NATIONAL RADIO ASTRONOMY OBSERVATORY
CHARLOTTESVILLE, VIRGINIA

ELECTRONICS DIVISION INTERNAL REPORT No. 276

DESIGN OF A MICROSTRIP DC BLOCK

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FEBRUARY 1988

NUMBER OF COPIES: 150

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1. Introduction

A frequent requirement in the design of active microwave circuits such as amplifiers and oscillators is a method of separating r.f. and d.c. for the purpose of biasing devices. Ideally we require a circuit that transmits microwave frequencies without attenuation and blocks d.c. In microstrip this is usually achieved by either a chip capacitor or a coupled transmission line section. Compared with coupled lines, chip capacitors have the disadvantages of the extra handling and bonding necessary to insert the capacitor into the circuit. At higher frequencies, the distributed behavior becomes important and loss significant. However, chip capacitors cover a broader bandwidth and occupy less area than a coupled transmission line. This report describes design, analysis and testing of a microstrip d.c. block for operation around 23 GHz.

Specifically, the design requirements are for a reflection coefficient of better than 0.1 (return loss greater than 20 dB) over a 3 GHz band centered on 23.5 GHz. The circuit is to be fabricated on 0.01" alumina substrate with a minimum dimension of 0.001" for line widths and spacing.

2. Design and Analysis

2.1 Design Theory

The design of d.c. blocks using microstrip coupled lines have been described by a number of authors [1]-[4]. The structure under consideration is shown in Figure 1. The most comprehensive treatment has been given by Kajfez and Vidula [3]. They show that the design procedure

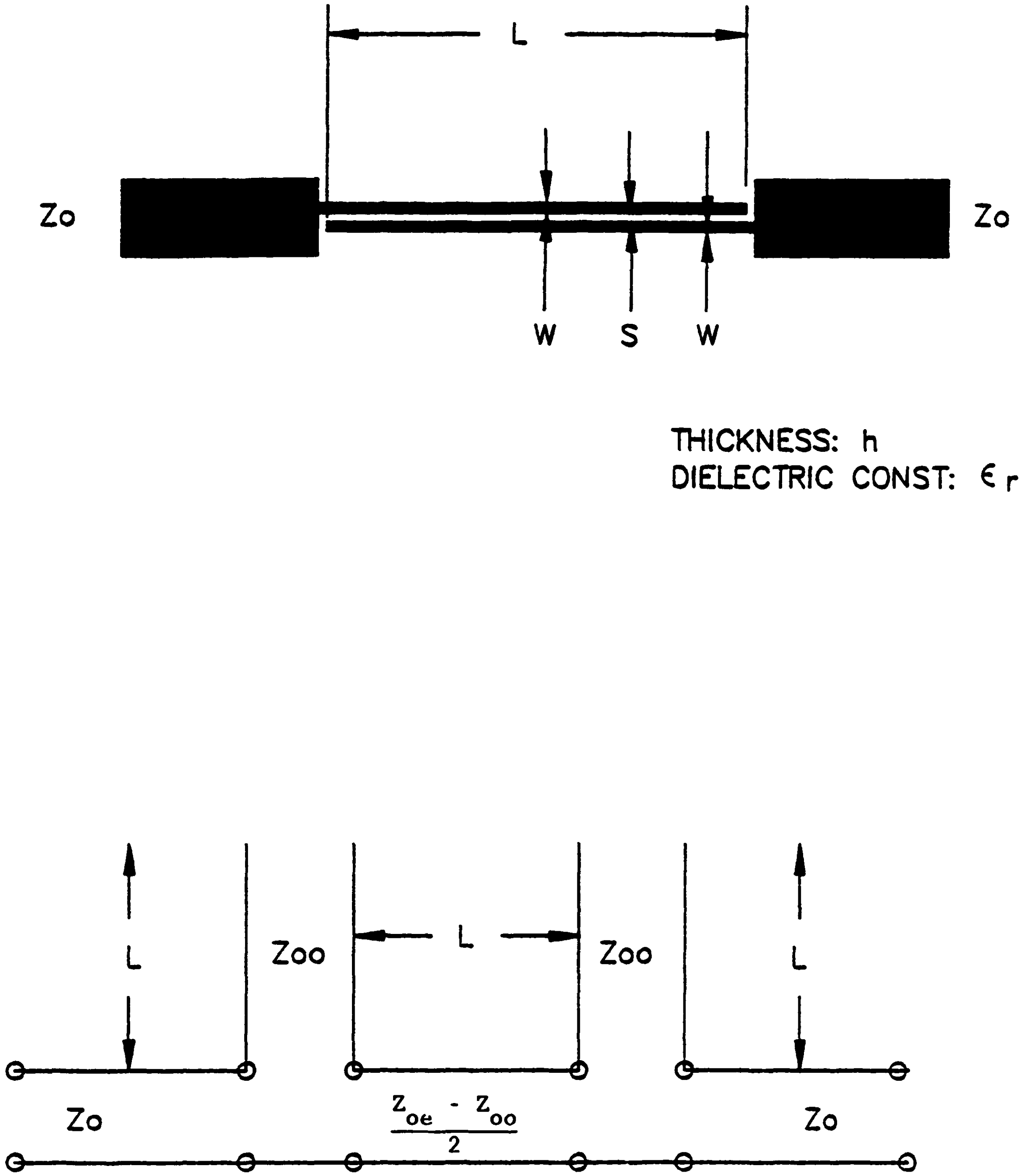


FIG 1 D.C. BLOCK MICROSTRIP CIRCUIT AND EQUIVALENT CIRCUIT.

can be based on the equations for pure TEM modes and, if necessary, a minor correction can be made to the physical length of the coupled section to allow for the presence of quasi-TEM modes. They demonstrate that the d.c. block can be designed to have either Chebyshev-like (rippled response) or maximally flat by appropriate choice of odd and even mode coupling impedances. Given a relative bandwidth B_r and a voltage standing wave ratio (VSWR) of S, then there are two possible solutions for the odd-mode coupling impedance Z_{oo} and the even-mode coupling impedance Z_{oe}. For microstrip, only one solution (called "solution one" by Kajfez and Vidula) is appropriate. Thus, from (17), (19) and (23) of [3]:

$$z_e = \sqrt{S}\left[1 + \sqrt{1 + \frac{\sqrt{1 + \Omega_c^2}}{\Omega_c^2}\left(1 - \frac{1}{S}\right)}\right]$$

$$z_o = z_e - 2\sqrt{S}$$

where $z_e = z_{oe}/z_o$

$$z_o = z_{oo}/z_o$$

and $\Omega_c = \cot\left[\frac{\pi}{2}\left(1 - \frac{B_r}{2}\right)\right]$

where Z_o is the characteristic impedance of the microstrip lines connecting to the d.c. block. These equations can be represented graphically in the manner shown in Figure 2 [3]. This universal impedance chart shows immediately the bandwidth and VSWR obtained from a given pair of even and odd mode impedances or conversely; the even and off mode impedances required to achieve a given bandwidth and VSWR. In principle, one can obtain very large bandwidths with small reflection if $Z_{oe} = 100$ and $Z_{oo} \approx 0$. However, practical microstrip constraints limit the range of even and odd mode

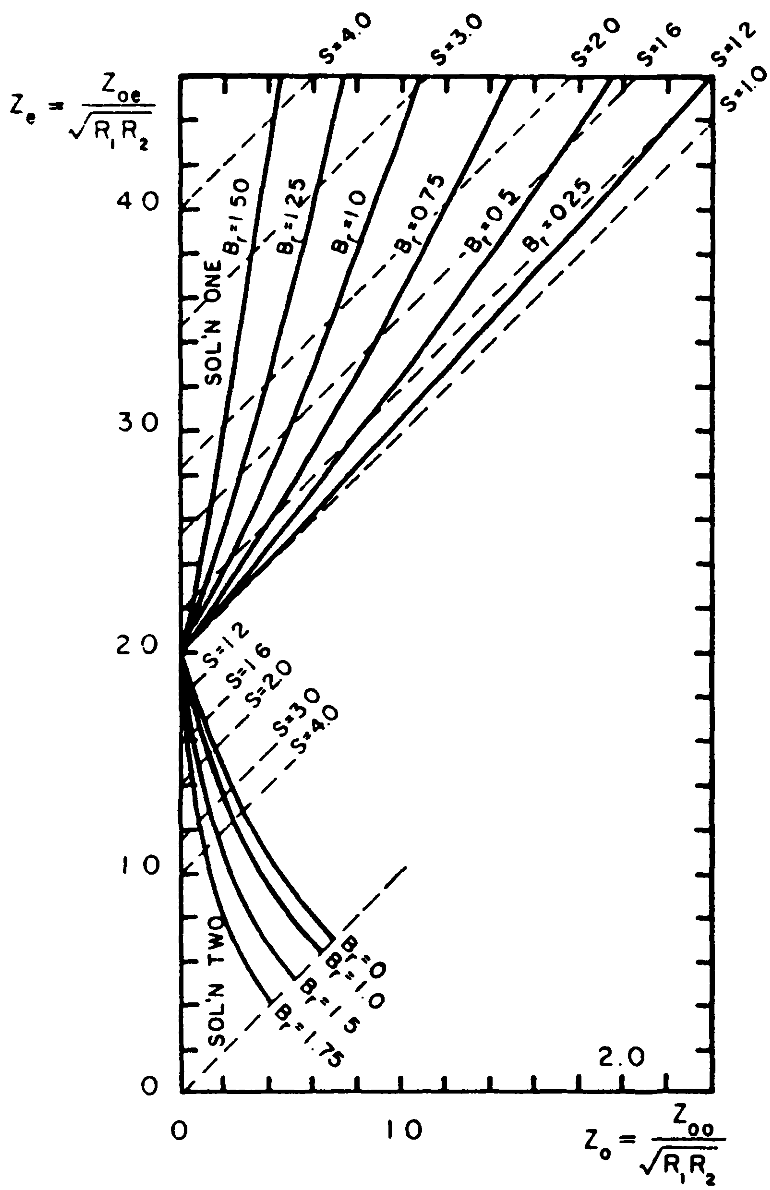


Fig. 2. Universal (Z_e, Z_o) plane. (From [3]).

impedances attainable. Figure 3 [3] shows the range achievable with a relative dielectric constant of 9. Note that only a small section above the S = 1.0 line overlaps with the "solution one" region of Figure 2.

2.2 Design and Analysis Programs

Two FARANT subprograms have been written to aid d.c. block design and analysis. The first subprogram "dcblockd" implements the Kajfez and Vidula design method, i.e., determines Z_{oe} and Z_{oo} from specified S and B_r. This program also analyzes the resulting design to display the frequency response of the resulting design. The second subprogram, "dcblocka", is an analysis-only subprogram for microstrip which has as input, physical microstrip parameters such as line widths, line separation and length, and substrate dielectric constant and then tabulates and plots the resulting frequency response of the design. No design program has been written which determines microstrip dimensions to give the required even and odd mode impedances. For common dielectric constants, this can easily be done graphically. If required, the FARANT optimization routine could be used to do this step. A more detailed description of the two subroutines follows.

The inputs to the program "dcblockd" are specified in statements 10135, 10140 and 10145 (see listing in appendix). They are the midband return loss, Return_loss, in dB, the relative bandwidth, B_rel, as a fraction and the center frequency, F_center in GHz. The current values of 30 dB return loss and .245 relative bandwidth should be satisfactory for many applications.

When the program is run, it prints the input data and also the value of VSWR and the frequencies of the upper and lower band edges, then calculates the required odd and even mode impedances (Z_{oo} and Z_{oe},

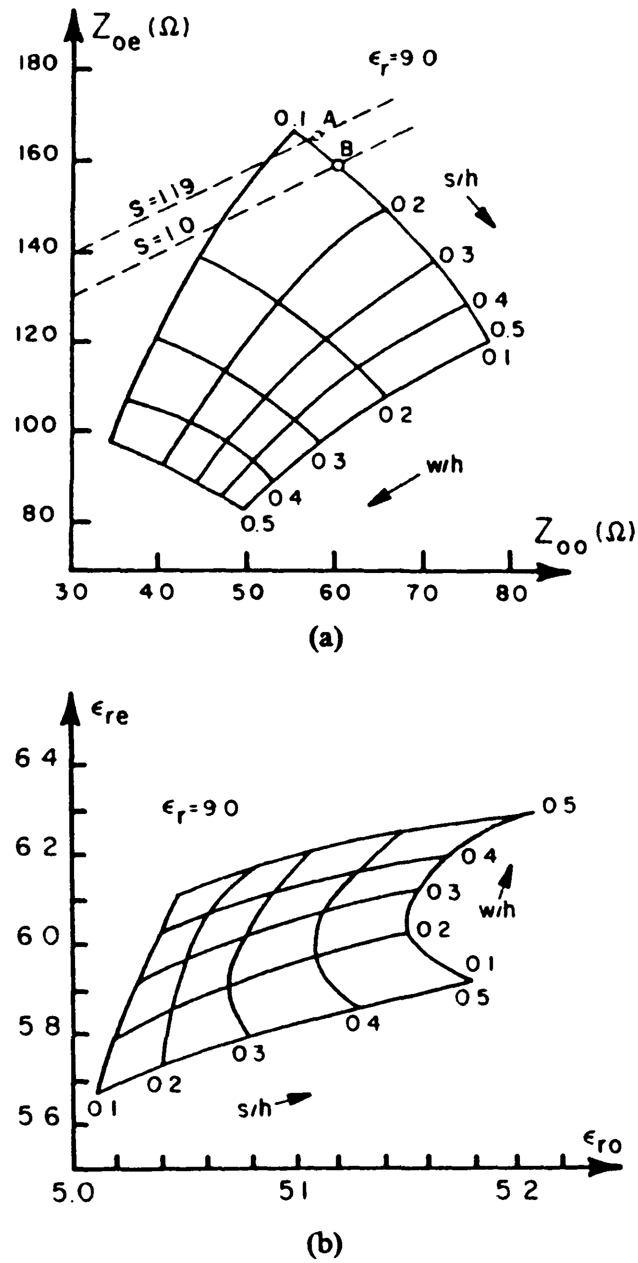


Fig. 3. (a) (Z_{oe}, Z_{oo}) plane for substrate $\epsilon_r = 9$.
(b) (ϵ_{re}, ϵ_{ro}) plane for substrate $\epsilon_r = 9$. (From [3]).

respectively) and the length of coupled section in free space. The input and output lines are assumed to be 50 ohms.

The program then pauses and displays:

CONT to analyze

If the CONT key is pressed, the program prints a table of S-parameters in 20 steps between F_start and F_end specified in statements 10330 and 10335 (currently 15 and 35 GHz). The program again pauses and displays:

CONT to plot graph

When the CONT key is pressed, the program plots a graph of input return loss magnitude vs. frequency to provide a quick check of the design response. Pressing CONT again will plot the input impedance normalized to 50 Ω on a Smith chart.

This program will give values for Z_{oo} and Z_{oe} for any reasonable value of return loss and bandwidth. However, the values obtained may not be realizable in microstrip (or other known transmission-line structure). For example, if the return loss is 30 dB and the relative bandwidth is unity, then Z_{oo} = 3.69 ohms and Z_{oe} = 106.90 ohms; values which are impossible for microstrip.

The second subprogram, "dcblocka", analyzes a microstrip design given physical microstrip parameters (losses are neglected). The data is input in statements 10135 to 10170 of the program. The d.c. block includes a section of input and output line. The line widths and gap spacing are specified relative to the substrate thickness, h, while the line lengths are in inches. The d.c. block is then analyzed using FARANT subroutines at 51 frequency points between F_start and F_end specified in statements 10185 to 10190 (current 21 and 26 GHz) and prints out a table of S-parameters. If the CONT key is pressed, the program will then plot a graph of return loss magnitude vs. frequency. A further CONT will plot the input impedance normalized to 50 Ω on a Smith chart.

The program "dcblocka" uses the subprograms "Mstrip" and "Cmstrip" to calculate the required microstrip parameters from physical dimensions. These subprograms are based on the equations by Hammerstad and Jensen [5]. The subprogram "Mstrip" calculates the impedance and effective dielectric constant of a microstrip line of given width and thickness. Loss and dispersion are neglected. The subprogram "Cmstrip" calculates odd and even mode impedances and effective dielectric constants for coupled lines of given width and spacing. The widths of the coupled lines are equal and of zero thickness, and loss and dispersion are neglected.

2.3 Design Example

As stated in the introduction, the design requirement was for a d.c. block with a return loss of better than 20 dB over a 3 GHz bandwidth centered on 23.5 GHz. To allow for fabrication tolerances, the d.c. block was designed for a 6 GHz bandwidth around 23.5 GHz ($B_r = .255$) and a return loss of 30 dB ($S = 1.065$). Using the program "dcblockd", this gave $Z_{oo} =$ 51.68 ohms and $Z_{oe} = 154.90$ ohms. If we specify equal line width and spacing for convenience, then these impedances can be achieved by $\frac{w}{h} = \frac{s}{h} =$ 0.12. (The subroutine "Cmstrip" gives values of $Z_{oo} = 51.94$ Ω and $Z_{oe} =$ 155.10 Ω for these conditions.) The coupled length was found to be 0.054". As a test of the effect of fabrication tolerances, a second design with $\frac{w}{h} = \frac{s}{h} = 0.14$ was also considered. This gives $Z_{oo} = 51.95$ Ω and $Z_{oe} =$ 147.12 Ω which is outside of the "solution one" region but gives a return loss of 26 dB at band center with a "maximally-flat" type of response.

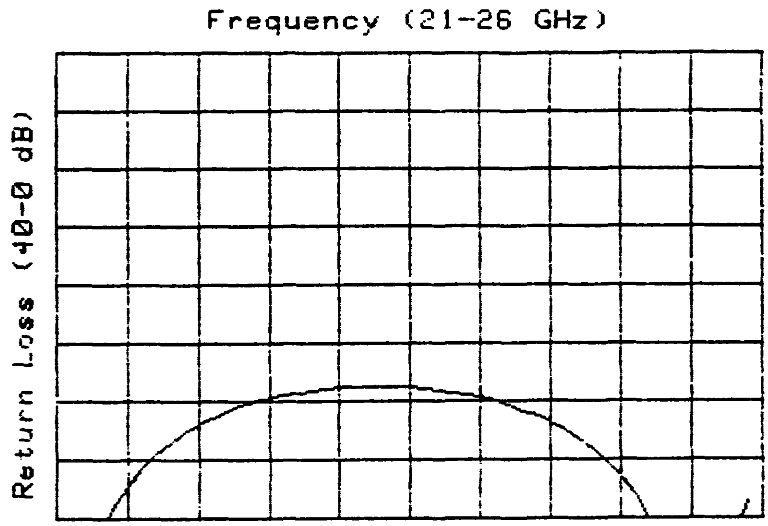
The theoretical responses for both designs are shown in Figure 4. Note that the return loss in design #1 is not exactly 30 dB because the input and output lines have calculated impedances of 49.76 Ω at w/h = 1.0, rather than 50 Ω.

3. Measurements

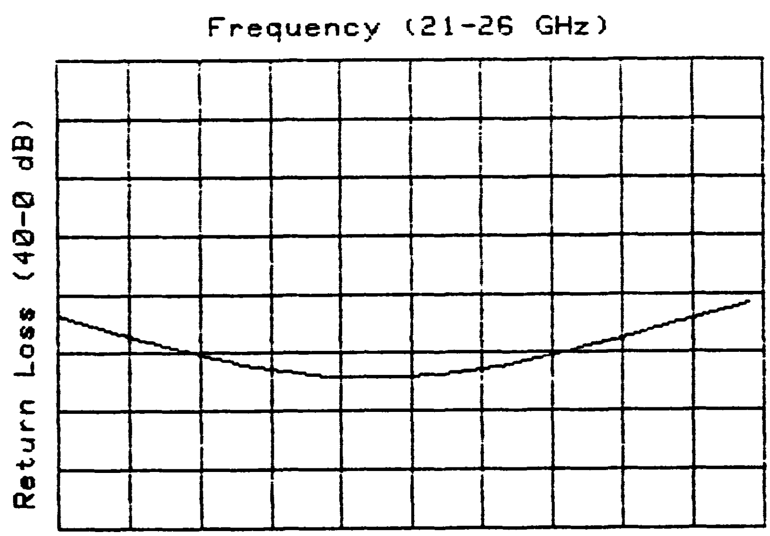
3.1 Scale Model Measurements

A series of scale model measurements were made to verify the design procedure and examine sensitivity of the design to fabrication tolerances. The model was fabricated at 100 times scale using Stycast as a substrate on an aluminum ground-plane. The microstrip lines were made using adhesive copper tape. Each end of the line was tapered to connect to an N-type connector (Figure 5). Figure 6 shows the result of one measurement with w/h = .12 and s/h = 0.1 and a coupled length of 5.1 inches. The return loss is 25 dB, the relative bandwidth is .25, and the center frequency is 25 GHz. The calculated values of impedances are Z_{oo} = 49.3 Ω and Z_{oe} = 157.2 Ω, giving a return loss of 22.4 dB, a relative bandwidth of .41 and the center frequency is 24.5 GHz (Figure 7). The agreement is good except for the bandwidth. However, the bandwidth is influenced greatly by the mismatch in the transitions, particularly as it affects the match at the center frequency. If the bandwidth is taken to be where the return loss is greater than the theoretical values of 22 dB, then a value of .34 is obtained which is much closer to theoretical.

From scale model measurements,it was determined by trimming the coupling fingers that the design is not sensitive to size of the gap at each end of the coupled line section. As would be expected, introducing asymmetry in line widths produced asymmetry in the response as well as



(a)



(b)

Fig. 4. Theoretical return loss of d.c. block with L = .054" and (a) w/h = s/h = .12 and (b) w/h = s/h = .14 calculated by "dcblocka".

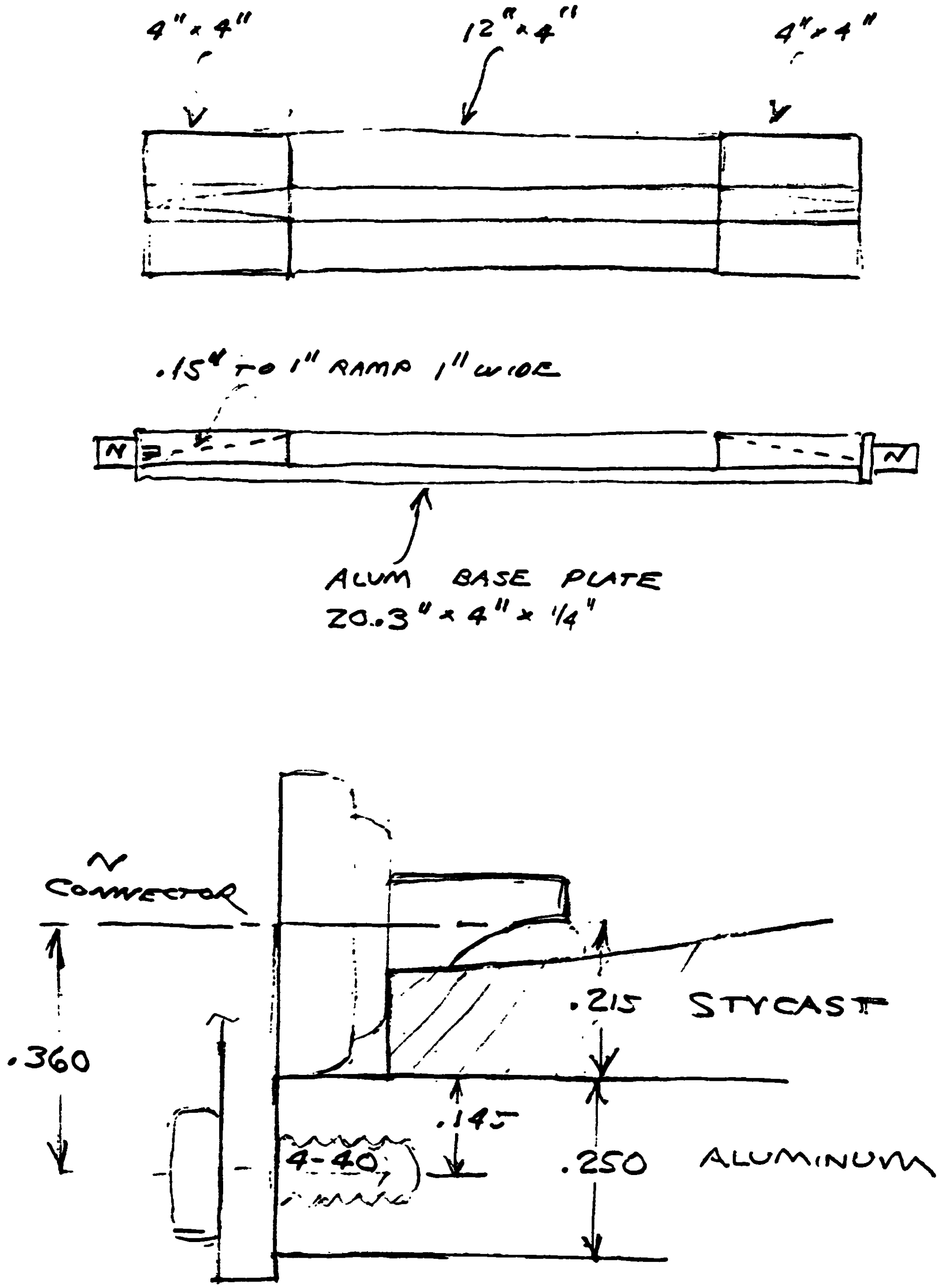


Fig. 5. Test fixture for scale-model measurements.

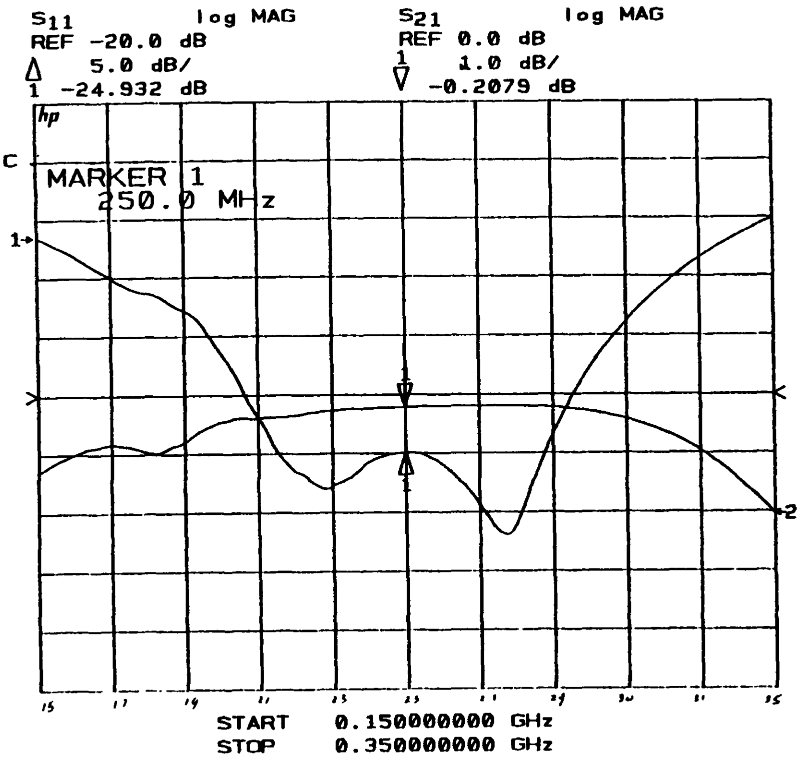


Fig. 6. Response of scale model with w/h = .12 and s/h = .01 and length of 5.1 inches.

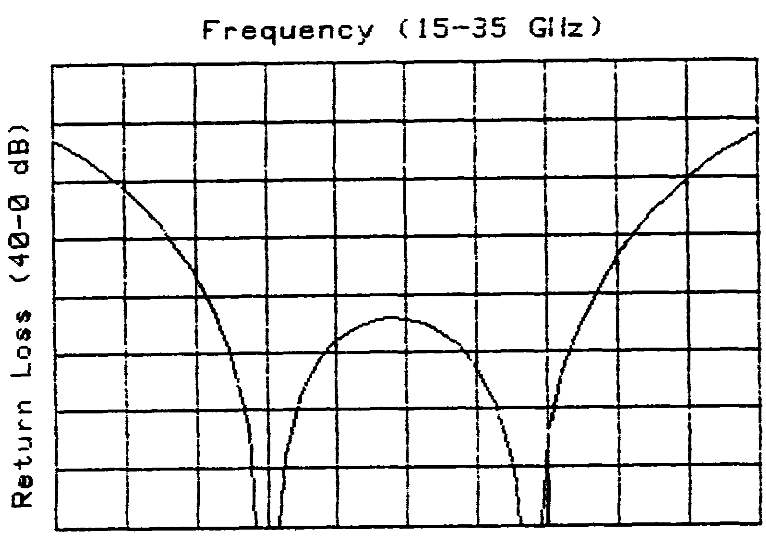


Fig. 7. Theoretical response corresponding to Fig. 6. (Return loss only).

some degradation in the return loss, but overall the design is not greatly affected by small variations in line widths or lengths, especially in a broadband design. Figure 8 shows the result if the coupled length is 4.9" and w/h = s/h = 0.11 for one finger and w/h = 0.15 for the other fingers; the result is still acceptable at 220 MHz.

3.2 K-Band Measurements

The final substrates were fabricated by MPC [6]. Two substrates were made for each design as well as a reference-through line. The dimensions of each substrate were checked using a measuring microscope; the results are given in Table I. Because the accuracy with which the edges could be determined using the measuring microscope was estimated to about ± .0001", estimating the tolerance in fabricating the substrate was difficult. However, it was possible to distinguish between the two designs (with differences in dimensions of .0002") and also the gap appeared to be smaller than the design value while the line widths were larger. If this was found to be consistent over a larger number of trials, then the mask could be modified to compensate. Average measured values were w/h = .148 and s/h = .093 for design #1 and w/h = .159 and s/h = .132 for design #2. S-parameter measurements were made of the reference line and of one substrate for each of the two designs. The substrates were mounted in a test fixture used for testing of amplifier designs with a Wiltron K connector and microstrip launcher at each end. The magnitudes of S_{11} and S_{21} as a function of frequency for a nominal 50 Ω through-line are shown in Figure 9. The return loss is somewhat poorer than desirable and no definite cause of this mismatch has yet been found. It was first believed to be due to the discontinuity at the join of the test substrate and connector substrate. However, time domain measurements

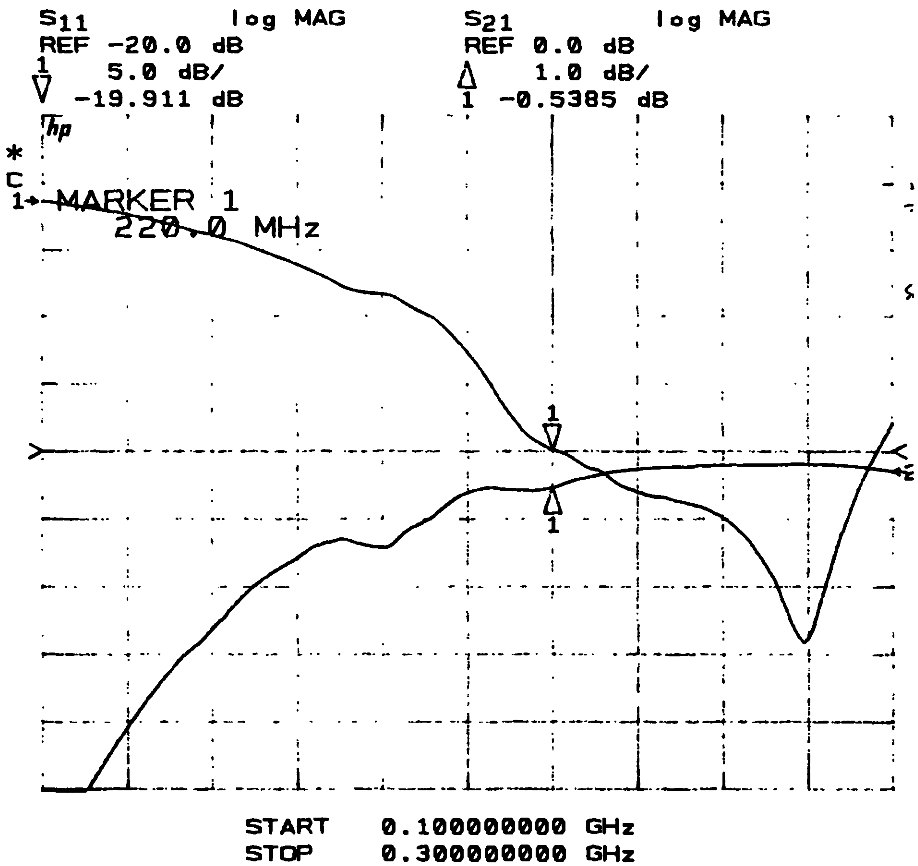
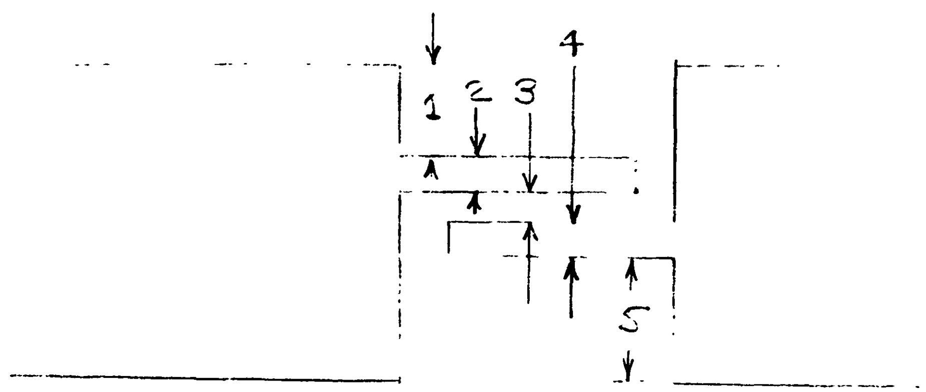


Fig. 8. Effect of changing dimensions on scale model to w/h = 0.11 for one line and w/h = 0.15 for other line and s/h = .11 and length = 4.9 inches.

TABLE I. Measured d.c. Block Dimensions

Dimension	Design Value	Substrate #		Dimension	Design Value	Substrate #	
		2	4			1	3
1	.0032	.00315	.00319	1	.0029	.00295	.00299
2	.0012	.00138	.00154	2	.0014	.00146	.00169
3	.0012	.00098	.00087	3	.0014	.00161	.00102
4	.0012	.00154	.00146	4	.0014	.00138	.00181
5	.0032	.00335	.00335	5	.0029	.00291	.00287
Total	.0100	.01040	.01041		.0100	.01031	.01038



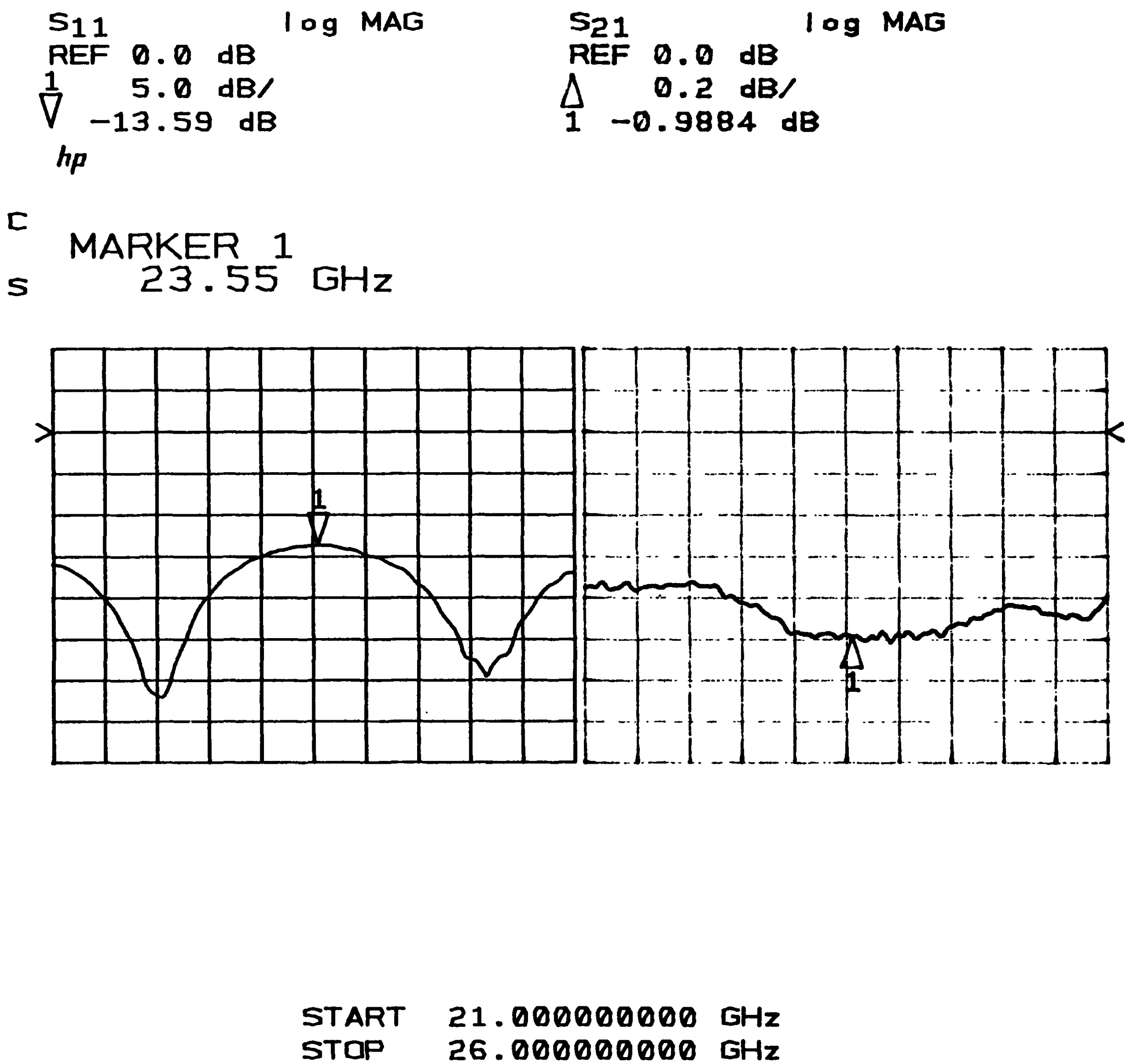


Fig. 9. Measured through-line (w/h = 1.0 on 0.01" alumina substrate). (5% smoothing applied).

(Figure 10) suggest that, in addition to a small discontinuity at the interface, the reference line has an impedance of 46.5 Ω, although this would require either a width-to-height ratio of greater than 1:1 or a dielectric constant greater than 10; neither of which seems consistent with other measurements.

Because of this mismatch, the accurate measurement of the behavior of the d.c. blocks is not possible, at least until the source of the mismatch is found and removed (either physically or by calculations). Figures 11 and 12 show the measured responses of designs #1 and #2, respectively. While there is clearly a difference between the two designs, it is not possible to accurately compare these responses with theory. However, comparison with the through-line indicates that either design should be acceptable.

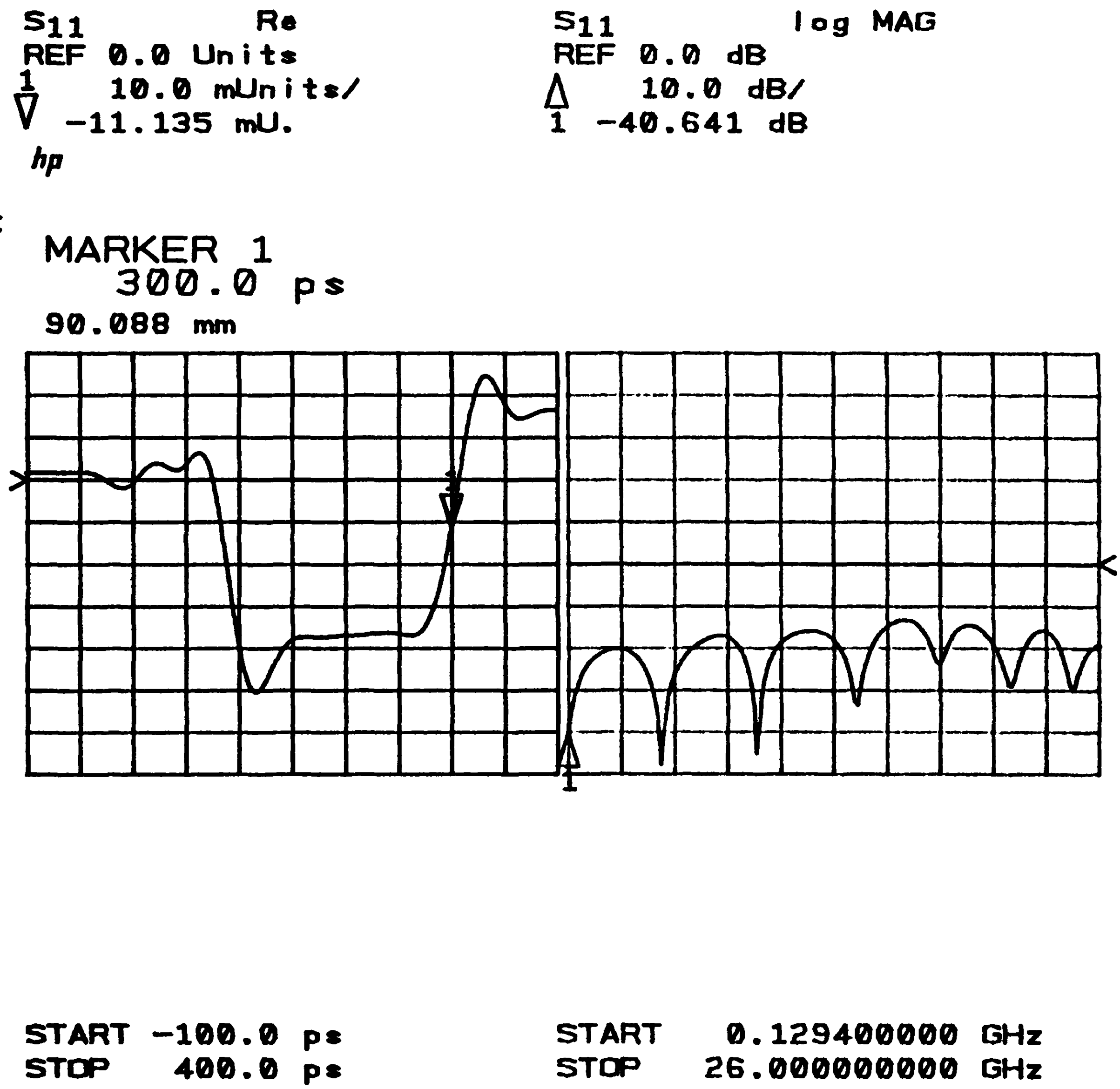


Fig. 10. Low-pass time domain measurement of through-line.

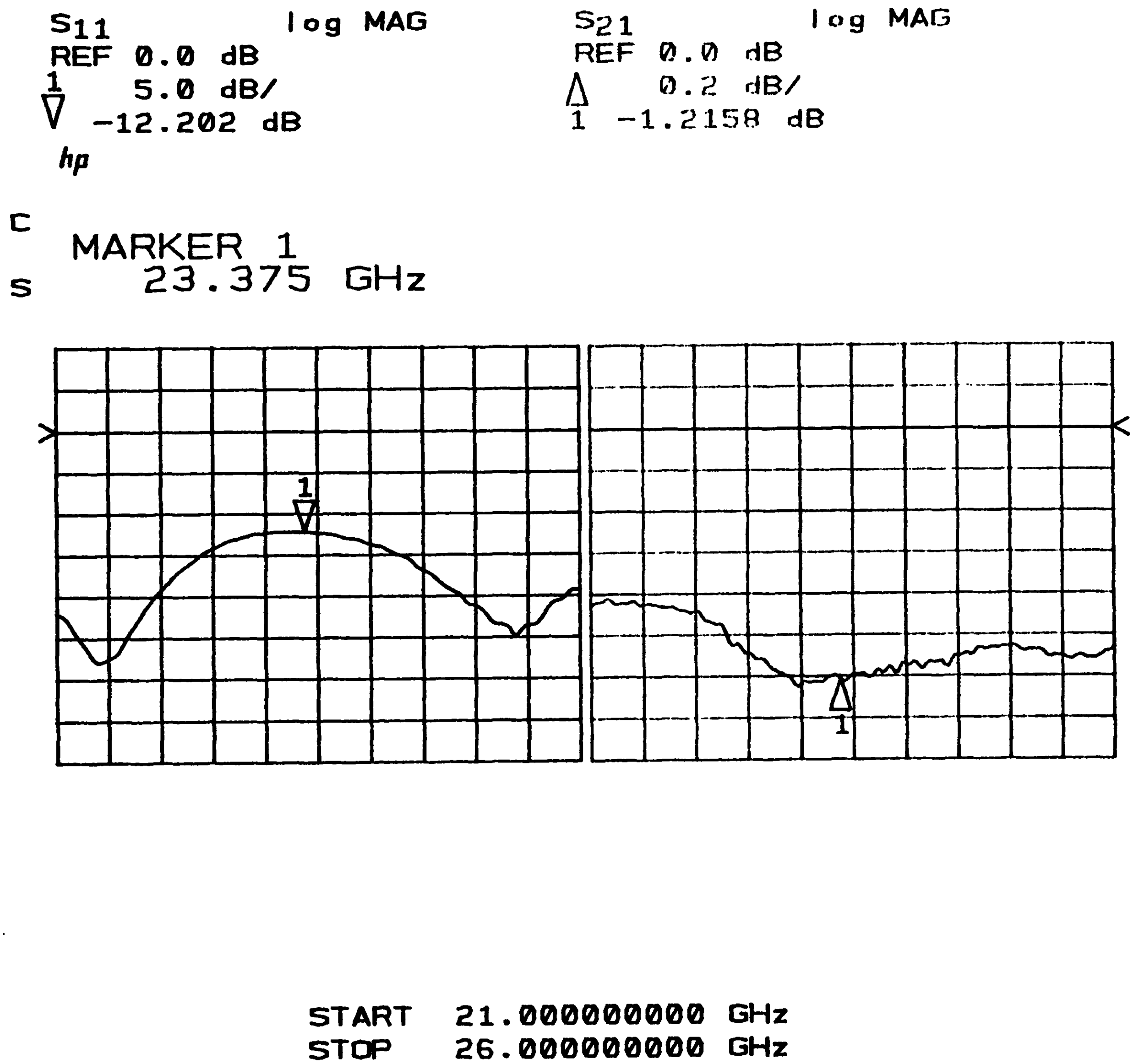


Fig. 11. Measured frequency response of design #1 (substrate #2). (Refer to Table I for dimensions.)

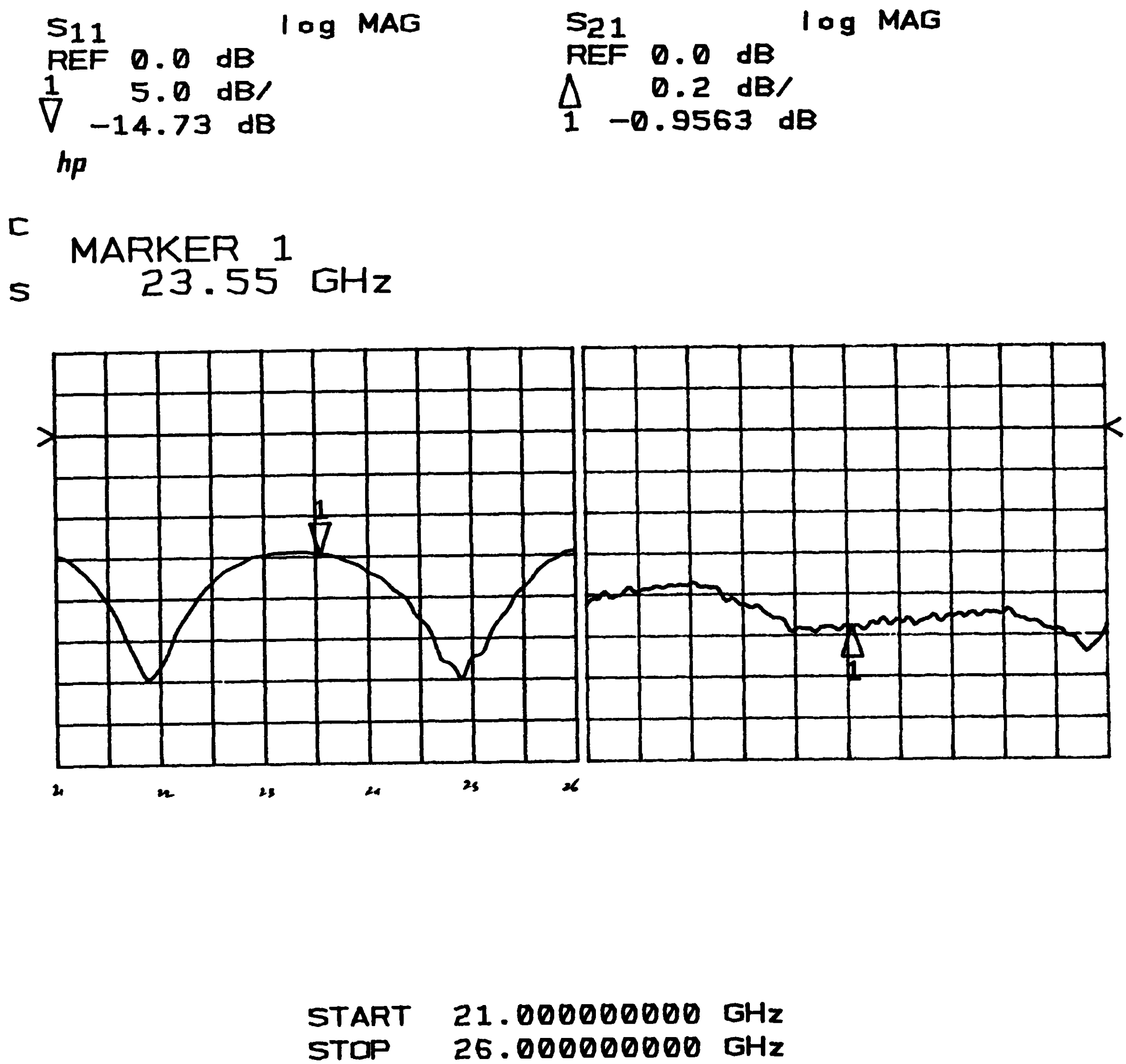


Fig. 12. Measured frequency response of design #2 (substrate #1).

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[2] V. Rizzoli, "Analysis and Design of Microstrip DC Blocks," Microwave J., vol. 20, pp. 109-110, June 1977.

[3] D. Kajfez and B. S. Vidula, "Design Equations for Symmetric Microstrip DC Blocks," IEEE Trans. Microwave Theory Tech., vol. MTT-26, pp. 974-981, Sept. 1980.

[4] T. Q. Hol and Y. C. Shih, "Broadband Millimeter-Wave Edge-Coupled Microstrip DC Blocks," MSN & CT, pp. 74-78, April 1987.

[5] E. Hammerstad and O. Jensen, 1980 IEEE MTT-S Symposium Digest, pp. 407-409.

[6] Microwave Printed Circuitry.

APPENDICES. Program Listings and Output

APPENDIX A. "dcblockd" (FARANT subprogram).

APPENDIX B. Output from runs of "dcblockd."

APPENDIX C. "dcblocka" (FARANT subprogram).

APPENDIX D. Output from run of "dcblocka."

APPENDIX E. "Mstrip" (subprogram used by "dcblocka").

APPENDIX F. "Cmstrip" (subprogram used by "dcblockd").

APPENDIX A. "dcblockd."

```
10000 SUB Farstart           !     'S CONTROL OF FARANT BEGINS HERE
10005   OPTION BASE 1
10010   INTEGER N
10015   READ N                  !# OF PARAMETERS TO OPTIMIZE
10020   ALLOCATE X(N)
10025   READ X(*)               !FOR INITIAL GUESSES ONLY WHEN OPTIMIZING
10030   DATA 4,1,1,1,1          !PUT N. INITIAL GUESSES HERE (USE NO ZEROS)
10035   Cktanalysis(X(*),0,2)   !FOR PRE-OPTIMIZED ANALYSIS; THE DEFAULT
10040!  Optimize(X(*),1)        !MAKE THIS A STATEMENT TO DO OPTIMIZATION
10045 SUBEND
10050 SUB Cktanalysis(X(*),Fvalue,INTEGER Opt)                       !#########
10055! WHEN Opt=1 ASSIGN Fvalue: OTHERWISE DO NORMAL ANALYSIS & OUTPUT
10060   OPTION BASE 1
10065   COM Zo,F,Dat(*),INTEGER Nogo,Count    ![Dat] HOLDS FREQ, CKT & NOISE
10070   DIM A(6,4),B(6,4),C(6,4),D(6,4),E(6,4)
10075   Count=0                !Count = #FREQS CURRENTLY STORED IN DATA BASE
10080   Nogo=0
10085   Zo=50                  !FARANT'S REF Zo IS ASSIGNED ONLY HERE
10090   DEG                    !DEFAULT FOR TRIG FUNCTIONS IS DEGREES
10095! USER DESCRIBES HIS CKT AND REQUESTS ANALYSIS AND OUTPUT NEXT . . . .
10100   DISP "D.C. Block Design & Analysis - BDB 12/23/86"
10105   PRINT "D.C. Block Design & Analysis - BDB 12/23/86"
10110   PRINT
10115   !____________________________________________________________
10120   !
10125   ! Specify design parameters here
10130   !____________________________________________________________
10131   !
10135   Return_loss=30.  !Return loss at midband in dB
10140   B_rel=.245       !Relative bandwidth
10145   F_center=23.5    !Center frequency in GHz
10150   !
10155   ! Or specify F_low and F_high and use:
10160   ! B_rel=2.*(F_high-F_low)/(F_high+F_low)
10165   ! F_center=SQR(F_high*F_low)
10170   !____________________________________________________________
10175   GCLEAR
10180   Rho=10^(-Return_loss/20)
10185   S=(1+Rho)/(1-Rho)
10190   PRINT "Return Loss = ":Return_loss:" dB                 VSWR = ":S
10195   PRINT "Center frequency = ":F_center:" GHz      Relative B/W = ":B_r
el
10200   PRINT
10205   F_high=F_center+B_rel*F_center/2
10210   F_low=F_center-B_rel*F_center/2
10215   PRINT "F_high = ":F_high:" GHz             F_low = ":F_low:" GHz"
10220   Omega_c=1/TAN((1-B_rel/2)*90)
10225   Phiom=(1+SQR(1+Omega_c*Omega_c))/(Omega_c*Omega_c)
10230   Zze=SQR(S)*(1+SQR(1+Phiom*(1-1/S)))
10235   Zzo=Zze-2*SQR(S)
10240   Zoo=Zzo*Zo
10245   Zoe=Zze*Zo
10250   PRINT USING 10255:Zoo:Zoe
10255   IMAGE "Zoo = ",3D.DD," ohms                    Zoe = ",DDD.DD," ohms"
10260   ! Simulation starts here
10265   Z_in=50.
10270   L_in=1.
10275   Eeff_in=1.0
10280   Eeff_out=1.0
10285   Z_out=Z_in
10290   L_out=1.
```

```
10295   Eeff_coupled=1.0
10300   !
10305   Z_coupled=(Zoe-Zoo)/2.
10310   L_coupled=11.803/(4*F_center*SQR(Eeff_coupled))
10315   PRINT USING 10320:L_coupled
10320   IMAGE "Coupled length = ",2D.4D," inches"
10325   Eeo=Eeff_coupled
10330   F_start=15
10335   F_end=35
10340   DISP "CONT to analyse"
10345   PAUSE
10350  !
10355  ! Analyse
10360  !
10365   FOR F=F_start TO F_end STEP ((F_end-F_start)/20)
10370     Trline(A(*),Z_in,L_in,Eeff_in)       !Input line
10375     Trline(B(*),Zoo,L_coupled,Eeo)       !Branch line
10380     Branch(B(*),"S")
10385     Cas(A(*),B(*))
10390     Trline(C(*),Z_coupled,L_coupled,Eeff_coupled)  !Coupled line
10395     Cas(A(*),C(*))
10400     Cas(A(*),B(*))                       !Branch line again
10405     Trline(D(*),Z_out,L_out,Eeff_out)    !Output line
10410     Cas(A(*),D(*))
10415     Saveckt(A(*),0,4,0)
10420   NEXT F
10425   Prt(4,0)
10430   DISP "CONT to plot graph"
10435   PAUSE
10440   ALPHA OFF
10445   GINIT
10450   GRAPHICS ON
10455   LORG 5
10460   MOVE 65,95
10465   LABEL "Frequency ("&VAL$(F_start)&"-"&VAL$(F_end)&" GHz)"
10470   MOVE 5,50
10475   LDIR 90
10480   LABEL "Return Loss (40-0 dB)"
10485   LINE TYPE 1
10490   VIEWPORT 10,120,15,90
10495   FRAME
10500   WINDOW F_start,F_end,-40,0
10505   GRID 2,5,F_start,0
10510   S11_mag=SQR(Dat(1,2)*Dat(1,2)+Dat(1,3)*Dat(1,3))
10515   Dbel=20.*LGT(S11_mag)
10520   MOVE Dat(1,1),Dbel
10525   FOR I=1 TO Count
10530     S11_mag=SQR(Dat(I,2)*Dat(I,2)+Dat(I,3)*Dat(I,3))
10535     Dbel=20.*LGT(S11_mag)
10540     PLOT Dat(I,1),Dbel
10545   NEXT I
10550   PAUSE
10555   Smith(-.2,.2,-.2,.2)
10560 ! Smith(-1,1,-1,1)
10565   Splot(1,1)
10570 SUBEND
```

APPENDIX B. Output from runs of "dcblockd".

Block Design & Analysis - BDB 12/23/86

Return Loss = 30 dB
Center frequency = 23.5 GHz

VSWR = 1.06531086407
Relative B/W = .245

F_high = 26.37875 GHz

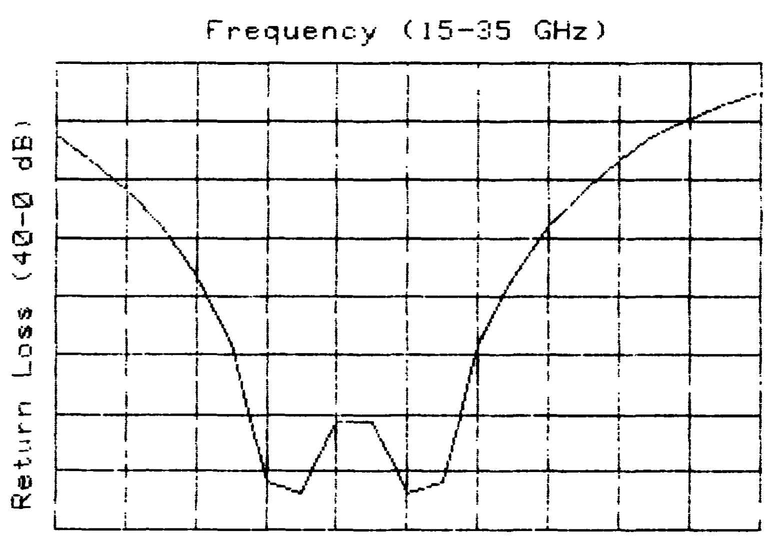
F_low = 20 62125 GHz

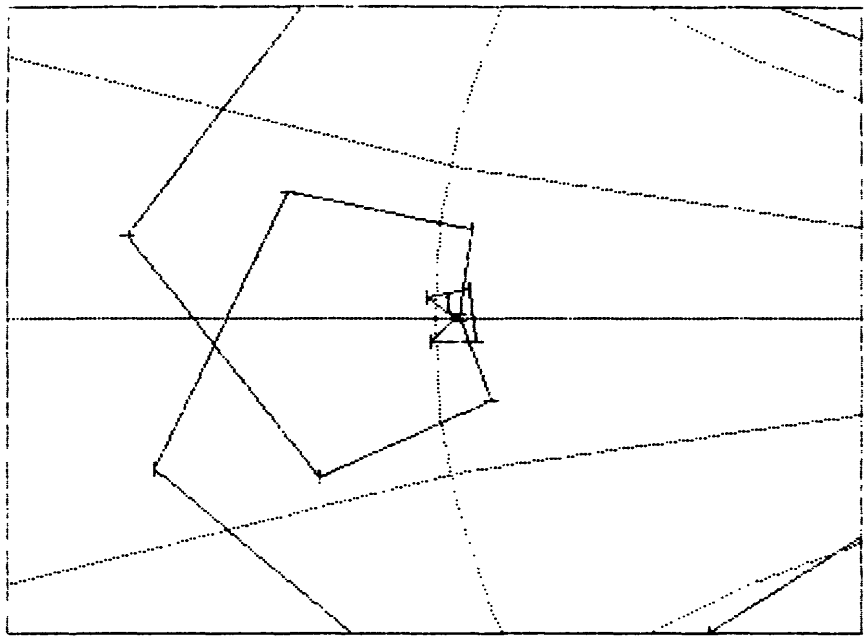
Zoo = 54.91 ohms
Coupled length = .1256 inches

Zoe = 158.13 ohms

[S] PARAMETERS IN MAGNITUDE AND PHASE

	11		12		21		22		K
FREQ	MAG	ANG	MAG	ANG	MAG	ANG	MAG	ANG	FACT
15.000	.4828	61.5	.8757	151.5	.8757	151.5	.4828	61.5	1.00
16.000	.3836	-9.7	.9235	80.3	.9235	80.3	.3836	-9.7	1.00
17.000	.2873	-80.7	.9578	9.3	.9578	9.3	.2873	-80.7	1.00
18.000	.1993	-151.4	.9799	-61.4	.9799	-61.4	.1993	-151.4	1.00
19.000	.1235	138.3	.9924	-131.7	.9924	-131.7	.1235	138.3	1.00
20.000	.0620	68.5	.9981	158.5	.9981	158.5	.0620	68.5	1.00
21.000	.0160	-1.0	.9999	89.0	.9999	89.0	.0160	-1.0	1.00
22.000	.0145	109.9	.9999	19.9	.9999	19.9	.0145	109.9	1.00
23.000	.0297	40.9	.9996	-49.1	.9996	-49.1	.0297	40.9	1.00
24.000	.0297	-28.0	.9996	-118.0	.9996	-118.0	.0297	-28.0	1.00
25.000	.0145	-97.0	.9999	173.0	.9999	173.0	.0145	-97.0	1.00
26.000	.0160	13.9	.9999	103.9	.9999	103.9	.0160	13.9	1.00
27.000	.0621	-55.6	.9981	34.4	.9981	34.4	.0621	-55.6	1.00
28.000	.1235	-125.4	.9923	-35.4	.9923	-35.4	.1235	-125.4	1.00
29.000	.1993	164.3	.9799	-105.7	.9799	-105.7	.1993	164.3	1.00
30.000	.2874	93.6	.9578	-176.4	.9578	-176.4	.2874	93.6	1.00
31.000	.3837	22.6	.9235	112.6	.9235	112.6	.3837	22.6	1.00
32.000	.4828	-48.6	.8757	41.4	.8757	41.4	.4828	-48.6	1.00
33.000	.5789	-119.8	.8154	-29.8	.8154	-29.8	.5789	-119.8	1.00
34.000	.6666	169.3	.7454	-100.7	.7454	-100.7	.6666	169.3	1.00
35.000	.7426	98.9	.6698	-171.1	.6698	-171.1	.7426	98.9	1.00





APPENDIX C. "dcblocka."

```
      SUB Farstart          !USER'S CONTROL OF FARANT BEGINS HERE ###
  .05    OPTION BASE 1
 .0010   INTEGER N
10015    READ N                       !# OF PARAMETERS TO OPTIMIZE
10020    ALLOCATE X(N)
10025    READ X(*)                    !FOR INITIAL GUESSES ONLY WHEN OPTIMIZING
10030    DATA 4,1,1,1,1               !PUT N, INITIAL GUESSES HERE (USE NO ZEROS)
10035    Cktanalysis(X(*),0,2)        !FOR PRE-OPTIMIZED ANALYSIS; THE DEFAULT
10040!   Optimize(X(*),1)             !MAKE THIS A STATEMENT TO DO OPTIMIZATION
10045 SUBEND
10050 SUB Cktanalysis(X(*),Fvalue,INTEGER Opt)                    !#########
10055! WHEN Opt=1 ASSIGN Fvalue; OTHERWISE DO NORMAL ANALYSIS & OUTPUT
10060    OPTION BASE 1
10065    COM Zo,F,Dat(*),INTEGER Nogo,Count    ![Dat] HOLDS FREQ, CKT & NOISE
10070    DIM A(6,4),B(6,4),C(6,4),D(6,4),E(6,4)
10075    Count=0                   !Count = #FREQS CURRENTLY STORED IN DATA BASE
10080    Nogo=0
10085    Zo=50                     !FARANT'S REF Zo IS ASSIGNED ONLY HERE
10090    DEG                       !DEFAULT FOR TRIG FUNCTIONS IS DEGREES
10095! USER DESCRIBES HIS CKT AND REQUESTS ANALYSIS AND OUTPUT NEXT . . . .
10100    DISP "D.C. Block Analysis - BDB 12/23/86"
10105    PRINT "D.C. Block Analysis - BDB 12/23/86"
10110    !
10115    !________________________________________________________________
10120    !
10125    ! Parameters of D.C Block
10130    !
10135    L_coupled=.054          ! Length of coupled section in inches
10140    U=.14                   ! w/h of coupling fingers
10145    G=.14                   ! g/h of coupling gap
10150    Er=9.6                  ! Relative dielectric constant of substrate
10155    U_in=1.0                ! w/h of input line
10160    L_in=.1716              ! Length of input line
10165    U_out=1.0               ! w/h of output line
10170    L_out=.1716             ! Length of output line
10175    !________________________________________________________________
10180    !
10185    F_start=21.             ! Start frequency of analysis
10190    F_end=26.               ! End frequency of analysis
10195    !
10200    ! Get line impedances and effective dielectric constants
10205    !
10210    Mstrip(U_in,0,Er,Z_in,Eeff_in)
10215    Mstrip(U_out,0,Er,Z_out,Eeff_out)
10220    Cmstrip(U,G,Er,Zoo,Eeo,Zoe,Eee)
10225    Z_coupled=(Zoe-Zoo)/2.
10230    Eeff_coupled=(SQR(Eeo)+SQR(Eee)) 2/4.
10235    !
10240    ! Analyse
10245    !
10250    FOR F=F_start TO F_end STEP (F_end-F_start)/50
10255      Trline(A(*),Z_in,L_in,Eeff_in)           !Input line
10260      Trline(B(*),Zoo,L_coupled,Eeo)           !Branch line
10265      Branch(B(*),"S")
10270      Cas(A(*),B(*))
10275      Trline(C(*),Z_coupled,L_coupled,Eeff_coupled)   !Coupled line
10280      Cas(A(*),C(*))
10285      Cas(A(*),B(*))                           !Branch line again
10290      Trline(D(*),Z_out,L_out,Eeff_out)        !Output line
10295      Cas(A(*),D(*))
```

```
10300       Saveckt(A(*),0.4,0)
10305     NEXT F
10310     Prt(4,0)
10315     DISP "CONT to plot graph"
10320     PAUSE
10325     ALPHA OFF
10330     GINIT
10335     GRAPHICS ON
10340     LORG 5
10345     MOVE 65,95
10350     LABEL "Frequency ("&VAL$(F_start)&"-"&VAL$(F_end)&" GHz)"
10355     MOVE 5,50
10360     LDIR 90
10365     LABEL "Return Loss (40-0 dB)"
10370     LINE TYPE 1
10375     VIEWPORT 10,120,15,90
10380     FRAME
10385     WINDOW F_start.F_end,-40,0
10390     GRID (F_end-F_start)/10,5,F_start,0
10395     S11_mag=SQR(Dat(1,2)*Dat(1,2)+Dat(1,3)*Dat(1,3))
10400     Dbel=20.*LGT(S11_mag)
10405     MOVE Dat(1,1),Dbel
10410     FOR I=1 TO Count
10415       S11_mag=SQR(Dat(I,2)*Dat(I,2)+Dat(I,3)*Dat(I,3))
10420       Dbel=20.*LGT(S11_mag)
10425       PLOT Dat(I,1),Dbel
10430     NEXT I
10435     PAUSE
10440     Smith(-.2,.2,-.2,.2)
10445 !   Smith(-1,1,-1,1)
10450     Splot(1,1)
10455 SUBEND
```

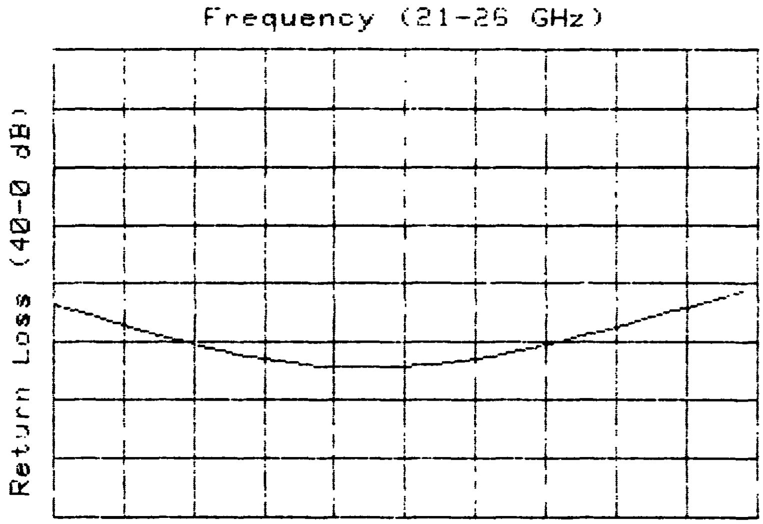
APPENDIX D. Output from run of "dcblocka".

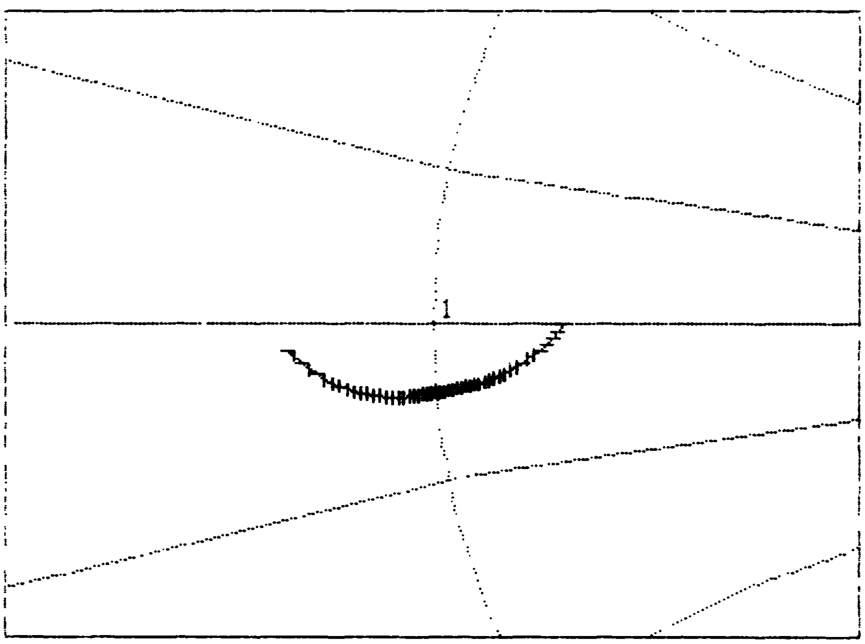
Block Analysis - BDB 12/23/86

[S] PARAMETERS IN MAGNITUDE AND PHASE

	11		12		21		22		K
FREQ	MAG	ANG	MAG	ANG	MAG	ANG	MAG	ANG	FACT
21.000	.0821	.4	.9966	90.4	.9966	90.4	.0821	.4	1.00
21.100	.0787	-3.1	.9969	86.9	.9969	86.9	.0787	-3.1	1.00
21.200	.0754	-6.6	.9972	83.4	.9972	83.4	.0754	-6.6	1.00
21.300	.0723	-10.1	.9974	79.9	.9974	79.9	.0723	-10.1	1.00
21.400	.0694	-13.6	.9976	76.4	.9976	76.4	.0694	-13.6	1.00
21.500	.0666	-17.1	.9978	72.9	.9978	72.9	.0666	-17.1	1.00
21.600	.0640	-20.5	.9979	69.5	.9979	69.5	.0640	-20.5	1.00
21.700	.0616	-24.0	.9981	66.0	.9981	66.0	.0616	-24.0	1.00
21.800	.0593	-27.5	.9982	62.5	.9982	62.5	.0593	-27.5	1.00
21.900	.0571	-31.0	.9984	59.0	.9984	59.0	.0571	-31.0	1.00
22.000	.0552	-34.5	.9985	55.5	.9985	55.5	.0552	-34.5	1.00
22.100	.0533	-38.0	.9986	52.0	.9986	52.0	.0533	-38.0	1.00
22.200	.0517	-41.4	.9987	48.6	.9987	48.6	.0517	-41.4	1.00
22.300	.0502	-44.9	.9987	45.1	.9987	45.1	.0502	-44.9	1.00
22.400	.0488	-48.4	.9988	41.6	.9988	41.6	.0488	-48.4	1.00
22.500	.0476	-51.9	.9989	38.1	.9989	38.1	.0476	-51.9	1.00
22.600	.0466	-55.3	.9989	34.7	.9989	34.7	.0466	-55.3	1.00
22.700	.0457	-58.8	.9990	31.2	.9990	31.2	.0457	-58.8	1.00
22.800	.0450	-62.3	.9990	27.7	.9990	27.7	.0450	-62.3	1.00
22.900	.0444	-65.7	.9990	24.3	.9990	24.3	.0444	-65.7	1.00
23.000	.0440	-69.2	.9990	20.8	.9990	20.8	.0440	-69.2	1.00
23.100	.0437	-72.7	.9990	17.3	.9990	17.3	.0437	-72.7	1.00
23.200	.0436	-76.1	.9991	13.9	.9991	13.9	.0436	-76.1	1.00
23.300	.0436	-79.6	.9990	10.4	.9990	10.4	.0436	-79.6	1.00
23.400	.0437	-83.1	.9990	6.9	.9990	6.9	.0437	-83.1	1.00
23.500	.0440	-86.5	.9990	3.5	.9990	3.5	.0440	-86.5	1.00
23.600	.0445	-90.0	.9990	-0.0	.9990	-0.0	.0445	-90.0	1.00
23.700	.0451	-93.5	.9990	-3.5	.9990	-3.5	.0451	-93.5	1.00
23.800	.0458	-96.9	.9989	-6.9	.9989	-6.9	.0458	-96.9	1.00
23.900	.0467	-100.4	.9989	-10.4	.9989	-10.4	.0467	-100.4	1.00
24.000	.0477	-103.9	.9989	-13.9	.9989	-13.9	.0477	-103.9	1.00
24.100	.0488	-107.3	.9988	-17.3	.9988	-17.3	.0488	-107.3	1.00
24.200	.0501	-110.8	.9987	-20.8	.9987	-20.8	.0501	-110.8	1.00
24.300	.0516	-114.3	.9987	-24.3	.9987	-24.3	.0516	-114.3	1.00
24.400	.0531	-117.7	.9986	-27.7	.9986	-27.7	.0531	-117.7	1.00
24.500	.0548	-121.2	.9985	-31.2	.9985	-31.2	.0548	-121.2	1.00
24.600	.0566	-124.7	.9984	-34.7	.9984	-34.7	.0566	-124.7	1.00
24.700	.0586	-128.2	.9983	-38.2	.9983	-38.2	.0586	-128.2	1.00
24.800	.0607	-131.6	.9982	-41.6	.9982	-41.6	.0607	-131.6	1.00
24.900	.0629	-135.1	.9980	-45.1	.9980	-45.1	.0629	-135.1	1.00
25.000	.0652	-138.6	.9979	-48.6	.9979	-48.6	.0652	-138.6	1.00
25.100	.0677	-142.1	.9977	-52.1	.9977	-52.1	.0677	-142.1	1.00
25.200	.0703	-145.5	.9975	-55.5	.9975	-55.5	.0703	-145.5	1.00
25.300	.0730	-149.0	.9973	-59.0	.9973	-59.0	.0730	-149.0	1.00
25.400	.0759	-152.5	.9971	-62.5	.9971	-62.5	.0759	-152.5	1.00
25.500	.0789	-156.0	.9969	-66.0	.9969	-66.0	.0789	-156.0	1.00
25.600	.0820	-159.5	.9966	-69.5	.9966	-69.5	.0820	-159.5	1.00
25.700	.0852	-163.0	.9964	-73.0	.9964	-73.0	.0852	-163.0	1.00
25.800	.0885	-166.4	.9961	-76.4	.9961	-76.4	.0885	-166.4	1.00
25.900	.0920	-169.9	.9958	-79.9	.9958	-79.9	.0920	-169.9	1.00

D.C. Block Analysis - BDB 12/23/86





APPENDIX E. "Mstrip."

```
        UB Mstrip(U,T,Er,Z0,Ee)
        ! Program "MSTRIP"  BDB 1/14/87
        ! Calculates microstrip impedance and effective dielectric constant
1,J     ! using formulae of Hammerstad and Jensen, IEEE MTT-S Digest, p407,
180     ! 1980.
181     !
182     ! Input parameters:
183     !     U:   strip width/substrate thickness
184     !     T:   strip thickness/substrate thickness
185     !     Er:  substrate relative dielectric constant
186     ! Output parameters:
187     !     Z0:  Characteristic impedance
188     !     Ee:  Effective dielectric constant
190     !
210     X=U
220     GOSUB Calz
230     IF T=0 THEN
240       Z0=Z01/SQR(Ee)
270       SUBEXIT
280     END IF
290     Cothh=FNCoth(SQR(6.517*U))
300     Delu1=(T/PI)*LOG(1+4*EXP(1)/(T*Cothh*Cothh))
310     U1=U+Delu1
320     Ur=U+Delu1*(1+1/FNCosh(SQR(Er-1)))/2
330     X=U1
340     GOSUB Calz
350     Z01_u1=Z01
360     X=Ur
370     GOSUB Calz
380     Z0=Z01/SQR(Ee)
390     Ee=Ee*(Z01_u1/Z01)^2
410     SUBEXIT
420     ! This SUBroutine calculates Z0 and Ee for zero thickness strip
430 Calz:    F=6+(2*PI-6)*EXP(-(30.666/X)^.7528)
440         Z01=376.73/(2*PI)*LOG(F/X+SQR(1+4/(X*X)))
450         F=6+(2*PI-6)*EXP(-(30.666/X)^.7528)
460         A=1+(1/49)*LOG((X^4+(X/52)^2)/(X^4+.432))+(1/18.7)*LOG(1+(X/18.1
)^3)
470         B=.564*((Er-.9)/(Er+3))^.053
480         Y=-A*B
490         Ee=((Er+1)/2)+((Er-1)/2)*(1+10/X)^Y
500         RETURN
510     SUBEND
520     DEF FNSinh(X)
530         RETURN (EXP(X)-EXP(-X))/2
540     FNEND
550     DEF FNCosh(X)
560         RETURN (EXP(X)+EXP(-X))/2
570     FNEND
580     DEF FNCoth(X)
590         RETURN FNCosh(X)/FNSinh(X)
600     FNEND
```

```
      SUB Cmstrip(U,G,Er,Zoo,Eeo,Zoe,Eee)
        Calculates coupled microstrip odd and even mode impedance
        and effective dielectric constants using formulae of Hamme
      ! and Jensen, 1980 IEEE MTT Symposium Digest, pp. 407-409.
10020 !
10025 ! Input parameters:
10030 !   U:    strip width/substrate height
10035 !   G:    gap width/substrate height
10040 !   Er:   relative dielectric constant of substrate
10045 ! Output parameters:
10050 !   Zoo:  Odd-mode coupled impedance
10055 !   Eeo:  Odd-mode effective dielectric constant
10060 !   Zoe:  Even-mode coupled impedance
10065 !   Eee:  Even-mode effective dielectric constant
10070 !
10075     RAD
10080 ! Do even mode first
10085     B=.564*((Er-.9)/(Er+3))^.053
10090     Mu=G*EXP(-G)+U*(20+G*G)/(10+G*G)
10095     Fe=(1+10/Mu)^(-FNA(Mu)*B)
10100     Phi=.8645*U^.172
10105     Psi=1+G/1.45+G^2.09/3.95
10110     Alpha=.5*EXP(-G)
10115     M=.2175+(4.113+(20.36/G)^6)^(-.251)+LOG(G^10/(1+(G/13.8)^10))/323
10120     Phie=Phi/(Psi*(Alpha*U^M+(1-Alpha)*U^(-M)))
10125     Eee=(Er+1)/2+(Er-1)/2*Fe
10130     Etao=376.73
10135     Z01=Etao/(U+1.98*U^.172)
10140     Z01e=Z01/(1-Z01*Phie/Etao)
10145     Zoe=Z01e/SQR(Eee)
10150 ! Do odd mode next
10155     Theta=1.729+1.175*LOG(1+.627/(G+.327*G^2.17))
10160     Beta=.2306+LOG(G^10/(1+(G/3.73)^10))/301.8+LOG(1+.646*G^1.175)/5.3
10165     Temp=-6.424-.76*LOG(G)-(G/.23)^5
10170     IF Temp>-1000 THEN
10175          N=1/17.7+EXP(Temp)
10180     ELSE
10185          N=1/17.7
10190     END IF
10195     N=N*LOG((10+68.3*G*G)/(1+32.5*G^3.093))
10200     R=1+.15*(1-EXP(1-(Er-1)*(Er-1)/8.2)/(1+G^(-6)))
10205     F01=1-EXP(-.179*G^.15-.328*G^R/LOG(EXP(1)+(G/7)^2.8))
10210     P=EXP(-.745*G^.295)/FNCosh(G^.68)
10215     Q=EXP(-1.366-G)
10220     Ffo=F01*EXP(P*LOG(U)+Q*SIN(PI*LOG(U)/LOG(10)))
10225     Fo=Ffo*(1+10/U)^(-FNA(U)*B)
10230     Temp=Beta*U^(-N)*LOG(U)
10235     Phio=Phie-Theta/Psi*EXP(Temp)
10240     Eeo=(Er+1)/2+(Er-1)/2*Fo
10245     Z01o=Z01/(1-Z01*Phio/Etao)
10250     Zoo=Z01o/SQR(Eeo)
10255 SUBEND
10260 DEF FNA(U)
10265     RETURN 1+LOG((U^4+(U/52)^2)/(U^4+.432))/49+LOG(1+(U/18.1)^3)/18.7
10270 FNEND
10275 DEF FNCosh(X)
10280     RETURN (EXP(X)+EXP(-X))/2
10285 FNEND

:HP8290X, 700
```