along the time-honored four-pole analysis method. Obviously, a method which could combine rapid graphical operations with four-pole parameters would simplify amplifier design, give a better insight to overall operation of the system, and reduce the total amount of time involved.

Such a method was described by J. G. Linvill[3] and when applied to a linear active network (LAN) gave a graphical display of most of the important functions involved. Numerous articles have appeared using this technique successfully at lower frequencies with excellent correlation between theory and technique. With the introduction of L-band transistors it became desirable to apply the Linvill technique at L-band frequencies.

This paper will concern itself with the design of an L-band, 1 Gc transistor amplifier using the Linvill method (based on the admittance parameters of the device), and the subsequent construction of a laboratory model to corroborate the results. A brief review of the theory behind the Linvill method will be presented for completeness. It is not intended to be mathematically rigorous in this treatment. A complete mathematical derivation is detailed in Reference 1.

ANALYSIS

Any linear network, active or passive, may be completely characterized by a description of its two-port parameters from which the power transfer in the network can be analyzed. At low frequencies it is beneficial to use the hybrid parameters (h matrix); at microwave frequencies it is common to use the short circuit admittance (y) parameters. In general, any set of parameters may be used provided that they are a consistent set. Consider the network given in Fig. 1. The active network is characterized by its h-parameters. The source and the load have been replaced by a current generator and a voltage generator, respectively. These generators will simulate any value of source and load, both active and passive. At this point interest will only be shown in the passive loads. The input current generator is taken as the reference and has zero phase and unit amplitude. The voltage generator at the input is complex and is described generally by the variables a + jb and also in terms of the L- and M-variables which will be developed later. P_1 is taken as the power delivered to the LAN and P_o is the power delivered to the load by the LAN. It is clear that by careful choice of a and b any load and source can be stimulated on the LAN. Optimization of amplifier performance will depend on finding values of a and b which will give maximum power gain with stable operation.

Referring to Fig. 1, we may write loop equations for the circuit. Thus,

$$e_1 = i_1 h_{11} + e_2 h_{12}$$

$$i_2 = i_1 h_{21} + e_2 h_{22}$$

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but $$i_1 = 1 + j0$$

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and $$e_2 = a + jb = (L + jM)\left(\frac{-h_{21}}{2h_{22r}}\right)$$

substituting $$i_2 = h_{21}\,(1 + j0) + (L + jM)\left(\frac{-h_{21}}{2h_{22r}}\right) h_{22}$$

$$P_o = \mathrm{Re}\,(-e_2^* i_2)$$

$$P_o = L\,\frac{h_{21}^{\;2}}{2h_{22r}} - \frac{(L^2 + M^2)\,|h_{21}|^2}{4h_{22r}}\,. \tag{1}$$

The expression for P_o is now in terms of L and M. Since we intend to design around a single frequency, or at worst a narrow band, we can make an approximation that the h parameters will not be a function of frequency in our limited band. Equation (1), therefore, expresses P_o as a function of the L- and M-variables or in functional notation, $P_o = f\,(L,M)$. The form of the equation is a hyperboloid of revolution centered at L = 1 and M = 0 whose maximum positive value is given by

$$P_{o\,max} = P_{oo} = \frac{|h_{21}|^2}{4h_{22r}}\,. \tag{2}$$

The power out surface intersects the LM plane in a unit circle centered at (1,0). Figure 2 describes (graphically) the P_o function. The graphical interpretation of the P_i plane may be handled in a similar manner.

$$P_i = \mathrm{Re}\,(e_1^* i_1)$$

but $$i_1 = 1 + j0$$

therefore, $$P_i = \mathrm{Re}\,(e_1)^*.$$

From the loop equations

$$e_1 = i_1 h_{11} + e_2 h_{12}$$

$$e_1 = h_{11}\,(1 + j0) + (L + M)\,\frac{-h_{21}}{2h_{22r}}\,h_{12}$$

$$P_i = h_{11r} + L\mathrm{Re}\left(\frac{-h_{12}h_{21}}{2h_{22r}}\right) + M\mathrm{Im}\left(\frac{-h_{12}h_{21}}{2h_{22r}}\right).$$

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The form of the equation for P_i is a plane. This is illustrated in Fig. 3. We note in Fig. 2 that the maximum value of P_o was at (1,0) and called P_{oo}, Eq. (2). The value of P_i at the same L,M coordinates is called P_{io} and is given by

$$P_{io} = \frac{2h_{11r}\, h_{22r} - \mathrm{Re}\,(h_{12}h_{21})}{2h_{22r}} \,. \qquad (3)$$

The gain of the LAN at this point is simply the ratio of the two terms or

$$\frac{P_{oo}}{P_{io}} = G_{oo} = \frac{|h_{21}|^2}{4h_{11}h_{22r} - 2\,\mathrm{Re}\,(h_{12}h_{21})} \,. \qquad (4)$$

The gradient of P_i plane is the space derivative of the equation we have developed for P_i. It will be a vector quantity and can be expressed as a magnitude and a phase angle.

$$P_i = Gr = \left| \frac{h_{12}h_{21}}{2h_{22r}} \right| \; e^{j\theta}. \qquad (5)$$

An interesting point is that if the LAN is unilateral or, in other words, the h_{12} term is zero, then the P_i plane is parallel to the LM plane. The effect of the feedback then is to incline the plane.

On the basis of the above, a stability factor may be developed. When both P_o and P_i are plotted as a function of L and M and superimposed, then the P_i plane will slice through the paraboloid representing P_o (Fig. 4). It is obvious that for certain conditions the P_i plane will assume negative values, for the same points in the L-M plane where P_o is positive. The LAN is then unstable. Linvill defines a stability factor, C, which geometrically is simply the fractional amount of P_{io} which is found at the lowest point on the P_i plane within the unit circle defined by the intersection of the paraboloid and the L-M plane.

$$C = \frac{|h_{21}h_{12}|}{2h_{11r}h_{22r} - \mathrm{Re}(h_{12}h_{21})} = \frac{2\,P_{oo}}{P_{io}} \left| \frac{h_{12}}{h_{21}} \right|. \qquad (6)$$

It can be seen that if C is greater than 1, P_i will be negative while P_o is positive. When C is less than 1, both P_i and P_o will be positive and their ratio will have a maximum inside the circle unit.

To find the maximum, we must find a point inside the unit circle where the ratio of P_o to P_i is a maximum. For a case where there is no feedback, the P_i plane has no inclination, and the maximum value of the ratio will occur at (1,0) because the elevation is a maximum there, while the value of P_i over the plane is constant. If there is a non-zero h_{12} term then the P_i plane is inclined and the maximum value of the P_o to P_i ratio will occur

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somewhere along the gradient line of P_i that passes above (1,0).

To simplify the picture, we may consider a plane through the P_o and P_i surfaces along the gradient line passing through P_{io} and perpendicular to the LM-plane (see Fig. 5).

From geometrical considerations it can be shown that G_{max} is larger than G_{oo} by the ratio f/e and approaches 2 as a limit. We may call this ratio K_g and express it in terms of the stability factor, C.

$$K_g = \frac{2\left(1 - \sqrt{1 - C^2}\right)}{C^2} \quad . \tag{7}$$

Clearly then G_{max} is within 3 db of G_{oo}.

From Fig. 4, both P_o and P_i can be written in terms of a new coordinate system xy, located in the LM-plane. The x-axis is located along the gradient of the input power plane.

$$P_o = P_{oo} - P_{oo}x^2 - P_{oo}y^2$$

$$P_i = P_{io}\,(1 + Cx)$$

with
$$g = \frac{P_o}{P_{oo}} \; \frac{P_{io}}{P_i}$$

a constant gain equation can be written

$$1 + \left(\frac{gc}{2}\right)^2 - g = \left(x + \frac{gc}{2}\right)^2 + y^2 \, . \tag{8}$$

This equation describes concentric circles centered at L = 1 and M = 0 if the h_{12} term is zero. If it is not zero then the circles will not be centered at (1,0) and will not be concentric. They will have their centers located along the gradient line, at a distance gc/2 where g is any number between 0 and its maximm value K_g, g represents values of f/e other than the one obtained for G_{max}. The radius of the circles is given by

$$\text{radius} = \sqrt{1 - g + \frac{gc}{2}}^{\;2} \, . \tag{9}$$

The gain at any point on the unit circle can be related to the value of load admittance which will produce this gain by simply writing the load as a function of the L- and M-variables. Remembering that

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$$y = -\frac{i_2}{e_2}$$

$$i_2 = i_1 h_{21} + e_2 h_{22} = (i + j0)\, h_{21} + (L + jM) - \frac{-h_{12}}{2h_{22_r}}\; h_{22} = -y_L e_2$$

$$= y_L \frac{L + jM}{2h_{22_r}}\; h_{21} \qquad (10)$$

$$\therefore\; y_2 + h_{22} = \frac{2h_{22}}{L + jM} \quad .$$

We may draw on the LM plane loci of constant real and imaginary parts of $2h_{22}/L + jM$ and call them $G_2 + jB_2$. These loci will be an orthogonal set of the type that appears on a Smith chart. The input impedance of the terminated LAN may also be developed by remembering that

$$e_1 = i_1 h_{11} + e_2 h_{12} = Z_{in} \text{ since } i_1 = 1 + j0$$

$$z_{in} = (1 + j0)\, h_{11} + (L + jM) \frac{-h_{21}}{2h_{22_r}}\; h_{12} \qquad (11)$$

or

$$z_{in} - h_{12} = (L + jM) \frac{h_{12} h_{21}}{2h_{22_r}} \quad .$$

Just as in the case of load admittance, we may construct an orthogonal coordinate system for z_{in}. This will take the form of a rectangular coordinate system over the unit circle from which values of $R_1 + jx_1$ may be read that are associated with a given gain and load admittance. Z_{in} in terms of the LM variables is simply:

$$\frac{R_1 + jx_1}{|Gr|} = (L + jM)e^{-j\theta}. \qquad (12)$$

AMPLIFIER DESIGN

With the above background, we may proceed with the amplifier design. A number of transistor devices were available with useable properties for application in the 1 Gc region. Some preliminary calculations were made from the four-pole data. The unit that was selected for the proposed amplifier design calculation was primarily chosen from the calculated values of unilateral gain and gain figure. The y-parameters of the device were used as they are considered the most reliable at the frequency of operation. The material has so far been developed in terms of the h-parameters. The method of approach was perfectly general, and any consistent set of parameters could have been used. All the performance equations are invariant under transformation between matrix sets. The above y-parameters will be used in all the calculations to follow instead of the h-matrix which was used in the background development. An amplifier which gives a maximum power gain at 1 Gc will now be designed around this transistor. The parameters of the device chosen and other data are presented:

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$y_{11} = (16.2 + j68)\ 10^{-3} = 17.55 \times 10^{-3}$ at $22.9°$

$y_{12} = (-0.06 - j1.54)\ 10^{-3} = 1.54 \times 10^{-3}$ at $-90°$

$y_{21} = (5.76 - j49.8)\ 10^{-3} = 50 \times 10^{-3}$ at $-83.4°$

$y_{22} = (1.04 + j7)\ 10^{-3} = 7.13 \times 10^{-3}$ at $81.55°$

Unilateral Gain = 15.36 db

Gain Figure = 30.25 db

f_t = 2.85 Gc

h_{FE} = Ie = 5 ma at Vc = 5v

h_{fb} = 0.915 at 1 kc

I_{cbo} = 0.035 ma .

The first step is to calculate the ratio of P_{oo}/P_{01}, the gain of the device at (1,0) in the LM plane. Since the y_{12} term of the device is not zero, the P_1 plane will be inclined to the LM plane and the maximum value of gain will not occur at L = 1 and M = 0. From Eq. (4)

$$\frac{P_{oo}}{P_{1o}} = \frac{|y_{21}|^2}{4\ R_e(y_{11})\ Re(y_{12})\ -2\ Re(y_{21}y_{12})}$$

$$\frac{P_{oo}}{P_{1o}} = \frac{|50 \cdot 10^{-3}|^2}{4\ (16.2 \cdot 10^{-3})\ (1.04 \cdot 10^{-3})\ -2Re\ (1.54 \cdot 10^{-3}\ @\ -90)\ (50 \cdot 10^{-3}\ @\ -83.4)}$$

$$= \frac{2500}{67.4\ -\ 2Re77\ @\ -173.4} = \frac{2500}{67.4 + 153}$$

$$= 11.35 = 10.53\ \text{db} .$$

The maximum gain is within 3 db of G_{oo} (see Eq. (7)).

The stability factor, C, is evaluated as:

$$C = 2\ G_{oo}\left|\frac{y_{12}}{y_{21}}\right| = 2\ (11.35)\ \left|\frac{1.54 \cdot 10^{-3}\ @\ -90}{50 \cdot 10^{-3}\ @\ -83.4}\right|$$

$$C = 22.7\ |.0308|$$

$$C = 0.7.$$

Since this value is less than one, the amplifier will be stable; G_{max} will occur inside the unit circle. As previously mentioned, the constant gain

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circles will fall along the gradient line passing through the point (1,0). The angle that the gradient makes with the L-axis is found from the argument of $(-y_{12}y_{21})^*$.

$$y_{12}y_{21} = (1.54 \cdot 10^{-3} @ -90)\ (50 \cdot 10^{-3} @ -83.4)$$

$$y_{12}y_{21} = 77 \cdot 10^{-6} @ -173.4 = (-76.5 - j8.84)\ 10^{-6}$$

$$(-y_{12}y_{21})^* = (75.5 - j8.84)\ 10^{-6} = 77 \cdot 10^{-7} @ -6.67$$

$$\theta = -6.67^\circ .$$

For our case, G_{max} is larger than G_{oo} by the ratio f/e. To find G_{max} we must calculate the ratio from Eq. (7).

$$f/e = K_g = 2\left[\frac{1 - \sqrt{1C^2}}{C^2}\right]$$

$$K_g = 2\left[\frac{1 - \sqrt{1 - (0.7)^2}}{(0.7)^2}\right] = 2\left[\frac{1 - 0.721}{0.49}\right]$$

$$K_g = 1.14$$

$$G_{max} = K_g\ G_{oo} = (1.14)\ (11.35) = 12.9$$

$$G_{max} = 11.1 \text{ db.}$$

Constant gain circles can now be constructed on the L-M plane. As previously stated, we may use a Smith chart for convenience. We may use it as the unit circle in the L-M plane and draw on it the constant gain circles. The Smith chart has an orthogonal coordinate system which may be represented as constant $G_2 + jB_2$ loci and can be used to evaluate y_L. To find the centers and radii of constant gain circles we refer to Eq. (8) for "g" and find that the centers will be located along the gradient line passing through (1,0) and will be given by gC/2 where g is values of the ratio f/e, other than K_g. The parameter g may take on any value between 0 and K_g. The radius of each circle is given by Eq. (9)

$$\text{radius} = \sqrt{1 - g + (2C/2)^2} .$$

It is seen that the locus of G_{max} will appear as a point. The above operations are performed in tabular notation for five values of gain as shown in Table I.

Based on Table I, the gain circles have been constructed (Fig. 6). The chart of Fig. 5 can be used to choose appropriate values of source and load admittances to give a required value of gain.

$$y_L = G_2 + jB_2 - y_{22} \cdot$$

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The coordinates on the Smith chart of Fig. 6 represent values of G_2 and B_2. For maximum power gain

$$G_2 = 3.2y_{22_r}$$

$$B_2 = .25y_{22_r}$$

$$G_L = G_2 - y_{22_r} = (3.2 - 1)\ y_{22_r}$$

$$G = 2.3 \times 10^{-3} \text{ mho}$$

$$B_L = B_2 - y_{22_i} = (0.26 - 7)\ 10^{-3}$$

$$B_L = -6.74 \times 10^{-3} \text{ mho.}$$

The load admittance $(2.3 - j6.74)\ 10^{-3}$ mho will yield G_{max}. In the practical problem this amplifier must be coupled to a second stage. It will be assumed, for this design, that the coupling circuit will be followed by a 50 ohm impedance representing the input impedance of the next stage. The coupling network when terminated in the 50 ohm load should look like the admittance needed to yield G_{max}. A simple filter section will be chosen for the coupling network because of its inherent ease of calculation (Fig. 6).

The calculation of values for L and C can be performed graphically on an admittance-impedance chart, shown in Fig. 7.

It is obvious that any point on this chart is specified by an R + jX value and an equivalent G +jB, therefore, components can be combined in series and parallel configurations by alternately changing to impedance or admittance coordinates, graphically. The problem of designing a coupling network can be solved by using this chart. It will be advantageous to first normalize the scales in order to distribute the calculation over a convenient graphical space. A convenient factor is 200.

$$g_L \text{ (normalized)} = \frac{2.2 \cdot 10^{-3} \text{ mho}}{5 \cdot 10^{-3}} = 0.44 \text{ mho}$$

$$b_L \text{ (normalized)} = \frac{-6.75 \cdot 10^{-3} \text{ mho}}{5 \cdot 10^{-3}} = -1.35 \text{ mhos}$$

$$\text{normalized load} = (0.44 - j1.35) \text{ mho}$$

$$50 \text{ ohms (normalized)} = 0.25 \text{ ohm.}$$

The above values are located on the chart. Only the pertinent lines are drawn in Fig. 8 in order to simplify the diagram. To match the amplifier to 50 ohms, an impedance representing the capacitance is added to the 50 ohms representation, the resultant is added to the admittance representing the inductance of the matching network. This must result in a graphical reading equal to the "normalized load," above.

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$$\Delta X_c = 0.65 \text{ units} \times 200 \text{ ohm/units} = 130 \text{ ohms}$$

$$C = 1.22 \times 10^{-12} \text{ farad}$$

$$\Delta X_L = \frac{200 \text{ ohms/unit}}{2.65 \text{ unit}} = 75.5 \text{ ohms}$$

$$L = \frac{75.5}{6.25 \cdot 10^9} = 12.0 \times 10^{-9} \text{ henry.}$$

The resultant matching network is shown in Fig. 9.

To complete the design, an input coupling network must be calculated. The load admittance has already been evaluated and it remains to find the input impedance for the terminated amplifier. A Cartesian coordinate system in units of $G_1 + jB_1$ normalized by the magnitude of the gradient can be inscribed over the unit circle in the L-M plane. Such a system is illustrated in Fig. 10. The constant gain circles have been omitted for simplicity, and only G_{max} is shown. The real axis of the rectangular system is rotated until it is parallel to the gradient line. The system shown in Fig. 10 was rotated, -6.67°. For G_{max}

$$\frac{G_1}{|Gr|} = 0.605 \qquad \frac{B_1}{|Gr|} = 0.11$$

$$Gr = \left| \frac{y_{12}y_{21}}{2y_{22r}} \right| = \left| \frac{(1.54 \cdot 10^{-3}) @ -90 \; (50 \cdot 10^{-3}) @ -83.4}{2\,(1.04 \cdot 10^{-3})} \right|$$

$$|Gr| = 37 \cdot 10^{-3}$$

$$G_1 = (0.605)(37 \cdot 10^{-3}) = 22.3 \cdot 10^{-3} \text{ mho}$$

$$B_1 = (0.11)\,(37 \cdot 10^{-3}) = 4.07 \cdot 10^{-3} \text{ mho}$$

but $$Y_{in} = (G_1 + jB_1) + y_{11}$$

$$Y_{in} = 22.3 \cdot 10^{-3} + j4.07 \cdot 10^{-3} + 16.2 \cdot 10^{-3} + j6.8 \cdot 10^{-3} \text{ mho}$$

$$Y_{in} = (38.5 + j10.87) \cdot 10^{-3} \text{ mho.}$$

At this point, we are confronted with the same situation that we had in designing a coupling network between amplifier and load. Specifically, the input of the amplifier will be matched to a 50-ohm source impedance. The admittance impedance chart used to find the coupling circuit in the output can again be used. Referring to Fig. 11, the input admittance to the transistor is located on the circular coordinate system, and the 50-ohm termination on the

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rectangular system. To connect the Y_{in} to the constant conductance circle, on which the 50 ohm source is located, 0.366 ohm in the form of series capacitance must be added. It is then required to add a susceptance of -1.05 mhos to complete the solution, thereby determining the value of the shunt inductance. All values are scaled for convenience by a factor of 50. From Fig. 12, we note that the value of capacitance reactance is

$$X_c = (0.366)\ (50) = 18.3 \text{ ohms}$$

$$C = \frac{1}{(6.28 \cdot 10^9)\ (18.3)} = 8.7 \cdot 10^{-12} \text{ farad.}$$

For the inductive reactance

$$X_L = \frac{50 \text{ ohms}}{1.05} = 47.6 \text{ ohms}$$

$$L = \frac{47.6 \text{ ohms}}{6.28 \cdot 10^{+9}} = 7.56 \cdot 10^{-9} \text{ henry.}$$

The input circuit is illustrated in Fig. 12.

The devices are germanium, pnp units and all of the four-pole data were taken with a collector bias of 5 volts and an emitter current of 5 milliamperes. To isolate the dc- and rf-circuits, bias tees incorporating rf chokes and bypass condensers were used. The transistor was biased in the common base configuration though it operates as a common emitter amplifier in terms of the rf currents. A schematic drawing of the complete amplifier is presented in Fig. 13.

Another interesting figure of merit of the amplifier is its noise figure. Nielsen[5] has developed an appropriate expression for the noise figure:

$$F = 1 + \frac{r_b'}{r_s} + \frac{r_e}{2r_s} + \frac{\left[\frac{1}{H_{FE}} + \frac{I_{co}}{I_E} + \left(\frac{f}{f_a}\right)^2\right]\left[r_e + r_b' + r_s\right]^2}{2a_o^2\ r_s\ r_g} \quad . \qquad (13)$$

A simple tee-equivalent circuit was derived from the four-pole data. The noise figure was then calculated from Eq. (13).

$$F = 1 + \frac{40}{50} + \frac{10}{2(50)} + \frac{\left[\left(\frac{1}{5}\right) + \frac{.12 \cdot 10^{-3}}{5 \cdot 10^{-3}} + \left(\frac{3}{1}\right)^2\right]\left[10 + 40 + 50\right]^2}{2(50)\ (10)\ (.912)^2} =$$

$$F = 7.62 \text{ db.}$$

The measured noise figure is expected to be in the region of 7.0 db.

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CONSTRUCTION

The amplifier was evaluated by assembling a one-stage amplifier in General Radio coaxial components. A standard holder which accepts the TO-18 package was used in conjunction with stub tuners to form the amplifier circuit. The bias tees are illustrated in Fig. 14.

The amplifier was tuned for maximum power gain at 1 Gc and the actual load and source admittances were measured with a General Radio transfer function and immittance bridge (type 1607). The maximum gain obtained was 10.3 db, 0.8 db lower than calculated. This difference is mainly caused by input and output coupling circuit losses, and is not unreasonable. Y_L was measured to be $(2.5 - j6.05)\cdot 10^{-3}$ mho, and Y_g was $(30 - j3)\cdot 10^{-3}$ mho. These are very close to calculated values considering that it is physically impossible to measure either value close to the terminals of the device because of the components used. The bandwidth was measured on a Rhodes-Schwartz POLYSKOP type SWAB, and found to be 47 Mc. The noise figure was measured to be 8.0 db.

CONCLUSIONS

From the experiment performed, it is safe to assume that one is able to obtain fairly good correlation between the Linvill design approach and practical application at 1000 Mc.

The amplifier was designed graphically, complete with appropriate coupling circuits. Such a complete amplifier could be constructed with lumped components or in a stripline circuit where the coupling circuits could be fabricated in a manner dictated by the design. The losses would be higher in such circuits and would not allow an accurate check of the (graphical) power gain calculation.

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REFERENCES

1. G. E. Hambleton and V. Gelnovatch, "L-Band Germanium Mesa Transistors," Microwave Journal, Vol. 8, No. 1, pp. 42-68, Jan. 1965.

2. G. E. Hambleton and V. Gelnovatch, "Microwave Amplifier Performance of Germanium Transistors," USAECOM Tech. Rpt. 2579, April 1965.

3. J. G. Linvill and J. F. Gibbons, "Transistors and Active Circuits," McGraw Hill Book Co., Inc., New York, N. Y., (1961).

4. J. G. Linvill and L. G. Schimpf, "The Design of Tetrode Transistor Amplifiers," Bell System Tech. Journal, Vol. 35, pp. 813-840, July 1956.

5. E. C. Nielsen, "Behavior of Noise Figure in Junction Transistors, Proc. IRE, Vol. 45, pp. 957-962, July 1957.

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$$i_1 = 1$$
$$e_2 = (L + jM)(-h_{21}/2h_{22r})$$

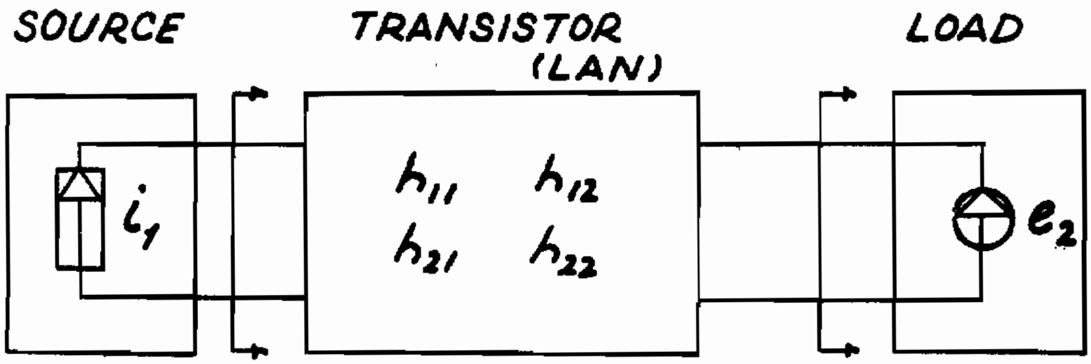

FIGURE 1 : MODEL FOR ELECTRICAL ANALYSIS (after Linvill)

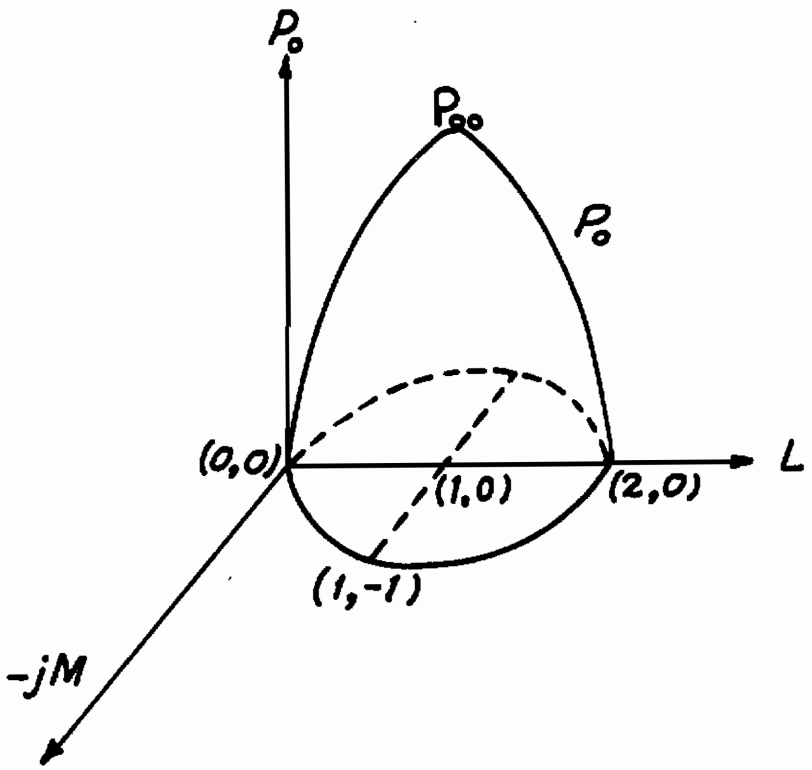

FIGURE 2: POWER-OUT AS A FUNCTION OF L AND M

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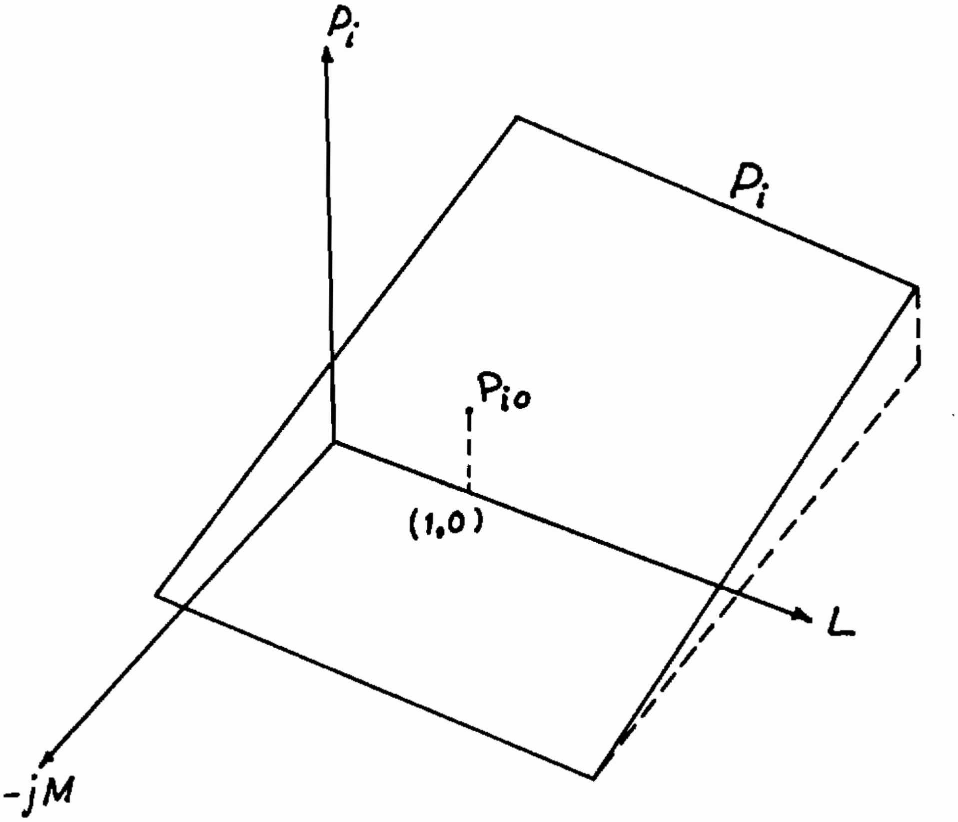

FIGURE 3: POWER-IN VERSUS L AND M

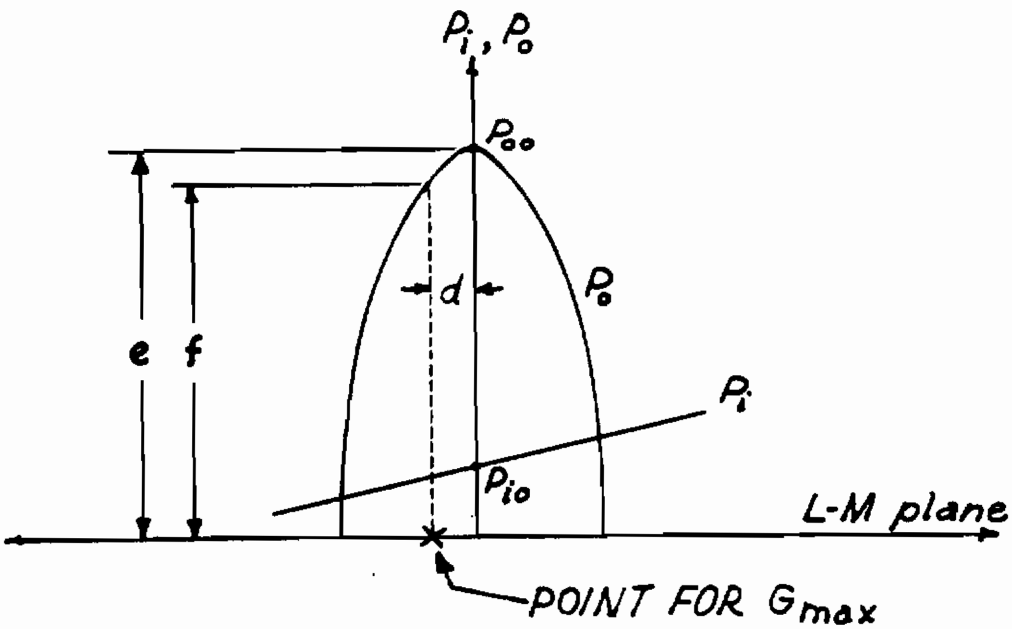

FIGURE 4: PLANE INCLUDING GRADIENT THROUGH P_{io} AND PERPENDICULAR TO THE L-M PLANE

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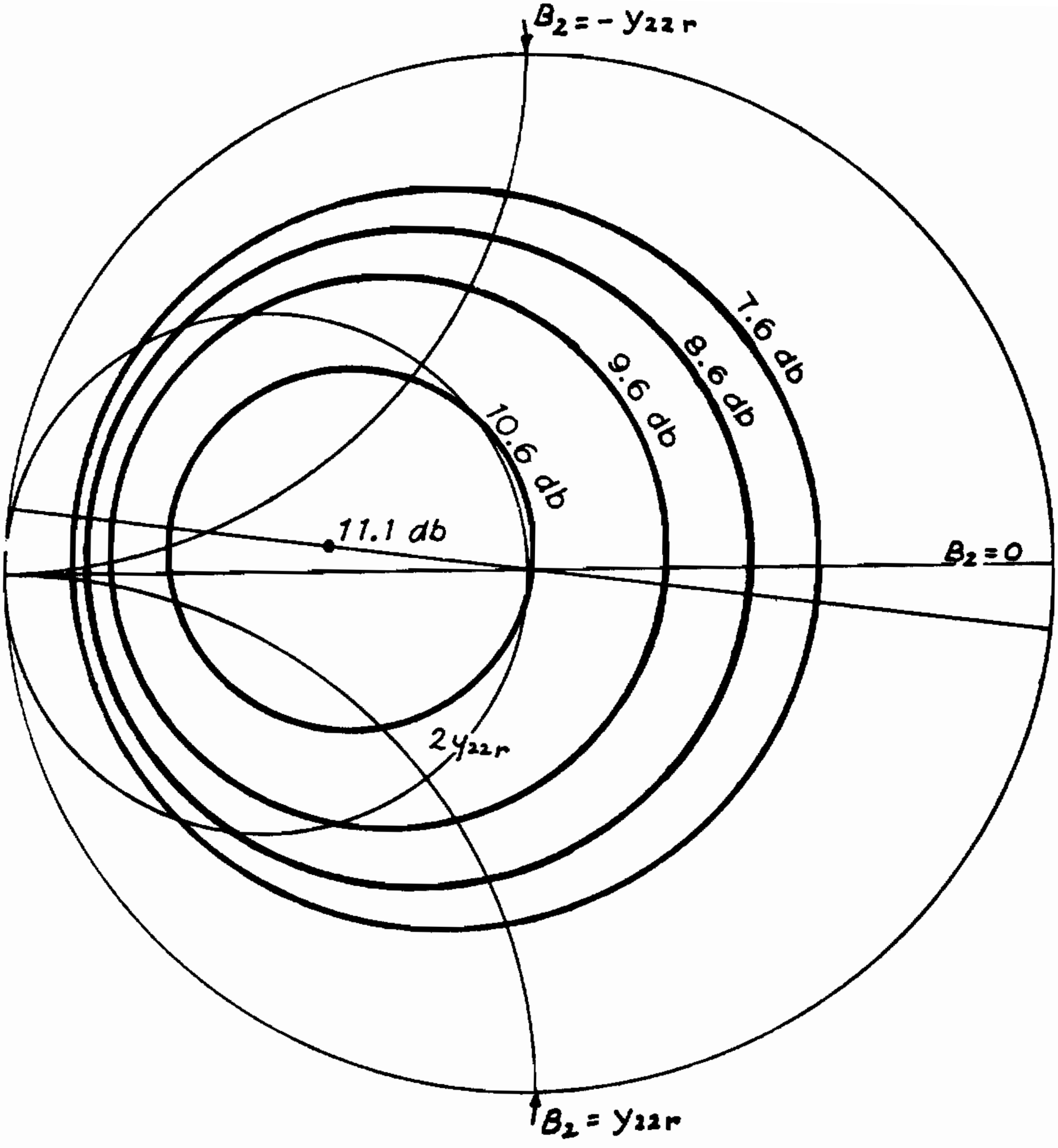

FIGURE 5: CONSTANT POWER GAIN AS A FUNCTION OF LOAD ADMITTANCE

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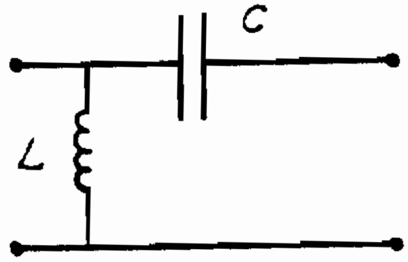

FIGURE 6: OUTPUT COUPLING CIRCUIT

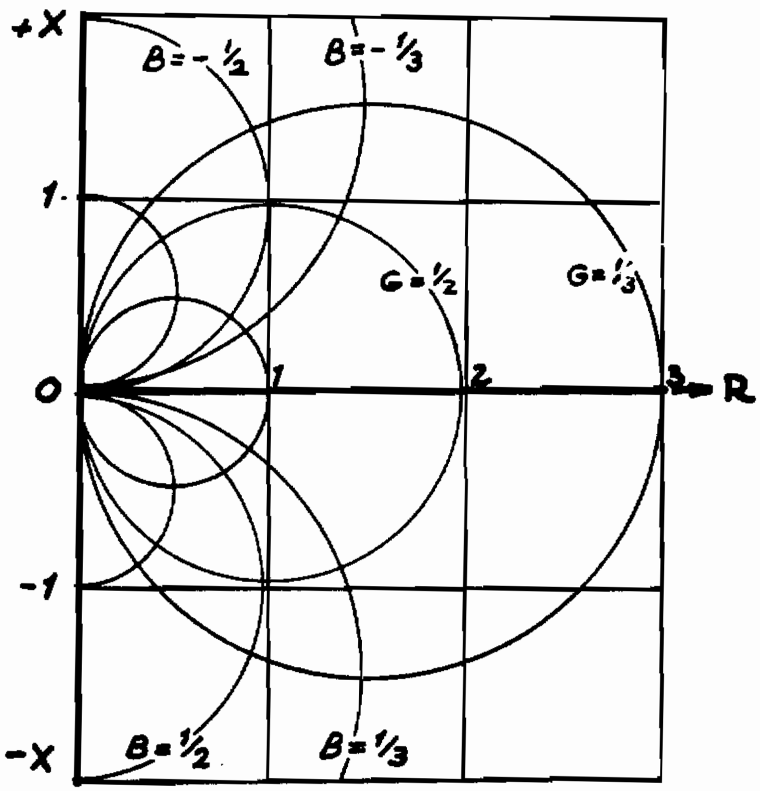

FIGURE 7: IMPEDANCE-ADMITTANCE CHART

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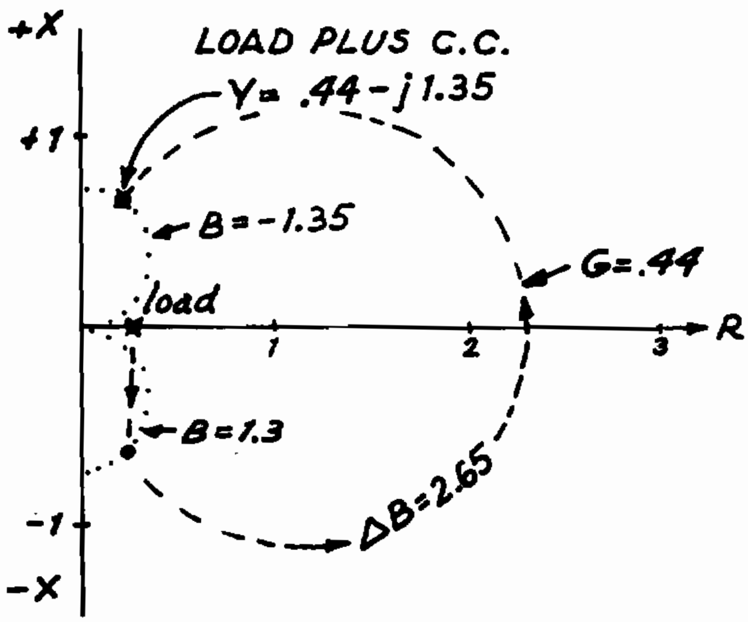

FIGURE 8: COUPLING CIRCUIT DESIGN

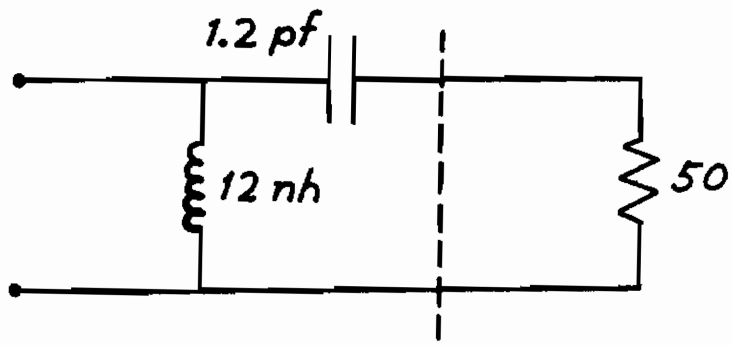

FIGURE 9: COUPLING CIRCUIT RESULT

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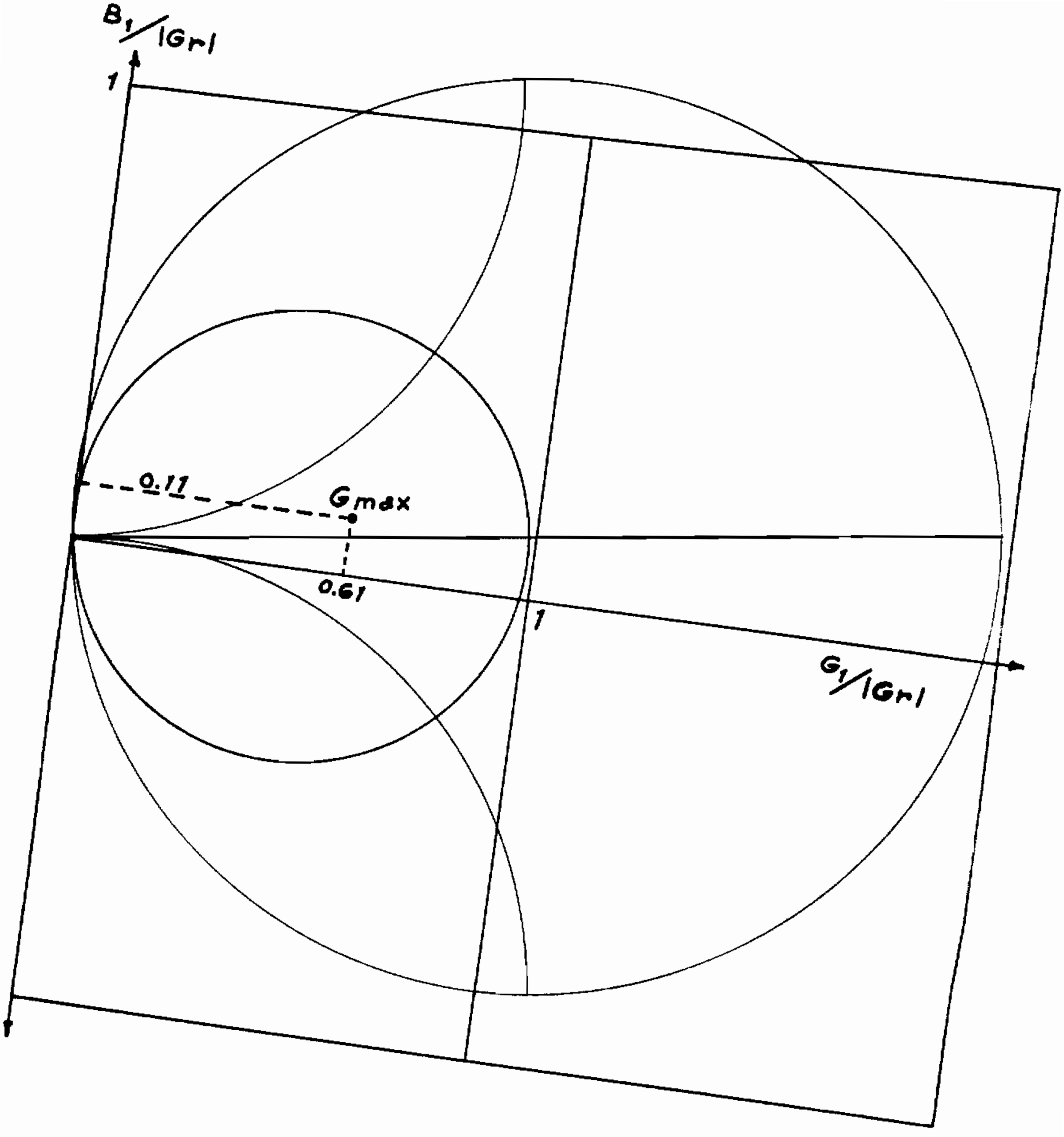

FIGURE 10: INPUT ADMITTANCE VERSUS POWER GAIN

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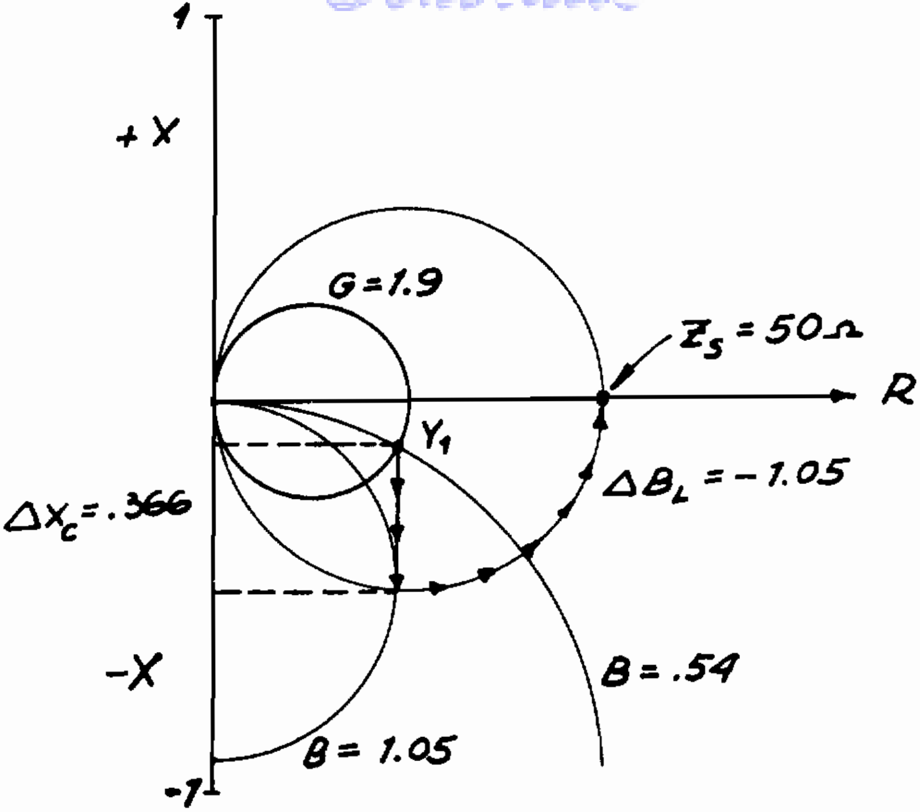

FIGURE 11: INPUT COUPLING CIRCUIT DESIGN

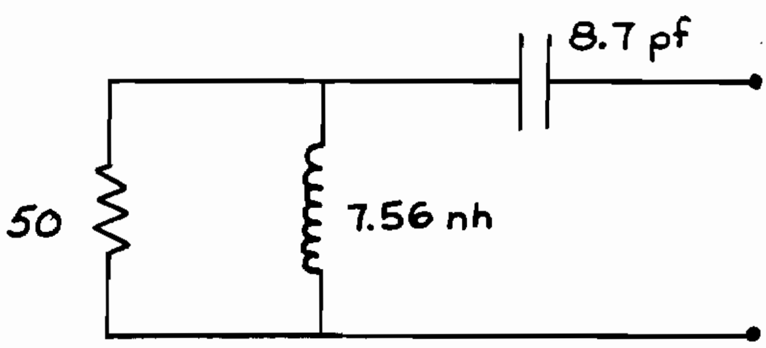

FIGURE 12: INPUT COUPLING CIRCUIT

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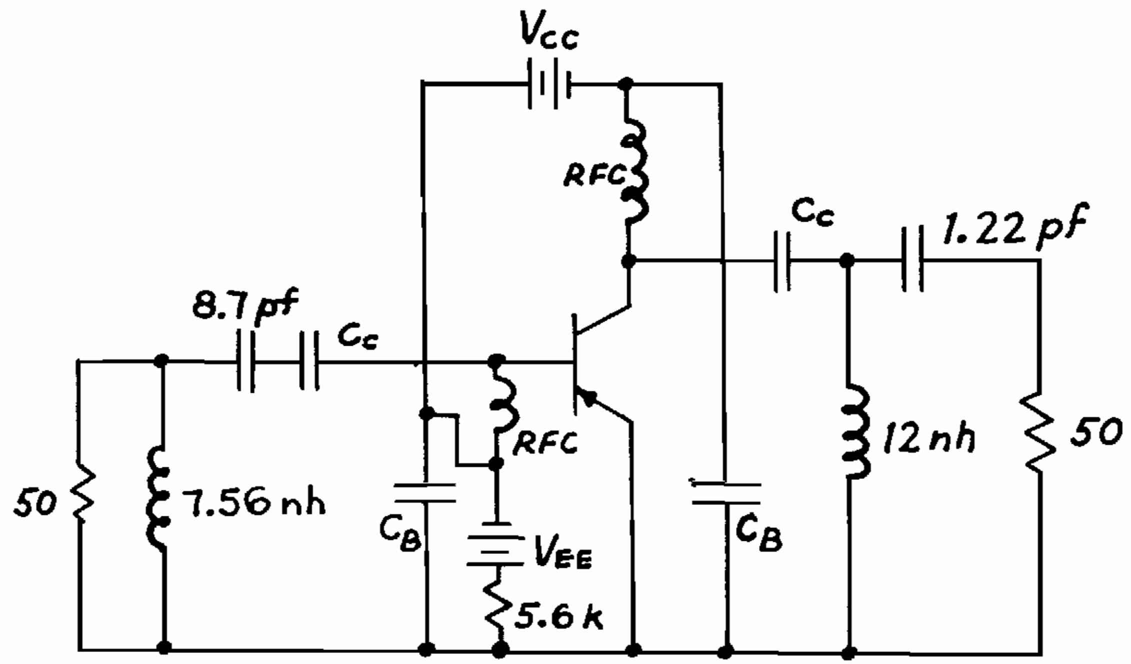

FIGURE 13 : COMPLETE AMPLIFIER SCHEMATIC

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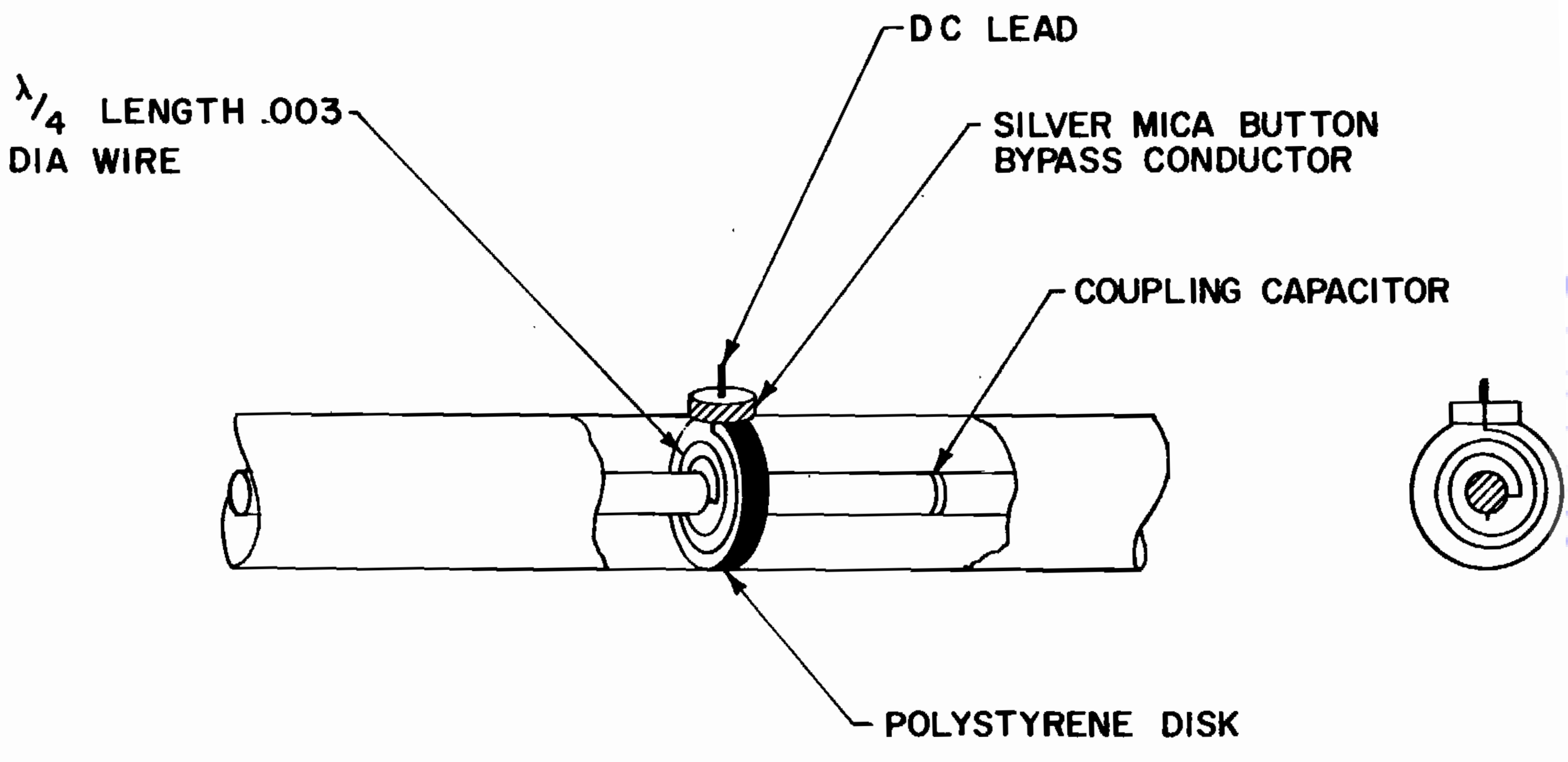

FIG. 14 COAXIAL BIAS TEE

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TABLE I

g	center	radius	gain
1.14	-0.40	0	11.1 db
1.00	-0.35	0.35	10.6 db
0.79	-0.28	0.53	9.6 db
0.63	-0.22	0.65	8.6 db
0.50	-0.17	0.73	7.6 db

TABLE I: CALCULATION OF GAIN LOCI

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3 REPORT TITLE
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4 DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Report

5 AUTHOR(S) (Last name, first name, initial)
Gelnovatch, V., and Hambleton, G. E.

6 REPORT DATE	7a. TOTAL NO. OF PAGES	7b NO. OF REFS
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Design and fabrication of an L-band transistor amplifier.	U. S. Army Electronics Labs., AMSEL-RD-PF U. S. Army Electronics Command Fort Monmouth, N. J. 07703

13 ABSTRACT

Transistors now possess the capability to operate in the L-band region. This report describes an amplifier design using y-parameters measured at the design frequency and the fabrication of a laboratory amplifier model. Design calculations and performance data are presented.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Amplifier, Solid-State						
L-Band Transistor Amplifier						
Linear Active Circuits						
Sampled Y-Parameters						
Microwave Devices						
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