DESIGN OF A MICROSTRIP DC BLOCK

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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
THICKNESS: $h$
DIELECTRIC CONST: $\varepsilon_r$

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]:

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

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

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 $Z_0$ 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 \((Z_e, Z_0)\) 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) $(\epsilon_{re}, \epsilon_{ro})$ 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_00 and Z_0e 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_00 = 3.69 ohms and Z_0e = 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 $w/h = s/h = 0.12$. (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 $w/h = s/h = 0.14$ 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 Z₀₀ = 49.3 Ω and Z₀ₑ = 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
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 \( w/h = 0.12 \) and \( s/h = 0.01 \) 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 S₁₁ and S₂₁ 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

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![Diagram showing the measurement of d.c. block dimensions](image-url)
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 $46.5 \, \Omega$, 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).
REFERENCES


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. "dcblokd."

```
00 SUB Farstart ! S CONTROL OF FARAN! BEGINS HERE
0105 OPTION BASE : != CONTROL OF PARAMETERS TO OPTIMIZE
0120 ALLOCATE X(N)
0125 READ X(*) ! FOR INITIAL GUESSES ONLY WHEN OPTIMIZING
0130 DATA 4.1,1,1 !PUT N. INITIAL GUESSES HERE (USE NO ZEROS)
0135 Cktanaysis(X(*),0.2) ! FOR PRE-OPTIMIZED ANALYSIS; THE DEFAULT!
0140! Optimize(X(*),1) !MAKE THIS A STATEMENT TO DO OPTIMIZATION
0145 SUBEND
0150 SUB Cktanaysis(X(*),Fvalue,INTEGER Opt)
0155! WHEN Opt=1 ASSIGN Fvalue; OTHERWISE DO NORMAL ANALYSIS & OUTPUT
0160 OPTION BASE 1
0165 COM Zo,F.Dat(*),INTEGER Nogo,Count ! [Dat] HOLDS FREQ, CKT & NOISE
0170 DIM A(6.4),B(6.4),C(6.4).D(6.4),E(6.4)
0175 Count=0 !Count = #FREqs STORED IN DATA BASE
0180! Nogo=0 !FARANT'S REF Zo IS ASSIGNED ONLY HERE
0185 Zo=50 !DEFAULT FOR TRIG FUNCTIONS IS DEGREES
0190 DEG !DEFAULT FOR TRIG FUNCTIONS IS DEGREES
0195! USER DESCRIBES HIS CKT AND REQUESTS ANALYSIS AND OUTPUT NEXT . . . .
0199! DISP "D.C. Block Design & Analysis - BDB 12/23/86"
0200 PRINT "D.C. Block Design & Analysis - BDB 12/23/86"
0205 PRINT
0210 ! Specify design parameters here
0215 ! Return loss at midband in dB
0220! B_rei=.245 !Relative bandwidth
0225 F_center=23.5 !Center frequency in GHz
0230 ! Or specify F_low and F_high and use:
0235 ! B_rei=2.*!/F_high-F_low)/(F_high+F_low)
0240 ! F_center=SQR(F_high*F_low)
0245 PRINT "Return Loss = ":Return_ioss": dB
0250 PRINT "Center frequency = ":F_center": GHz
0255 PRINT "Relative B/h = ":B_rei
0260 PRINT "F_high=F_center+B_rei*F_center/2
0265 F_low=F_center-B_rei*F_center/2
0270 PRINT "F_high = ":F_high": GHz
0275 F_low = ":F_low": GHz
0280! Omega_c=1/TAN((1-B_rei/2)*90)
0285 Phiom=1+SQR(1+Omega_c*Omega_c)/(Omega_c*Omega_c)
0290 Zzo=SQR(S)*!(1+SQR(1+Phiom*(1-1/S)))
0295 Zze=Zzo-Zze-2*SQR(S)
0300 Zo=Zzo+Zze
0305 Zo=e=Zze
0310 PRINT USING 10255:Zoo:Zoe
0315! IMAGE "Zoo = ",3.D.DD," ohms"
0325 Z_in=50,
0330 L_in=1.
0335 Eff_in=1.0
0340 Eff_out=1.0
0345 Z_out=Z_in
0350 L_out="."
```

23
10300  \textit{Z}_\text{coupled} = (\textit{Z}_\text{in} - \textit{Z}_\text{out})/2.
10310  \textit{L}_\text{coupled} = 1.1803/(4*\textit{F}_\text{center}*\text{SQR}(\textit{E}_{\text{eff\_coupled}}))
10315  \textbf{PRINT USING 10320}; \textit{L}_\text{coupled}
10320  \textbf{IMAGE "Coupled length - "} .2D.4D. \textbf{" inches}  
10325  \textit{Eeo} = \textit{E}_{\text{eff\_coupled}}
10330  \textit{F\_start} = 15
10335  \textit{F\_end} = 35
10340  \textbf{DISP "CONT to analyse"}
10345  \textbf{PAUSE}
10350  !
10355  ! Analyse
10360  !
10365  \textbf{FOR F=F\_start TO F\_end STEP ((F\_end-F\_start)/20)}
10370  Trline(A(*),Z\_in,L\_in,Eeff\_in) \quad \textbf{! Input line}
10375  Trline(B(*),Z\_out,L\_coupled,Eeo) \quad \textbf{! Branch line}
10380  Branch(B(*),"S")
10385  Cas(A(*),B(*))
10390  Trline(C(*),Z\_coupled,L\_coupled,Eeff\_coupled) \quad \textbf{! Coupled line}
10395  Cas(A(*),C(*))
10400  Cas(A(*),B(*)) \quad \textbf{! Branch line again}
10405  Trline(D(*),Z\_out,L\_out,Eeff\_out) \quad \textbf{! Output line}
10410  Cas(A(*),D(*))
10415  Saveckt(A(*),0.4,0)
10420  NEXT F
10425  \textbf{Prt(4,0)}
10430  \textbf{DISP "CONT to plot graph"}
10435  \textbf{PAUSE}
10440  \textbf{ALPHA OFF}
10444  \textbf{GINIT}
10445  \textbf{GRAPHICS ON}
10450  \textbf{L0RG 5}
10455  \textbf{MOV E 65,95}
10460  \textbf{LABEL "Frequency ("}&\textbf{VALS(F\_start)à"-"}&\textbf{VALS(F\_end)à" GHz)"}
10465  \textbf{MOVE 5,50}
10470  \textbf{LDIR 90}
10475  \textbf{LABEL "Return Loss (40-0 dB)"}
10480  \textbf{LINE TYPE 1}
10485  \textbf{VIEWPORT 10,120,15,90}
10490  \textbf{FRAME}
10495  \textbf{WINDOW F\_start,F\_end,-40,0}
10500  \textbf{GRID 2.5,F\_start,0}
10505  \textbf{S11\_mag=SQR(Dat(1,2)*Dat(1,2)+Dat(1,3)*Dat(1,3))}
10510  \textbf{Dbel=20.*LGT(S11\_mag)}
10515  \textbf{MOVE Dat(1,1).Dbel}
10520  \textbf{FOR I=1 TO Count}
10525  \textbf{S11\_mag=SQR(Dat(1,2)*Dat(1,2)+Dat(1,3)*Dat(1,3))}
10530  \textbf{Dbel=20.*LGT(S11\_mag)}
10535  \textbf{PLOT Dat(1,1).Dbel}
10540  \textbf{NEXT I}
10545  \textbf{PAUSE}
10550  \textbf{Smith(-.2,.2,-.2,.2)}
10555  \textbf{Smith(-1.1,-1.1)}
10560  \textbf{Splot(1,1)}
10565  \textbf{SUBEND}

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APPENDIX B. Output from runs of "dcblockd".

Block Design & Analysis - BDB 12/23/86

Return Loss = 30 dB
Center frequency = 23.5 GHz
F_high = 26.37875 GHz
Zoo = 54.91 ohms

VSWR = \(1.66531086407\)
Relative B/W = \(0.245\)
F_low = 20.62125 GHz
Zoe = 158.13 ohms
Coupled length = \(0.1256 \text{ inches}\)

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<td>.7426</td>
<td>98.9</td>
<td>1.00</td>
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</table>

Frequency (15-35 GHz)

Return Loss (dB)

25
APPENDIX C. "dcblocka."

SUB Fastart   'USER'S CONTROL OF FRACTANT BEGINS HERE ###
0025 READ X(*)   !# OF PARAMETERS TO OPTIMIZE
0040 ALLOCATE X(N) !FOR INITIAL GUESSES ONLY WHEN OPTIMIZING
0050 READ X(*)   !PUT N. INITIAL GUESSES HERE (USE NO ZEROS)
0060 DATA 4,1,1,1   !FOR PRE-OPTIMIZED ANALYSIS; THE DEFAULT
0070 Cktanalysis(X(*)').0.2   !MAKE THIS A STATEMENT TO DO OPTIMIZATION
0080 SUBEND
0090 SUB Cktanalysis(X(*),Fvalue,INTEGER Opt)   !*******
0100 WHEN Opt=1. Assign Fvalue; OTHERWISE DO NORMAL ANALYSIS & OUTPUT
0110 OPTION BASE 1
0120 OPTION BASE 1
0130 COM Zo,F.Dat(*),INTEGER Nogo,Count   ![Dat] HOLDS FREQ, CKT & NOISE
0140 DIM A(6,4),B(6,4),C(6,4),D(6,4),E(6,4)
0150 Count=0   !Count = #FREHS CURRENTLY STORED IN DATA BASE
0160 Nogo=0   !FARANT'S REF Zo IS ASSIGNED ONLY HERE
0170 Zo=50   !DEFAULT FOR TRIG FUNCTIONS IS DEGREES
0180 DEG   !DEFAULT FOR TRIG FUNCTIONS IS DEGREES
0190 USER DESCRIBES HIS CKT AND REQUESTS ANALYSIS AND OUTPUT NEXT . . .
0200 DISP "D.C. Block Analysis - BDB 12/23/86"
0210 PRINT "D.C. Block Analysis - BDB 12/23/86"
0220 Parameters of D.C Block
0230 L_coupled=0.054   !Length of coupled section in inches
0240 U=.14   !w/h of coupling fingers
0250 G=.14   !g/h of coupling gap
0260 Er=9.6   !Relative dielectric constant of substrate
0270 U_in=1.0   !w/h of input line
0280 L_in=.1716   !Length of input line
0290 U_out=1.0   !w/h of output line
0300 L_out=.1716   !Length of output line
0310 ! F_start=21.   ! Start frequency of analysis
0320 F_end=25.   ! End frequency of analysis
0330 Get line impedances and effective dielectric constants
0340 Mstrip(U_in,0,Er,Z_in,Eeff_in)
0350 Mstrip(U_out,0,Er,Z_out,Eeff_out)
0360 Cmstrip(U,G,Ezoo,Eeo,Ezeo,Eee)
0370 Z_coupled=(Zo-Zo)/2   !Coupled line
0380 Eeff_coupled=(SQR(Eeo)+SQR(Eeo)) 2/4.
0390 Analyse
0400 FOR F=F_start TO F_end STEP (F_end-F_start)'/50
0410 Trline(A(*),Z_in,L_in,Eeff_in)   !Input line
0420 Trline(B(*),Zo,L_coupled,Eeo)   !Branch line
0430 Branch(B(*),"S")
0440 Cas(A(*),B(*))
0450 Trline(C(*),Z_coupled,L_coupled,Eeff_coupled)   !Coupled line
0460 Cas(A(*),C(*))
0470 Cas(A(*),B(*))   !Branch line again
0480 Trline(D(*),Z_out,L_out,Eeff_out)   !Output line
0490 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 ↑
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(I,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
### Block Analysis - BDB 12/23/86

#### IS: PARAMETERS IN MAGNITUDE AND PHASE

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APPENDIX E. "Mstrip."

```
UB Mstrip(U,T,Er,Z0,Ee)
! Program "MSTRIP" BDB 1/14/87
! Calculates microstrip impedence and effective dielectric constant
! Input parameters:
! U: strip width/substrate thickness
! T: strip thickness/substrate thickness
! Er: substrate relative dielectric constant
! Output parameters:
! Z0: Characteristic impedence
! Ee: Effective dielectric constant
210 X=T
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 Delul=(T/PI)*LOG(1+4*EXP(1)/(T*Cothh*Cothh))
310 U1=U+Delul
320 Ur=U+Delul*(1+1/FNCosh(SQR(Er-1)))^2/2
330 X=Ur
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+(X/52)^2)+(1/18.7)*LOG(1+(X/18.1)
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
```
APPENDIX F. "Cmstrip."

```
SUB Cmstrip(U,G,Er,Zoo,Eeo,Zoe,Eee)


0020 ! Input parameters:
0030 ! U: strip width/substrate height
0035 ! G: gap width/substrate height
0040 ! Er: relative dielectric constant of substrate
0045 ! Output parameters:
0050 ! Zoo: Odd-mode coupled impedance
0055 ! Eeo: Odd-mode effective dielectric constant
0060 ! Zoe: Even-mode coupled impedance
0065 ! Eee: Even-mode effective dielectric constant

0070 RAD

0080 ! Do even mode first

0085 B=.564*((Er-.9)/(Er+3))-.053
0090 Mu=G*EXP(-G)+U*((20+G*G)/(10+G*G))
0095 Fe=(1+10/Mu)/(FNA(Mu)*B)
0100 Phi=.8645*X('^1.72)
0105 Psi=1+G/1.45+G^2.09/3.95
0110 Alpha=.5*EXP(-G)
0115 M=.2175*(4.113+(20.36/G)^6)*(-.251)+LOG(G^10/(1+(G/13.8)^10))/323
0120 Phie=Phi/Psi*(Alpha*U+1-A*U')*(M))
0125 Eee=(Er+1)/2+(Er-1)/2*Fe
0130 Etao=.376.73
0135 Zoo=Eto/(1+1.98*U'1.72)
0140 Z01e=Z01/(1-Z01*Phie/Etao)
0145 Zoe=Z01e/SQR(Eee)

0150 ! Do odd mode next

0155 Theta=1.729+1.175*L0G(1+.627/(G+.327*G^2.17))
0160 Beta=.2306+LOG((G+10)/20)/301.8+L0G(1+.646*G^1.75)/5.3
0165 Temp=-6.424-.76*L0G(1+.646*G^1.75)/3.73)
0170 IF Temp>-1000 THEN
0175 N=1/17.7+EXP(Temp)
0180 ELSE
0185 N=1/17.7
0190 END IF
0195 N=N*L0G((10+68.3*G*G)/(1+32.5*G^3.093))
0200 R=1+1.15*(1-EXP(1-(Er-1)*(Er-1)/8.2)/(1+G'-6))
0205 F01=1-EXP(-.179*G^-1.5-.328*G^R/LOG(EXP(1)+(G/7)^2.8))
0210 P=EXP(-.745*G^*.295)/FNCosh(G^-6.8)
0215 Q=EXP(-1.366-G)
0220 F0=FO1*EXP(P*LOG(U)+Q*SIN(PI*LOG(U)/LOG(10)))
0225 FO=F0/((1+10/U)^(1-FNA(U)*B))
0230 Temp=Beta*U-1-N*LOG(U)
0235 Phio=Phie-Theta/Psi*EXP(Temp)
0240 Eeo=(Er+1)/2+(Er-1)/2*F0
0245 Z01o=Z01/(1-Z01*Phio/Etao)
0250 Zoe=Z01o/SQR(Eeo)

0255 SUBEND

0260 DEF FNA(U)
0265 RETURN 1+LOG((U^4+(U/52)^2)/(U^4+.432))/49+LOG(1+(U/18.1)^3)/18.7
0270 FEND
0275 DEF FNCosh(X)
0280 RETURN (EXP(X)+EXP(-X))/2
0285 FEND

:HP8290X, 700
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```