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DESIGN OF MICROSTRIP COMPONENTS BY COMPUTER

by Terry C. Cisco

Prepared by
::CAED CORPORATION
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for Langley Research Center

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DESIGN OF MICROSTRIP COMPONENTS BY COMPUTER

by Terry C. Cisco
::CAED CORPORATION

SECTION I

INTRODUCTION

This study presents a number of computer programs used in the synthesis of microwave components with microstrip geometries. The programs accept component design requirements in terms of ordinary engineering data and, in return, compute the parameters needed to synthesize the component, either in terms of actual physical dimensions or in terms of parameters, which can be reduced to physical dimensions through the use of other analysis or synthesis programs.

This study includes designs for couplers, filters, circulators, transformers, power splitters, diode switches, multipliers, diode phase shifters and attenuators. Additional programs are included to analyze and optimize cascades of lumped elements and transmission line elements, to analyze and synthesize Chebyshev and Butterworth filter prototypes, and to compute mixer intermodulation products.

The programs are all written in FORTRAN IV and the emphasis of the study is placed on the use of these programs as opposed to their theoretical foundations, which are thoroughly discussed elsewhere in the literature.

This report is divided into four main sections, plus an introduction, a bibliography, and an appendix. It begins the main text with Section II, which deals with the fundamental properties and synthesis of microstrip transmission lines, both for the case of a single microstrip line and for coupled pairs of lines.

Transmission line theory has been extensively studied for a number of years, and as a result a large number of microwave devices have been created to take advantage of the unique distributed properties that transmission lines exhibit. The economy, convenience, and size of microstrip lines, in relation to microwave integrated circuits, have virtually demanded the use of microstrip lines in devices based on transmission line properties. Section III deals with the realization of these microstrip components.

Section IV deals with design aids which are peripheral to any one component, but are generally useful to either a wide variety of components or to the solution of interface problems between components. In this instance, the aids are programs designed to compute filter prototypes and intermodulation products and to analyze and optimize cascaded networks of shunt and series transmission lines, lumped elements and diodes.

Section V, the final section of this report, is designed to integrate the concepts of the first three sections into a whole, through the use of an example. A microstrip frequency tripler is designed by splitting the total requirement into smaller design requirements amenable to solution via the techniques of the first three sections. These smaller design efforts are then integrated together to form the desired illustrative multiplier component design.

Fifteen computer programs are interspersed throughout this report. For consistency's sake, the same discussion format has been used for each program. The programs have several commonalities worth noting. First, all are written in FORTRAN IV and are liberally sprinkled with comment cards and error tests. All but three of the programs (C115, C132 and C294) need only one data card to supply a complete set of input data for one design execution; and all data inputs are in real number formats (usually 9F8.2), in order to ease data decimal alignment problems by taking advantage of the floating point input feature, which provides that an explicit decimal point overrides the implicit decimal point alignment requirement.

All of the programs are designed to continuously loop back to their input sections after completing a given task in order to begin another design. Program termination will, therefore, occur automatically on running out of data. In some computer systems this will automatically initiate an undesirable core dump, which must either be aborted by a job control card or by a program change to recognize the last card (like a test for a zero dielectric constant).

Finally, the input/output commands of all the programs reference a variable name as opposed to a literal logical I/O unit number. This allows the user to change logical I/O unit numbers by changing one or two assignment statement cards at the beginning of the program, rather than having to add job control cards or to change every I/O statement card. The majority of the programs use the variables ICARD and IPRINT (except C261 and C267) to define the logical input and output unit numbers.

SECTION II

MICROSTRIP

1.0 BACKGROUND

A microstrip transmission line consists of a narrow strip conductor separated from a parallel conducting ground plane by an intervening and supporting dielectric material (Figure 1). This form of waveguide has a quasi-TEM mode of propagation with a fringing field bound to the main propagating fields, but extending some distance above the air-dielectric interface. Early investigations into the properties of microstrip lines (as early as 1952) generally did not stimulate widespread acceptance of the technique, due to the ease with which line discontinuities could excite radiation and unwanted modes.

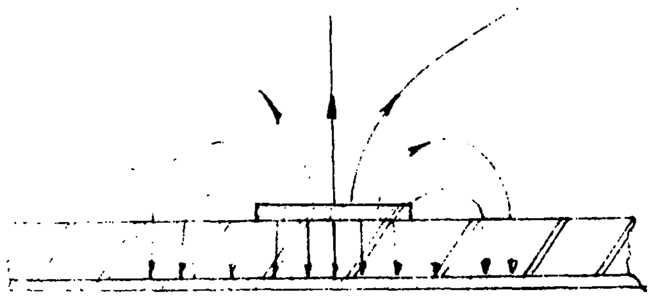


Figure 1 - Microstrip

Recent years have seen the rapid rise in importance of the miniature microwave integrated circuits, which are usually planar in structure. The planar nature of microstrip lines immediately caused renewed attention to the microstrip technique. Moreover, the use of high dielectric strength substrate materials tends to shrink the overall circuit size as well as tending to bind the fringing fields more tightly to the center conductor. These facts, plus the advantages of convenience and low batch fabrication costs, have tended to lessen the previous objections and have finally allowed microstrip to achieve a position of widespread application.

For design purposes, the microstrip line must be characterized in useful terms and parameters. H. A. Wheeler, in 1965, was able to achieve simple approximate solutions through the use of conformal mapping techniques for the dominant mode characteristic impedance, and effective dielectric constants for a single strip microstrip line. His analysis was based on the assumptions that the mode of propagation was TEM and that the strip conductor was negligibly thin.

Shortly after Wheeler's work, numerous authors, including S. B. Cohn, generated various equations and algorithms for the solution of the single strip problem based on Wheeler's technique and extending the range of validity, accuracy and simplicity of the results.

In 1968 three new papers appeared to extend these results and to include attenuation constant characterizations and radiation effects. In a detailed report, Pucel, Masse and Hartwig gave detailed expressions for conductive and mixed dielectric losses in microstrip. Next, E. J. Denlinger published a letter showing the dependence of unwanted radiated power on substrate thickness with respect to wavelength (h/λ) and on the effective substrate dielectric constant (ϵ') for the case of an open circuit line.

$$\frac{P_{rad}}{P_T} \propto \frac{(h/\lambda)^2}{Z_o}\left[\frac{\epsilon'+1}{\epsilon'} - \frac{(\epsilon-1)^2}{2\epsilon'\sqrt{\epsilon'}} \ln\left(\frac{\sqrt{\epsilon'}+1}{\sqrt{\epsilon'}-1}\right)\right]$$

Finally, the third paper published was by T. G. Bryant and J. A. Weiss on the characterization of both single microstrip and coupled pairs of microstrip lines. This article has since become, by general acceptance, the most definitive work on the subject of the characteristic impedances and effective dielectric constants of microstrip lines. Many articles have since appeared demonstrating numerous ways to compute these parameters, but they usually reference the results of Bryant and Weiss and attempt to find a simpler way of achieving them.

2.0 BRYANT AND WEISS

The approach taken by Bryant and Weiss derived an expression for the potential at any point on the dielectric interface due to a single uniformly charged line parallel to the ground plane and at the interface height. This point source problem was solved through the use of a unique and special "dielectric Green's function" which expresses the discontinuity of the fields at the dielectric interface.

Having the potential function it is an easy job to numerically solve for the charge on the conductors by slicing the strips into narrow substrips within which charge distribution may be assumed to be constant and lumped. The potential on any strip can then be calculated by the superposition of the potentials due to all the other strips or

$$V_i = \sum_{j=1}^{n} q_j \phi_{ij}$$

where ϕ_{ij} is the potential at the i^{th} strip due to a unit charge at the j^{th} strip and n is the number of substrips. Since the potential of the entire conductor is constant, all substrips have the same potential (say 1 volt) and the above set of equations can be inverted to solve for the set of charges q_j. Hence, the total charge on the conductor is determined.

$$Q = \sum_{j=1}^{n} q_j$$

The arbitrary value of one volt for the strip conductor simplifies the capacity relationship to where the capacity of the microstrip line is simply the total charge value just calculated. Under the assumption of TEM mode of propagation, the characteristic impedance can be calculated from the following well known equation:

$$Z_o = \frac{1}{vC}$$

where Z_o is the characteristic impedance and **v** is the propagation velocity.

The mixed dielectric interface can be equated to an equivalent relative dielectric constant K, which in turn can be used to calculate the propagation velocity:

$$K^2 = C/C_o \quad , \; v = {v_o}/K$$

where C_o is the capacity assuming no dielectrics are present and v_o is the speed of light. C_o is easily obtained by repeating the entire analysis with the dielectric assumed to be that of free space, hence

$$Z_o = \frac{1}{v_o \sqrt{C\, C_o}}$$

Coupled microstrip lines are analyzed by the same technique applied to the even and odd modes of the coupled lines. The odd mode is defined by equal and opposite voltages on the pair of lines, while the even mode assumes equal voltages.

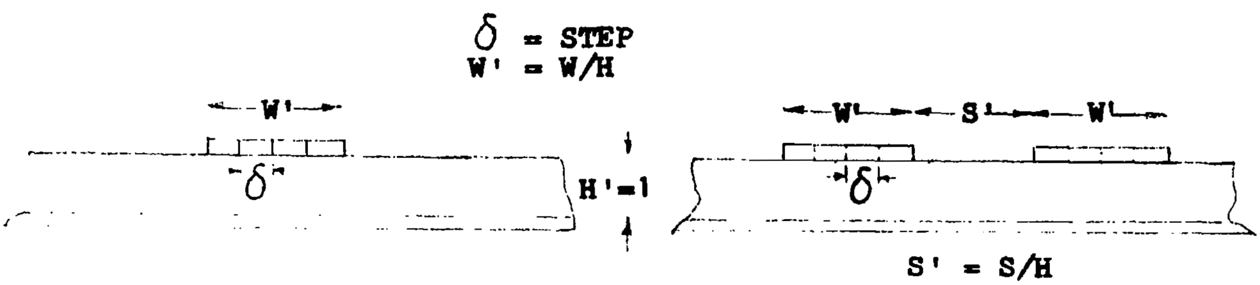
It is clear from the preceding remarks that the accurate analysis of microstrip lines and, in particular, coupled microstrip lines is an elaborate and tedious task and it is not surprising, therefore, that computers are called upon to perform this sort of work. The following two programs, C267 and C270, analyze and synthesize microstrip lines. C267 incorporates every feature of previously discussed coupled strip analysis because it is merely a slightly modified version of the program of Bryant and Weiss. C270 is a single strip synthesis program by S. B. Cohn and is illustrative as a representative of the Wheeler school of single strip analysis.

3.0 PROGRAM C267 - MICROSTRIP ANALYSIS

PURPOSE: The program computes the following parameters for either the even mode or odd mode of a coupled pair of microstrip lines, or a single microstrip line for a range of normalized strip conductor widths (normalized with respect to the substrate height): capacitance, characteristic impedance, phase velocity, and effective dielectric constant.

STRUCTURE: (Normalized)

Single Strip   Coupled Strips



INPUT: (Format 7F8.3)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
DIEK	1-8		Relative dielectric constant of the substrate material.
ANW1	9-16		Number of substrips in the initial normalized width value to be analyzed.
ANW2	17-24		Number of substrips in the final normalized width value to be analyzed.
DNW	25-32		Number of substrips with which to increment the normalized width values from the initial value to the final value.

NAME	COLUMNS	UNITS	DESCRIPTION
AIR	33-40		AIR=1.0 means the analysis is to be for coupled strips in the even mode, AIR=0.0 for single strip analysis, and AIR=1.0 for coupled strips in the odd mode.
AIS	41-48		Number of substrip widths in the distance separating the coupled strips.
STEP	49-56		Substrip width - all dimensions are expressed as integer multiples of this fundamental unit. The analysis assumes that this width is sufficiently small in relation to any of the other dimensions to effectively locate charge in the substrip at the center of the substrip in question.

OUTPUT:

1. Repetition of input data.

2. A trace variable IGO takes on the values 1,3, and 4 and displays these values as the program progresses through to completion. It is used to measure the current progress of the program in the event of a very long computation, or in the event of an unexpected termination.

3. A table of capacity, effective dielectric constant, characteristic impedances, propagation velocities, and effective wavelength ratios versus a range of normalized width values.

LIMITATIONS: Values of ANW1 less than 8 will result in solutions with greater than one per cent error, due to an insufficient number of substrips over which to approximate the charge distribution. Similarly low values of AIS will result in reduced accuracy, especially when the values of ANW1 are low at the same time.

The computer program has dimension statements which limit the upper values which can be used for the variables ANW1, ANW2, DNW, and AIS. Let d be the dimension of the variable B and let NSTEP be the program variable NSTEP, then the dimension of PHI

LIMITATIONS: is PHI(2,NSTEP) and the dimensions of SUMPF, A, and
(continued) B are SUMPF(2,d), A(d*d), and B(d). With this
understanding:

d must be greater than maximum (ANW1,ANW2,DNW)
NSTEP = 401 and must be greater than 2*d+AIS

MISCELLANEOUS:

C267 uses Routines S73, S266, S265 and S264

References: Bryant, T.G., and Weiss, J.A., "Parameters of Microstrip Transmission Lines and Coupled Pairs of Microstrip Lines," IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-16, No. 12, pp. 1021-1027, December 1968.

SAMPLE PROGRAM: C267 Continued

data

```
10.0     8.0     40.0     8.0     1.0     16.0     0.0125
```

results

```
                         INPUT DATA
 DIEK      ANW1      ANW2      DNW       AIR       AIS       STEP
10.000     8.000    40.000     8.000     1.000    16.000      .012

...1...

...3...

...4...
```

PARAMETERS OF MICROSTRIP

K = 10.00 -- COUPLED STRIPS, EVEN MODE -- S/H = .200

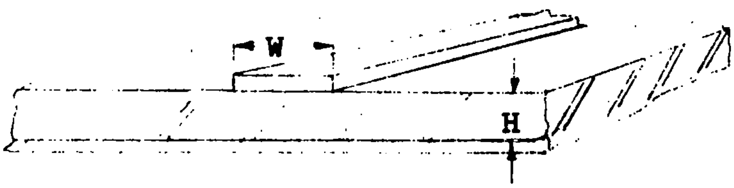
W/H	C PF/M	K-EFF	ZO OHMS	V E+08 M/SEC	L(K-EFF)/L(K)
.100	55.073	6.2715	151.679	1.1971	1.2627
.200	66.936	6.4301	126.366	1.182	1.2471
.300	77.271	6.5621	110.582	1.1703	1.2345
.400	87.020	6.6802	99.073	1.1599	1.2235
.500	96.483	6.7886	90.078	1.1506	1.2137

WHERE L(K-EFF)/L(K) IS THE RATIO OF EFFECTIVE MICROSTRIP WAVELENGTH TO A TEM WAVELENGTH IN PURE DIELECTRIC MEDIUM OF DIELECTRIC CONSTANT K.

4.0 PROGRAM C270 - SINGLE STRIP SYNTHESIS

PURPOSE: The program computes tables of microstrip strip widths and effective relative dielectric constants for a range of characteristic impedances.

STRUCTURE:



INPUT: (Format 9F8.2)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
Z01	1-8	OHMS	Initial characteristic impedance of the range of impedances to be synthesized.
Z02	9-16	OHMS	Final characteristic impedance.
DELTAZ	17-24	OHMS	Incremental impedance for the range.
H	25-32	Inches	Substrate thickness.
DIEK	33-40		Relative dielectric constant of the substrate material.

OUTPUT:

1. A table of strip widths and effective relative dielectric constants for the various impedances in the range desired.

MISCELLANEOUS:

C270 uses Subroutine S259

References: Cohn, S.B., private communication, and Wheeler, H.A., "Transmission-Line Properties of Parallel Strips Separated by a Dielectric Sheet," IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-13, No. 3, pp. 172-185, March 1965.

SAMPLE PROGRAM:

<u>data</u>

10.0	100.	2.0	0.05	9.6

<u>**results**</u>

Z0 (OHMS)	WIDTH (INCHES)	DIELECTRIC (EFFECTIVE)
10.00	.5068	8.23
12.00	.4089	8.06
14.00	.3396	7.91
16.00	.2876	7.77
18.00	.2475	7.64
20.00	.2156	7.52
22.00	.1896	7.41
24.00	.1681	7.30
26.00	.1501	7.21
28.00	.1347	7.11
30.00	.1214	7.03
32.00	.1099	6.95
34.00	.0998	6.88
36.00	.0909	6.81
38.00	.0829	6.74
40.00	.0759	6.68
42.00	.0695	6.63
44.00	.0638	6.58
46.00	.0587	6.53
48.00	.0540	6.47
50.00	.0498	6.42
52.00	.0459	6.38
54.00	.0424	6.34
56.00	.0391	6.30
58.00	.0361	6.26
60.00	.0334	6.23
62.00	.0308	6.20
64.00	.0285	6.17
66.00	.0264	6.14
68.00	.0244	6.12
70.00	.0226	6.09
72.00	.0209	6.07
74.00	.0193	6.05
76.00	.0179	6.03
78.00	.0165	6.01
80.00	.0153	5.99
82.00	.0142	5.97
84.00	.0131	5.96
86.00	.0122	5.94
88.00	.0113	5.93
90.00	.0104	5.91
92.00	.0096	5.90
94.00	.0089	5.88
96.00	.0083	5.87
98.00	.0077	5.86
100.00	.0071	5.85

SECTION III

MICROSTRIP COMPONENTS

1.0 INTRODUCTION

A wide variety of microwave devices and components incorporate the unique distributed properties of transmission lines into their designs, and a great many of these designs are applicable to the planar technology of microstrip lines. This places the microwave integrated circuit designer in the unique position of having a wide menu of well thought out and proven design techniques and structures at his disposal.

Unfortunately, the designer will probably not have much time to enjoy his unique position, since he will also have a new and different set of pitfalls and problems to cope with in this new technology. The attainable unloaded Q's of microstrip structures tend to be lower than those of equivalent stripline structures. The substrate material must be low-loss with a high dielectric constant which is homogeneous, and the surface must be free from pits. Tight coupling is difficult to achieve in microstrip as is multicomponent circuit isolation and the even and odd mode propagation velocities can differ significantly. Nevertheless, close attention to the choice of materials and processing techniques and good design practice can overcome these disadvantages for a variety of components.

Most microwave components, based on transmission line structures, can be separated into two classes: those that use the properties of coupled pairs of transmission lines and those that use single interconnected transmission lines. The component design programs which follow will be organized in this fashion with the single strip devices being presented first.

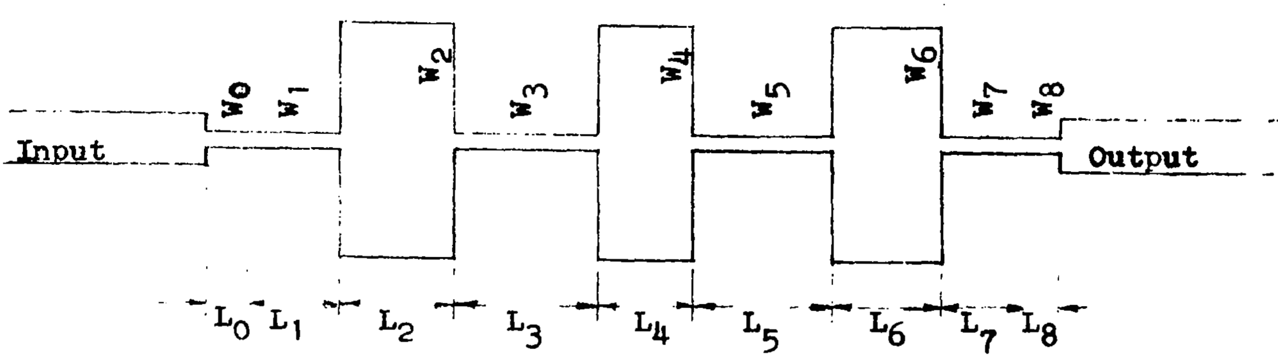
2.0 SINGLE STRIP COMPONENTS

Filter networks are among the most widely used microstrip applications and the following pages describe three single strip filter designs to accomplish low pass, high pass, and band reject filters.

2.1 PROGRAM C261 - LOW PASS FILTER

PURPOSE: The program computes normalized element values and physical dimensions of a lumped equivalent low pass filter using alternating high and low impedance cascade of transmission lines.

STRUCTURE:



INPUT: (Format 10F7.1)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
ZO	1-7	OHMS	Input and output impedance level.
ZOHIGH	8-14	OHMS	High impedance section level.
ZOLOW	15-21	OHMS	Low impedance section level.
EPS	22-28		Relative dielectric constant of the substrate material.
H	29-35	Inches	Substrate thickness.
BAND	36-42	GHZ	Filter cutoff frequency.
RIPPLE	43-49	DB	Chebyshev ripple magnitude, or if 0 a maximum flatness response is desired.
SECTN	50-56		Number of sections or 0 to indicate that the minimum number of sections to satisfy the attenuation conditions below is to be found.

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
FREQ	57-63	GHZ	Frequency at which a specified attenuation is desired.
ATTEN	64-70	DB	Specified attenuation desired.

OUTPUT:

1. Repetition of input data.
2. The width of the input line.
3. A table of normalized element values, lengths, widths and impedances for each section of the filter including the short impedance matching 0 and N+1th sections.

METHOD: A low pass prototype filter is computed and the element reactances and susceptances at cutoff are realized as short lengths of high and low impedance transmission lines. The capacitive sections are foreshortened to compensate for discontinuity capacitances as well as for the loading capacitances of the lines on either side of the section. Similarly the inductive sections are foreshortened due to the inductive loading of sections on either side of the section.

The computer program does not use the small argument approximations and hence solves a non-linear set of equations in terms of the actual microstrip propagation velocities, the cutoff frequency and the element prototype values in order to arrive at the lengths of each section.

The high and low impedance lines strip widths are calculated as in an input impedance matching short lengths of high impedance line.

LIMITATIONS: For filters in which very low capacitors are needed, it may turn out that the fringing fields for the low impedance sections exceed the desired capacity. In this event the design cannot converge to a solution, and the user must increase the impedance levels of the low impedance sections. Similarly, a design may require a very low inductance; therefore the design will fail, and the user must decrease the high impedance value. The reverse is also true. A high impedance that is too low or a low impedance that is too high will make the line so long that length effects will appear and make the design invalid.

MISCELLANEOUS:

C261 uses Routines S92, S96, and S259.

References: Matthaei, G.E., Young, G.E., and Jones, E.M.T., Microwave Filters, Impedance-Matching Networks, and Coupling Structures, McGraw-Hill, 1964, pp. 365-374.

Sample Problem:

A.

data

```
50.0     150.0   10.0     9.0    0.05     1.0       0.    3.0       0.       0.
```

results

```
          MAX FLAT LOW PASS MICROSTRIP FILTER
                3DB BANDWIDTH OF  1.000 GHZ

RELATIVE DIELECTRIC OF  9.000 AND HEIGHT OF .050 INCHES
INPUT IMPEDANCE OF  50.00 OHMS AND WIDTH OF  .0529 INCHES
```

SECTION NUMBER	NORMALIZED ELEMENT	LENGTH INCHES	WIDTH INCHES	IMPEDANCE OHMS
0	1.0000	.0195	.0012	150.00
1	1.0000	.2669	.0012	150.00
2	2.0000	.2126	.5263	10.00
3	1.0000	.2669	.0012	150.00
4	1.0000	.0195	.0012	150.00

B.

data

```
50.0  150.0   10.0   9.6   0.05   1.0   0.1   0.0  2.0   13.
```

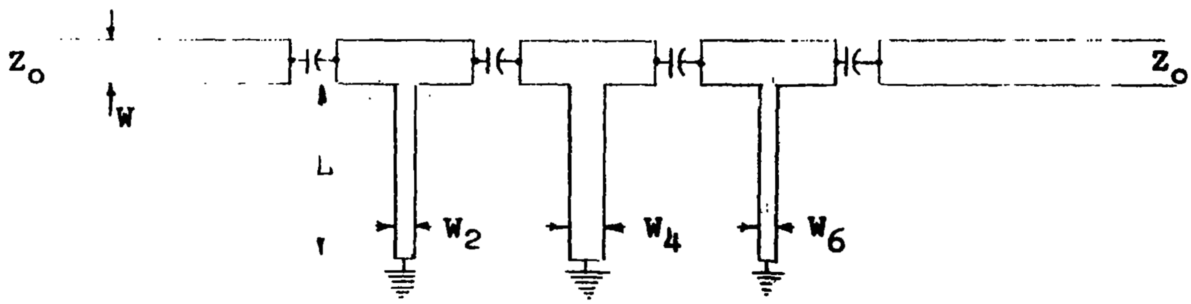
results

```
DESIGN REQUIRES ODD NUMBER OF SECTIONS,
SECTIONS INCREASED BY ONE TO  5



         CHEBYSHEV LOW PASS MICROSTRIP FILTER
        BANDWIDTH OF  1.000 GHZ AND .10 DB RIPPLE

RELATIVE DIELECTRIC OF  9.600 AND HEIGHT OF .050 INCHES
INPUT IMPEDANCE OF  50.00 OHMS AND WIDTH OF  .0498 INCHES

     SECTION NORMALIZED  LENGTH   WIDTH IMPEDANCE
      NUMBER   ELEMENT   INCHES  INCHES    OHMS

        0      1.0000    .0215    .0010   150.00
        1      1.1468    .3048    .0010   150.00
        2      1.3712    .1102    .5068    10.00
        3      1.9750    .5555    .0010   150.00
        4      1.3712    .1102    .5068    10.00
        5      1.1468    .3048    .0010   150.00
        6      1.0000    .0215    .0010   150.00
```

2.2 PROGRAM C290 - LUMPED HIGHPASS FILTER

PURPOSE: The program computes the lumped capacities and shunt inductances needed to realize a highpass filter and converts the inductances into equal length shorted stubs.

STRUCTURE:



INPUT: (Format 9F8.2)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
ZO	1-8	OHMS	Impedance Level
DIEK	9-16		Substrate Dielectric Constant
H	17-24	Inches	Substrate Thickness
WMIN	25-32	Inches	Minimum Microstrip Width Desired
FCUTOF	32-40	GHZ	High Pass Cutoff Frequency
RIPPLE	41-48	DB	Chebyshev Ripple or if 0 Maximum Flat Design.
SECTS	49-56		Number of Sections or if 0 the Computer is Required to Find the Minimum Number of Sections to Satisfy the Following Conditions.
FREQ	57-64	GHZ	Frequency at Which Attenuation is Desired.
ATTEN	64-72	DB	Attenuation Desired.

OUTPUT:

1. Input data.

2. Stub length in inches and in wavelengths.

3. A table containing:

   a. The normalized prototype element values ("gvalues").
   b. The lumped capacitor and inductor values.
   c. The widths required to realize the inductor as shorted strips of equal length.

METHOD: A set of low pass prototype element values are computed and transformed into high pass element values. The inductances are searched for the largest value and this inductance is realized using a short length of transmission line of width WMIN. This length then becomes the length for all other lumped inductor realizations and the impedance (i.e. width) of these lines are varied in order to obtain the desired line length. The common line is required to provide for a common shorting block to ground the inductors.

LIMITATIONS: High pass filters made of transmission line elements will always have a stop band somewhere in the pass band of the prototype filter due to the shunt inductors becoming 180 degrees long.

MISCELLANEOUS:

C290 uses Routines S262, S96, S92 and S259

References: Matthaei, Young and Jones, Microwave Filters, Impedance-Matching Networks, and Coupling Structures, McGraw-Hill, 1964, pp. 411-416.

Sample Problem:

data

```
50.0      9.0      0.1      .01      1.0      0.1      6.0      0.0      0.0
```

results

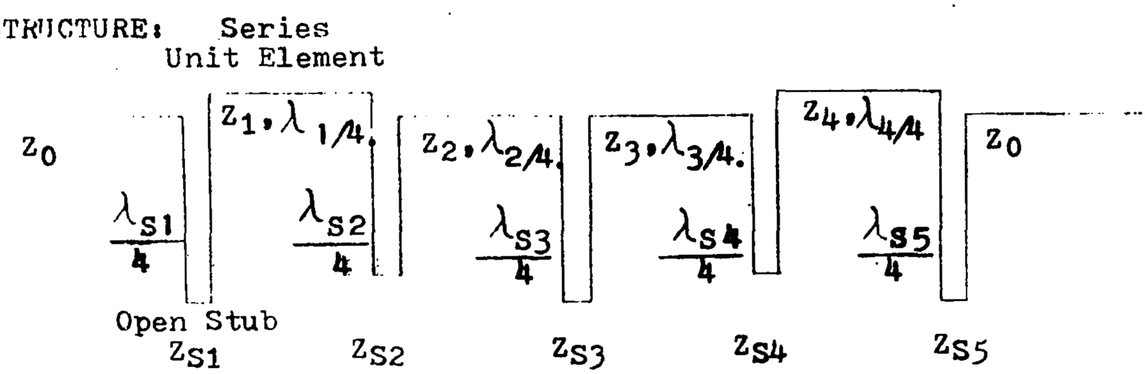
```
              LUMPED HIGHPASS FILTER

  1.000 GHZ CUTOFF FREQUENCY      .10 DB RIPPLE
 50.000 OHMS INPUT IMPEDANCE        6 SECTIONS
   .100 INCH THICK SUBSTRATE     9.00 DIELECTRIC

STUB LENGTH =      .415 INCHES
STUB WAVELENGTHS =    .0822
```

SECTION NUMBER	ELEMENT VALUE (NORM)	CAPACITY PICO-FARADS	INDUCTANCE NANO-HENRIES	WIDTH INCHES
1	1.1681	2.7249		
2	1.4040		5.6680	.0545
3	2.0568	1.5480		
4	1.5171		5.2454	.0669
5	1.9029	1.6728		
6	.8618		9.2333	.0100

2.3 PROGRAM C260 - MICROSTRIP STOPBAND FILTER

PURPOSE: The program computes the series and shunt microstrip quarter wave transmission line impedances to realize an optimum Bandstop Filter, as well as the width and length dimensions needed for physical layout.

STRUCTURE:



INPUT: (Format 9F8.2)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
HEIGHT	1-8	Inches	Height of Dielectric Substrate
DIEK	9-16		Dielectric Constant of Substrate
ZO	17-24	OHMS	Input Impedance Level
FCENTR	25-32	GHZ	Stopband Center Frequency
FCUTOF	33-40	GHZ	Upper Band Edge Cutoff Frequency. Cutoff Frequency must be Less Than the Center Frequency.
RIPPLE	41-48	DB	Chebyshev Ripple Factor in dB.
SECT	49-56		Number of Sections or Zero to have Computer Calculate Required Number of Sections.
FATTEN	57-64	GHZ	Frequency at which a Specified Minimum Attenuation is Needed.
ATTEN	65-72	DB	Attenuation Required at Above Frequency - The Program Determines the Minumum Number of

DESCRIPTION (cont'd)

Sections to Satisfy these Requirements when the Variable SECT is Zero.

OUTPUT:

1. The input data is repeated.
2. The impedance, length and strip width of each microstrip transmission line stub is displayed.
3. The impedance, length and strip width of each series unit element microstrip transmission line is displayed.

METHOD: The procedure starts by mapping a low pass Chebyshev response into a bandstop filter response through the use of the Richards' transform variable ($S = j\ TAN(\pi f/2fo)$) obtaining a polynomial representation of a squared magnitude reflection coefficient polynomial. Next find the roots of the denominator and the left hand poles of the reflection coefficient. Since the numerator is a perfect square, form the reflection coefficient by taking the ratio of the numerator polynomial root function to the left hand denominator poles. Form the input impedance polynomial from the reflection coefficient:

$$Z_{in} = \frac{1+P(s)}{1-P(s)}$$

Synthesize the circuits by extracting, alternately, a capacitor and then a unit element, reducing the polynomial after each extraction until the impedance polynomial is exhausted.

Multiply the shunt capacitor values and unit element values by the generator admittance to denomalize the values. Realize the filter as a cascade of quarter wavelength shunt open stubs alternating with series quarter wavelength unit elements, being cautious to account for the various wavelengths required for different strip widths.

LIMITATIONS: Since the filter is composed of quarter wavelength sections, the response will repeat itself every odd multiple of the center frequency. The program does

LIMITATIONS: (cont'd.) not design filters requiring more than 16 sections, the expense and inaccuracy involved in manipulating and finding the roots of large polynomials is not worth the added expenditure. Very accurate results can be obtained in large filter networks by simply repeating the central sections of the filter design for the case of greater than 8 stubs.

The program will synthesize filters with bandwidths in the range 30% through 150%. The value of ATTEN must be greater than the value of RIPPLE and the value of FATTEN must be between the values of FCENTR and FCUTOF.

Finally, the program does not produce physical dimensions which compensate for fringing effects and for more accurate results the stubs need to be shortened.

MISCELLANEOUS:

C260 uses Routines S259, S105, S106, S107 and S108.

Reference: Gupta, O.P., and Wenzel, R.J., private communication and Wenzel, R.J. and Horton, M.C., "General Theory and Design of Optimum Quarter-Wave TEM Filters," IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-13, No. 3, May 1965, pp. 316-327.

Sample Problem:

A.

<u>data</u>

```
0.050      9.6    50.0      1.0      0.8      0.1      4.0      0.0      0.0
```

<u>results</u>

```
        OPTIMUM BANDSTOP MICROSTRIP FILTER

  .400 FRACTIONAL BANDWIDTH CENTERED AT  1.0000 GHZ
        5 STUB ELEMENTS AND  .100 DB RIPPLE
        50.0 OHM INPUT STRIP OF WIDTH  .050 INCHES
  ON  .050 INCHES HIGH,  9.600 DIELECTRIC SUBSTRATE
```

	SHUNT OPEN STUB			SERIES UNIT ELEMENT		
SECTION NUMBER	IMPEDANCE (OHMS)	WIDTH (INCHES)	LENGTH (INCHES)	IMPEDANCE (OHMS)	WIDTH (INCHES)	LENGTH (INCHES)
1	131.44	.0021	1.234	55.26	.0403	1.174
2	78.28	.0164	1.204	57.10	.0374	1.178
3	74.08	.0193	1.200	57.10	.0374	1.178
4	78.28	.0164	1.204	55.26	.0403	1.174
5	131.44	.0021	1.234			

B.

data

0.050 9.6 50.0 1.0 0.4 0.1 0.0 0.5 33.0

results

OPTIMUM BANDSTOP MICROSTRIP FILTER

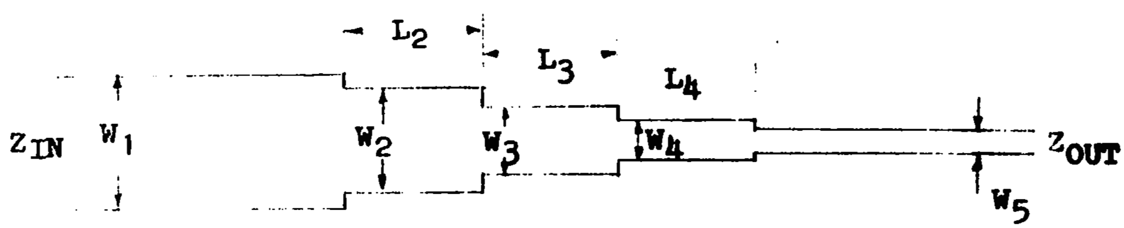
1.200 FRACTIONAL BANDWIDTH CENTERED AT 1.0000 GHZ
5 STUB ELEMENTS AND .100 DB RIPPLE
50.0 OHM INPUT STRIP OF WIDTH .050 INCHES
ON .050 INCHES HIGH, 9.600 DIELECTRIC SUBSTRATE

	SHUNT OPEN STUB			SERIES UNIT ELEMENT		
SECTION NUMBER	IMPEDANCE (OHMS)	WIDTH (INCHES)	LENGTH (INCHES)	IMPEDANCE (OHMS)	WIDTH (INCHES)	LENGTH (INCHES)
1	30.50	.1184	1.114	113.90	.0042	1.227
2	17.34	.2596	1.065	124.75	.0027	1.232
3	16.67	.2732	1.062	124.75	.0027	1.232
4	17.34	.2596	1.065	113.90	.0042	1.227
5	30.50	.1184	1.114			

2.4 PROGRAM C289 - STEPPED IMPEDANCE TRANSFORMER

PURPOSE: The program computes the impedances of quarter wave sections to transform from one impedance to another over a band of frequencies, compensating for junction discontinuity effects.

STRUCTURE:



INPUT: (Format 8F8.2)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
H	1-8	Inches	Substrate Thickness
DIEK	9-16		Substrate Dielectric Constant
SECT	17-24		Number of Sections Required
FLOW	25-32	GHZ	Low Band Edge
FHIGH	33-40	GHZ	High Band Edge
EXPAND	41-48		Expansion Factor Input for Compensating Bandwidth.
ZIN	49-56	OHMS	Input Impedance (by convention the lower of the two).
ZOUT	57-64	OHMS	Output Impedance

OUTPUT:

1. Input data.

2. Maximum VSWR expected.

3. A table containing:

   a. The impedance of each section.
   b. The width and length of each section.

METHOD: Chebyshev-like transformers are synthesized through the use of Dolph-Chebyshev linear antenna array a_i. The m^{th} impedance ratio at a step is, therefore,

$$\frac{Z_{m+1}}{Z_m} = \epsilon \left\{ \frac{a_n \ln R}{\sum_{i=1}^{n} a_i} \right\}$$

The next step is to add corrections to compensate for the discontinuities introduced by the change in microstrip width. Since the discontinuities are reactive, rather than susceptive, the dual of the equations in the reference were used to correct the original design.

LIMITATIONS: The accuracy of the analysis is reduced only at the extremes of the data, such as the design of a large impedance transformer ratio, together with a very thick substrate, at very low impedance levels and with multi-octave bandwidth ratios.

MISCELLANEOUS:

C289 uses Routine S259

References: Cohn, S.B., private correspondence, and Cohn, S.B., "Optimum Design of Stepped Transmission-Line Transformers," IRE Trans. on Microwave Theory and Techniques, Vol. MTT-3, No. 3, pp. 16-21, April 1955.

Sample Problem:

A.

data

0.1	9.5	4.0	2.0	4.0	1.17	25.0	50.0

results

MICROSTRIP STEPPED IMPEDANCE TRANSFORMER

TRANSFORMING 25.00 OHMS INTO 50.00 OHMS
USING 4 SECTIONS AND HAVING A MAXIMUM VSWR OF 1.016
ON .100 INCHES THICK, 9.50 DIELETRIC SUBSTRATE

SECTION	IMPEDANCE (OHMS)	WIDTH (INCHES)	LENGTH (INCHES)
1	25.00	.3197	
2	26.68	.2913	.3745
3	31.60	.2259	.3707
4	39.56	.1561	.3733
5	46.86	.1143	.3795
6	50.00	.1006	

B.

data

0.1 9.5 9.0 1.0 3.0 1.17 25.0 50.0

results

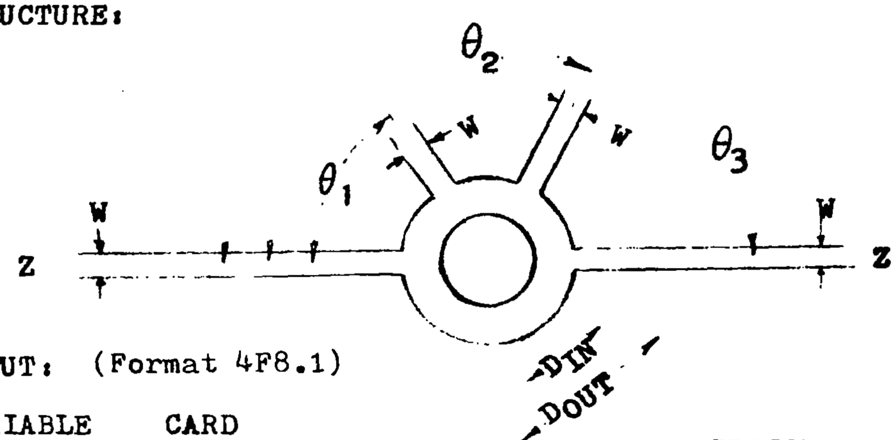
```
MICROSTRIP STEPPED IMPEDANCE TRANSFORMER

TRANSFORMING  25.00 OHMS INTO  50.00 OHMS
USING   9 SECTIONS AND HAVING A MAXIMUM VSWR OF 1.001
ON  .100 INCHES THICK,  9.50 DIELETRIC SUBSTRATE
```

SECTION	IMPEDANCE (OHMS)	WIDTH (INCHES)	LENGTH (INCHES)
1	25.00	.3197	
2	25.20	.3161	.5539
3	25.96	.3030	.5557
4	27.74	.2751	.5570
5	30.89	.2340	.5593
6	35.36	.1888	.5637
7	40.47	.1499	.5698
8	45.06	.1232	.5748
9	48.15	.1084	.5796
10	49.60	.1022	.5822
11	50.00	.1006	

2.5 PROGRAM C283 - HYBRID RING

PURPOSE: The program computes the physical dimensions of a microstrip hybrid ring.

STRUCTURE:



INPUT: (Format 4F8.1)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
F	1-8	GHZ	Center Frequency
DIEK	9-16		Substrate Dielectric Constant
Z	17-24	OHMS	Impedance Level
H	25-32	Inches	Substrate Thickness

OUTPUT:

1. The input data is repeated.
2. The outer and inner ring diameters are displayed.
3. The input strip width is printed.
4. The reference plane angles for each of the ports is printed in degrees from the input port.

METHOD: A ring with a median length of six quarter wavelengths plus 8 reference plane compensating lengths is calculated. The reference plane data is then converted into angular measurements and displayed to specify the location of the ring inputs and outputs.

LIMITATIONS: The basic limitations of the hybrid ring is the overall bandwidth of the ring which usually cannot be much larger than ± 20% of the center frequency.

MISCELLANEOUS:

C283 uses Routines S284 and S259

References: F. S. Coale, private communication.

Sample Problem:

A.

data

```
1.0       9.6     50.0    0.050
```

results

```
MICROSTRIP HYBRID RING SYNTHESIS

FREQUENCY              =    1.000 GHZ
INPUT IMPEDANCE        =    50.00 OHMS
DIELECTRIC CONSTANT =        9.60
SUBSTRATE THICKNESS =        .050 INCHES

OUTER DIAMETER         =   2.3576 INCHES
INNER DIAMETER         =   2.3137 INCHES
INPUT STRIP WIDTH      =    .0498 INCHES
OUTPUT ANGLES
              1            60.655 DEGREES
              2           121.309 DEGREES
              3           181.964 DEGREES
```

data

```
0.1       9.6     50.0    0.050
```

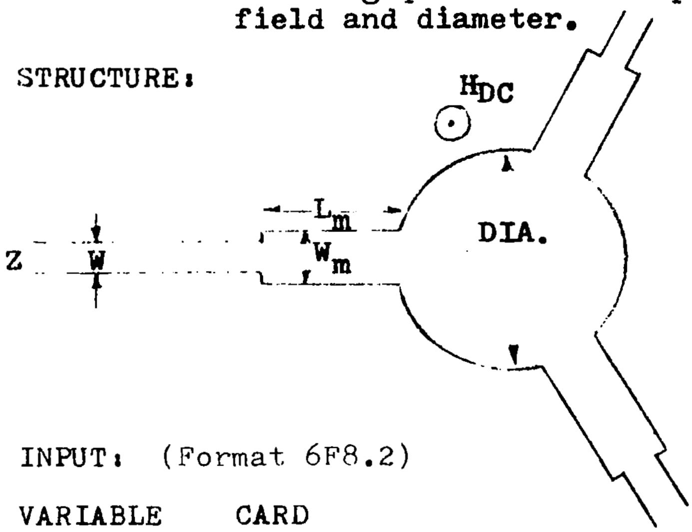
results

```
MICROSTRIP HYBRID RING SYNTHESIS

FREQUENCY              =     .100 GHZ
INPUT IMPEDANCE        =    50.00 OHMS
DIELECTRIC CONSTANT =        9.60
SUBSTRATE THICKNESS =        .050 INCHES

OUTER DIAMETER         =  22.9202 INCHES
INNER DIAMETER         =  22.8763 INCHES
INPUT STRIP WIDTH      =    .0498 INCHES
OUTPUT ANGLES
              1            60.067 DEGREES
              2           120.134 DEGREES
              3           180.201 DEGREES
```

2.6 PROGRAM C288 - FERRITE CIRCULATOR

PURPOSE: The program computes physical dimensions of a microstrip ferrite circulator together with its matching quarter wave input and ferrite magnetic field and diameter.

STRUCTURE:



INPUT: (Format 6F8.2)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
FLOW	1-8	GHZ	Low Band Edge Frequency
FHIGH	9-16	GHZ	High Band Edge Frequency
REQISO	17-24	DB	Required Isolation
FDIEK	25-32		Ferrite Dielectric Constant
SDIEK	33-40		Substrate Dielectric Constant
Z	41-48	OHMS	Impedance Level

OUTPUT:

1. The input data.
2. The DC magnetic field in oersteds.
3. Ferrite disk diameter, height and equivalent impedance.
4. Matching section, impedance, width and length.
5. Input line width.

METHOD: The approach of Fay and Comstock is primarily used except where the ferrite height is involved. Here the substrate thickness is used instead and is equal to half the ground plane spacing assumed for stripline.

The isolation requirement is converted into a matching requirement between the ferrite resonator equivalent circuit and the quarter wave input transformer in terms of VSWR. The VSWR, in turn, defines the phase angle of the equivalent resonator admittance which, when combined with the bandwidth specifications, determines the loaded Q_L of the resonator.

The ferrite is to be operated in the just saturated condition ($H_{dc}=4\pi M_s$) which simplifies the calculations for μeff. From Q_L the fractional frequency splitting between the individual rotating mode resonators is found

$$\left(\delta' = \frac{1}{\sqrt{3}\,Q_L}\right)$$

from which the value of K/μ is determined ($K/\mu = 2.46\delta'$) and, hence, μeff $= (1-(K/\mu)^2)$ is found for the condition of just saturation. Now the propagation constant k can be determined which will result in the value for the radius of the ferrite pack. $R = 1.8412/k$.

The next step is to determine a satisfactory impedance transformation ratio which will allow the best match for the given VSWR and bandwidth requirement. Knowing the transformer ratio and the input line characteristic impedance, a matching impedance may be determined as well as the desired input conductance of the resonator. Finally, the height of the resonator can be determined by $H = .74 * W_o R^2 \epsilon/(Q_L G_R)$, where W_o is the center frequency, R is the ferrite radius, G_R is the conductance of the resonator at resonance and ϵ is the dielectric constant of the ferrite.

LIMITATIONS: The bandwidths that can be realized by this program are limited to moderate bandwidths typically not exceeding the 20% range significantly. Large bandwidths tend to increase the ferrite diameter significantly beyond this region.

MISCELLANEOUS:

C288 uses Routine S259

References: Fay, C.E. and Comstock, R.L., "Operation of the Ferrite Junction Circulator," IEEE Transactions on Microwave Theory and Techniques, MTT-B, January, 1965, pp. 15-27.

Sample Problem:

A.

data

.924	1.076	30.0	14.0	9.6	50.0

results

FERRITE CIRCULATOR DESIGN

REQUIREMENTS

.924	GHZ	LOW BAND EDGE
1.076	GHZ	HIGH BAND EDGE
30.000	DB	ISOLATION REQUIRED
14.000		SUBSTRATE DIELECTRIC
9.600		FERRITE DIELECTRIC
50.000	OHMS	INPUT IMPEDANCE

DESIGN PARAMETERS

947.78	OER.	DC MAGNETIC FIELD
2.0394	IN.	DIAMETER OF FERRITE DISK
.0779	IN.	INPUT LINE WIDTH
.3204	IN.	MATCHING QUARTER WAVE LINE WIDTH
1.0794	IN.	MATCHING SECTION LENGTH
20.7840	OHMS	MATCHING SECTION IMPEDANCE
.0782	IN.	FERRITE SUBSTRATE HEIGHT
8.6395	OHMS	FERRITE EQUIVALENT RESISTANCE

B.

data

0.9	1.1	30.0	14.0	9.6	50.0

results

FERRITE CIRCULATOR DESIGN

REQUIREMENTS

.900	GHZ	LOW BAND EDGE
1.100	GHZ	HIGH BAND EDGE
30.000	DB	ISOLATION REQUIRED
14.000		SUBSTRATE DIELECTRIC
9.600		FERRITE DIELECTRIC
50.000	OHMS	INPUT IMPEDANCE

DESIGN PARAMETERS

1247.08	OER.	DC MAGNETIC FIELD
2.2236	IN.	DIAMETER OF FERRITE DISK
.1785	IN.	INPUT LINE WIDTH
.5640	IN.	MATCHING QUARTER WAVE LINE WIDTH
1.0961	IN.	MATCHING SECTION LENGTH
25.1523	OHMS	MATCHING SECTION IMPEDANCE
.1792	IN.	FERRITE SUBSTRATE HEIGHT
12.6528	OHMS	FERRITE EQUIVALENT RESISTANCE

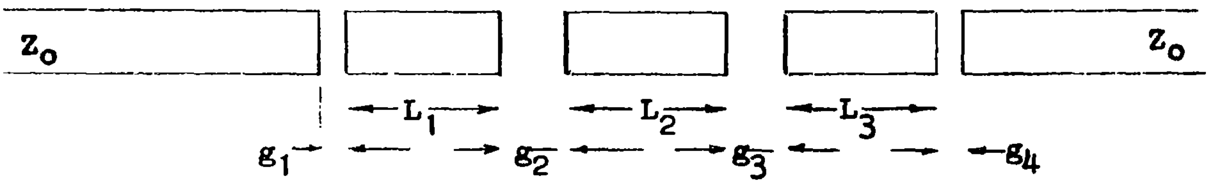
3.0 DEVICES USING COUPLED MICROSTRIP LINES

Two broad classes of devices use coupled microstrip lines: filters and couplers. The following programs illustrate two examples of bandpass filters using coupled lines and an example each of a directional coupler and a power splitter.

3.1 PROGRAM C279- END COUPLED BANDPASS FILTER

PURPOSE: The program computes gap susceptance needed to end couple half wave resonators to realize a bandpass filter and provides the length, width and gap dimensions needed to realize the structure in microstrip form.

STRUCTURE:



INPUT: (Format 9F8.2)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
ZO	1-8	OHMS	Impedance Level
DIEK	9-16		Substrate Dielectric Constant
H	17-24	Inches	Substrate Thickness
FCENTR	25-32	GHZ	Filter Center Frequency
BANWTH	33-40	GHZ	Filter Bandwidth
RIPPLE	41-48	DB	Chebyshev Ripple or if 0 a Max Flat Design.
SECTS	49-56		Number of Sections, if 0 the Computer finds the Minimum Number of Sections to Satisfy the Below Conditions.
FREQ	57-64	GHZ	Frequency at which a Specified Attenuation is Desired.
ATTEN	65-72	DB	Specified Attenuation Desired

OUTPUT:

1. The input data is repeated.

2. The width of the microstrip line is displayed.

OUTPUT: (cont'd.)

3. A table is presented containing for each section

   a. The normalized gap susceptances.
   b. The prototype element values ("gvalues").
   c. The length and gap sizes required to realize the filter in microstrip format.

METHOD: A low pass prototype network is computed and transformed into cascade of admittance inverters separated by resonant circuits. This network is realized by replacing the resonant circuits with half wave resonator strips and the admittance inverters by end coupled gaps. The gaps are realized by viewing the resonator strips as very wide parallel coupled strips of short lengths. The capacitive coupling between the resonators thereby becomes a combination of odd and even mode capacitance, which is then synthesized as a gap between coupled lines by a set of subroutines which perform an approximate coupled strip synthesis which could be refined later through the use of the C267 routine.

LIMITATIONS: The approximate synthesis routines are generally 4% accurate over a wide variety of dielectric values and geometries, but the percentage error rises markedly for tight coupling situations of $S/H < .2$ and with $W/H < .2$ or $W/H > 2.$. The filter routine is capable of bandwidths up to 20% depending on the ripple size.

MISCELLANEOUS:

C279 uses Routines S280, S278, S262, S96, S97 and S259.

References: Cohn, S.B., private communication, Cohn, S.B., "Direct-Coupled-Resonator Filters," Proc. of the IRE, February, 1957, pp. 187-196.

Sample Program:

A.

data

```
50.0      9.0      0.1      3.1      0.2      0.5      3.0      0.0      0.0
```

results

```
          END GAP COUPLED BANDPASS FILTER

 3.100 GHZ CENTER FREQUENCY    .200 GHZ BANDWIDTH
  .500 DB RIPPLE                  3 SECTIONS
  .100 INCH SUBSTRATE         9.000 DIELECTRIC CONSTANT
50.000 OHM MICROSTRIP LINE OF WIDTH    .1058 INCHES


SEC ELEMENT   SUSCEPT   LENGTH  LENGTH    GAP
NUM  VALUE    (NORM)   DEGREES  INCHES  INCHES

 1   1.5963    .2690   161.478    .614   .0333
 2   1.0967    .0770   171.240    .618   .1015
 3   1.5963    .0770   161.478    .614   .1015
 4   1.0000    .2690     0.000   0.000   .0333
```

B.

data

50.0	9.0	0.1	3.1	0.2	0.1	3.0	0.0	0.0

results

END GAP COUPLED BANDPASS FILTER

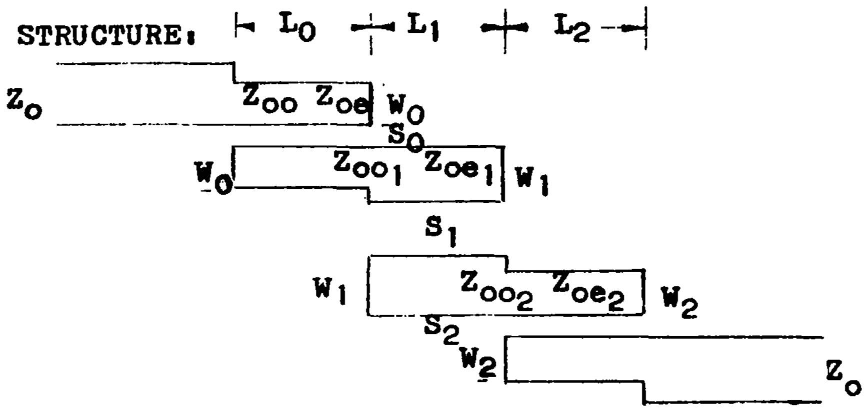
3.100 GHZ CENTER FREQUENCY .200 GHZ BANDWIDTH
.100 DB RIPPLE 3 SECTIONS
.100 INCH SUBSTRATE 9.000 DIELECTRIC CONSTANT
50.000 OHM MICROSTRIP LINE OF WIDTH .1058 INCHES

SEC NUM	ELEMENT VALUE	SUSCEPT (NORM)	LENGTH DEGREES	LENGTH INCHES	GAP INCHES
1	1.0316	.3476	157.276	.612	.0209
2	1.1474	.0940	169.357	.621	.0872
3	1.0316	.0940	157.276	.612	.0872
4	1.0000	.3476	0.000	0.000	.0209

3.2 PROGRAM C276 - PARALLEL COUPLED BANDPASS FILTERS

PURPOSE: The program computes the even and odd mode impedance for a parallel coupled bandpass filter and the microstrip dimensions of length, width and gap to realize the filter.

STRUCTURE:



INPUT: (Format 9F8.2)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
ZO	1-8	OHMS	Impedance Level
DIEK	9-16		Substrate Dielectric Constant
H	17-24	Inches	Substrate Thickness
BAND	25-32	GHZ	Filter Bandwidth (if negative a bandwidth shrinkage correction factor is automically applied)
CENTER	33-40	GHZ	Center Frequency of Filter
RIPPLE	41-48	DB	Chebyshev Ripple Magnitude in dB, 0 Means Maximum Flat Response.
SECTN	49-56		Number of Sections or 0 to Indicate that the Required Number Should be Computed from Next Data.

NAME	COLUMNS	UNITS	DESCRIPTION
FREQ	57-64	GHZ	Frequency at which a Desired Minimum Attenuation is Wished.
ATTEN	65-72	DB	Attenuation Desired if SECTN is Zero; Find Number of Sections Needed to Produce Desired Skirt.

OUTPUT:

1. Input data repeated.

2. The design bandwidth - this differs from the required bandwidth only if pre-distortion is desired to compensate for an expected bandwidth shrinkage between design and actual hardware.

3. A table of:

   a. Even and odd impedances required for each section.
   b. The element values ("gvalues") used in the prototype.
   c. The length, width and gaps needed to realize the design in microstrip technology.

METHOD: A low pass prototype circuit transformed into a cascade of resonant circuits separated by admittance inverters. The actual circuit is realized by replacing the admittance inverters by quarter wave parallel coupling between strips. The even and odd mode impedances required by the coupled strips are synthesized using approximate techniques developed by T. Cisco. The final structure is then foreshortened to account for fringing capacity effects.

An experimentally derived bandwidth reduction factor is included in the program and is activated by a negative input data item. A compensation factor then multiplies the desired bandwidth in order to predistort the design.

LIMITATIONS: The overall bandwidth of the filter is limited by the realizability of reasonable coupling factors between the initial resonant circuits. Values as high as 30% can be achieved. The approximate solutions for the coupled lines are usually in the 4% range, but for tight coupling and very low S/H and W/H ratios the results can rapidly deteriorate, and program C267 should be used to accurately affirm the correct geometries.

MISCELLANEOUS:

C276 uses Routines C277, S278, S262, S96, S92 and S259.

References: Matthaei, G.E., Young, G.E. and Jones, E.M.T., Microwave Filters, Impedance-Matching Networks, and Coupling Structures, McGraw-Hill, 1964, pp. 472-476.

Sample Problem:

A.

data

50.0	9.6	0.05	-.30	1.0	0.01	6.0	0.0	0.0

results

PARALLEL COUPLED MICROSTRIP FILTER

1.000 GHZ CENTER FREQUENCY   .300 GHZ BANDWIDTH
.010 DB RIPPLE   6 SECTIONS
.050 INCH SUBSTRATE   9.600 DIELECTRIC CONSTANT
50.0 OHM MICROSTRIP INPUT LINE OF WIDTH   .0498 INCHES
.334 GHZ BANDWIDTH DUE TO PRE-COMPENSATION

SEC NUM	ELEMENT VALUE	WIDTH INCHES	GAP INCHES	LENGTH INCHES	ZOO OHMS	ZOE OHMS
0	1.0000	.0132	.0062	1.227	42.59	124.50
1	.7814	.0287	.0089	1.200	37.50	88.36
2	1.3600	.0378	.0155	1.182	38.69	73.27
3	1.6897	.0388	.0169	1.180	39.02	71.57
4	1.5350	.0378	.0155	1.182	38.69	73.27
5	1.4970	.0287	.0089	1.200	37.50	88.36
6	.7098	.0132	.0062	1.227	42.59	124.50

B.

data

50.0 9.6 0.05 -.12 1.2 0.01 6.0 0.0 0.0

results

PARALLEL COUPLED MICROSTRIP FILTER

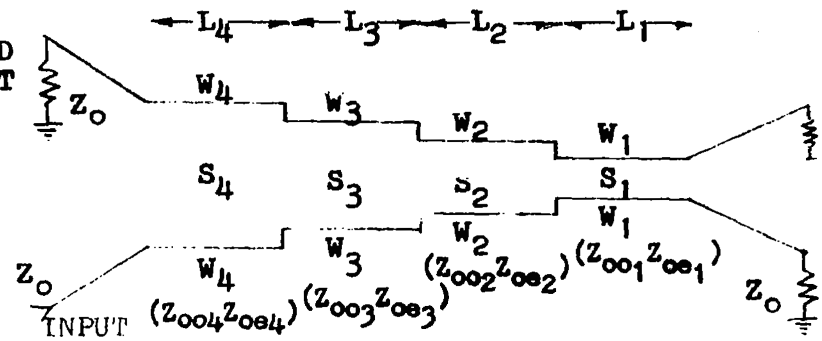
1.200 GHZ CENTER FREQUENCY .120 GHZ BANDWIDTH
.010 DB RIPPLE 6 SECTIONS
.050 INCH SUBSTRATE 9.600 DIELECTRIC CONSTANT
50.0 OHM MICROSTRIP INPUT LINE OF WIDTH .0498 INCHES
.122 GHZ BANDWIDTH DUE TO PRE-COMPENSATION

SEC NUM	ELEMENT VALUE	WIDTH INCHES	GAP INCHES	LENGTH INCHES	ZOO OHMS	ZOE OHMS
0	1.0000	.0320	.0105	.994	37.62	82.74
1	.7814	.0471	.0430	.965	43.48	58.90
2	1.3600	.0487	.0631	.961	45.30	55.80
3	1.6897	.0488	.0667	.961	45.55	55.43
4	1.5350	.0487	.0631	.961	45.30	55.80
5	1.4970	.0471	.0430	.965	43.48	58.90
6	.7098	.0320	.0105	.994	37.62	82.74

3.3 PROGRAM C291 - MICROSTRIP DIRECTIONAL COUPLER

PURPOSE: The program computes the even and odd mode impedances needed to realize an asymmetrical directional coupler and the physical dimensions to realize the impedances in a microstrip format.

STRUCTURE:



INPUT: (Format 7F8.2)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
SECT	1-8		Number of Sections Desired
CPLDB	9-16	DB	Coupling Desired
BANWTH	17-24		Fractional Bandwidth (Bandwidth/FCENTR)
FCENTR	25-32	GHZ	Center Frequency
DIEK	33-40		Substrate Dielectric Constant
HEIGHT	41-48	Inches	Substrate Thickness
ZO	49-56	OHMS	Impedance Level

OUTPUT:

1. The input data.

2. The port input strip width.

3. A table containing:

   a. The even and odd mode impedances of each section.
   b. The width, gap and length for microstrip structure realizing coupler function.

METHOD: The coupler is analyzed by noting that the entire analysis of the performance of the coupler is possible through an analysis of the even mode network. Conversely, the synthesis of the even mode network will completely specify the overall coupled network. Due to the asymmetrical structure of the coupler, the Chebyshev reflection coefficient of the coupler can be directly constructed without any intermediary polynomial root extraction by using the formulas of Levy. The reflection coefficient polynomial is then used to formulate the input impedance polynomial function for the even mode network. The input impedance function is then converted into a transfer matrix representation which is derived by splitting the input impedance polynomial into their even and odd parts. The circuit is then synthesized as a cascade of transmission lines by repeatedly reducing the input impedance matrix by extracting a unit element. The odd mode impedances are then calculated through the use of the equation $Z_{oo}Z_{oe}=1$. An approximate coupled strip synthesis technique is then applied to the even and odd mode impedances to realize the physical dimensions.

LIMITATIONS: The program has provisions for realizing networks of up to 40 sections and bandwidth ratios of up to 10 to 1 over a wide variety of coupling coefficients. The approximate solutions for the coupled strip dimensions are usually good to an average of 4%, but for very tight coupling and high impedance lines the accuracy of the approximation can deteriorate rapidly. The phase response of the asymmetrical coupler in the passband is not as good as that of the symmetrical coupler type.

MISCELLANEOUS:

C291 uses Routines S292, S293, S277, S278, S262 and S259

References: Levy, R., "General Synthesis of Asymmetrical Multi-Element Coupled-Transmission-Line Directional Couplers," IEEE Trans. on Microwave Theory and Techniques, pp. 226-237, July 1963.

Sample Problem:

data

5.0	10.0	~~10.0~~ 4.0	~~4.8~~ 5.0	9.6	0.05	50.0

results

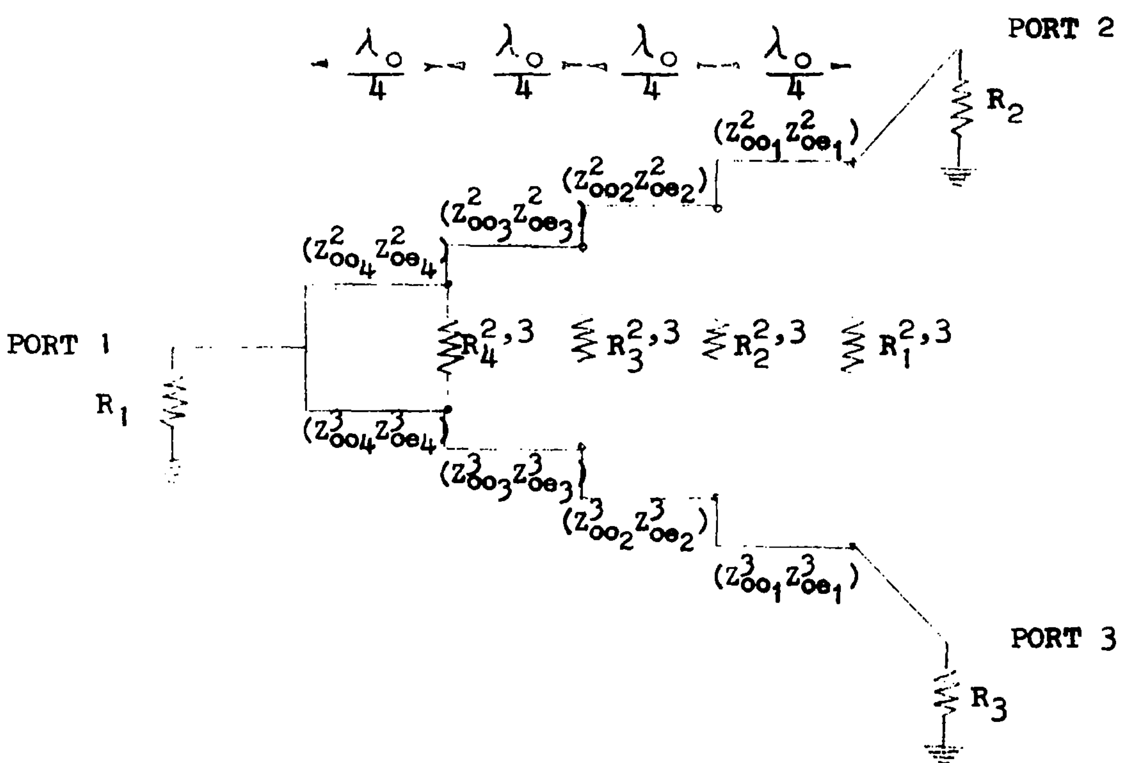
```
          ASYMMETRIC DIRECTIONAL COUPLER

10.000 DB COUPLING                .00 DB RIPPLE
 4.000 GHZ LOWER FREQ         5.000 GHZ UPPER FREQ
   .050 INCHES DIELECTRIC      9.60 DIELECTRIC CONSTANT
 50.000 OHM PORTS             .0498 INCHES WIDE MICROSTRIP
                 5 SECTIONS
```

SECT NUM	ZOEVEN OHMS	ZOODD OHMS	WIDTH INCHES	GAP INCHES	LENGTH INCHES
1	80.19	31.17	.0378	.0051	.267
2	60.57	41.27	.0470	.0524	.260
3	52.90	47.26	.0487	.1861	.258
4	50.53	49.48	.0498	.3204	.257
5	50.05	49.95	.0496	1.1445	.257

3.4 PROGRAM C115 - HYBRID T SYNTHESIS

PURPOSE: The program computes even and odd mode impedances and isolation resistors required to synthesize a matched equiphase power divider consisting of a cascade of coupled transmission lines with intermediate resistors.

STRUCTURE:



INPUT: (Format 9F8.2)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
SECT	1-8		Number of Quarter Wave Sections
PRATIO	9-16		Power Division Ratio R_3/R_2
ZRATIO	17-24		Impedance Ratio Input to Output R_1/R_2
VSWR	25-32		Desired Maximum VSWR at the Input Port
	NEXT CARD		
CF(1)	1-8		Coupling coefficients for each section
CF(2)	9-16		starting with the output and working
thru	thru		backward to the input sections. May
CF(9)	65-72		be zero, used only to compute odd mode impedance from even mode impedance.
	NEXT CARD		
CF(10)	1-8		
thru	thru		
CF(18)	65-72		

OUTPUT:

1. Input data, power and impedance ratio, sections and maximum VSWR.

2. Relative even mode bandwidth.

3. The even and odd mode impedances for each side (Port 2 and Port 3) of each section and the isolation resistance and coupling coefficients between sections, all normalized to the Port 1 resistance.

METHOD: The power splitter is synthesized in a manner similar to the directional coupler. The network is synthesized in three parts: the even mode as an impedance inverter, the odd mode in accordance with the coupling coefficients defined by the user, and the isolation resistors by an optimization technique.

Chebyshev polynomials are used to design the even mode transformer resulting in an explicit expression for the reflection coefficient, which is then realized through the standard techniques of unit element extraction from a transfer matrix of the input impedance.

METHOD: (cont'd.) The odd mode impedances are next evaluated using the coupling coefficients provided and the isolation resistances are calculated by manipulating their values until the zeroes of the even and odd mode reflection coefficient are as identical as is practicable.

LIMITATIONS: The odd mode excitation is not defined in the usual way and, therefore, the mutual capacities are not related to the characteristic impedances in the usual fashion. See the reference article for more details. Since the program uses extensive polynomial manipulations and an optimization routine, problems requiring more than eight sections can take long execution times and at that will s ill not be guaranteed of accurate answers.

MISCELLANEOUS:

C115 uses Routines S118, S116, S117, S120, S121, S122, S123, S125, S119, and S124

References: Ekinge, R.B., "A New Method of Synthesizing Matched Broadband TEM-Mode Three-Ports," IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-19, No. 1, pp. 81-88, January 1971.

Sample Problem:

A.

data

4.0	1.0	1.0	1.1
.055	.129	.214	.284

results

HYBRID T SYNTHESIS

```
POWER DIVISION RATIO (R-PORT3/R-PORT2)  1.000
IMPEDANCE RATIO (R-PORT1/R-PORT2)       1.000
 4 SECTIONS      MAX VSWR AT PORT1      1.100
RELATIVE BANDWIDTH OF EVEN MODE         1.201
```

ALL IMPEDANCES NORMALIZED TO PORT 1

SECT	PORT 2 SIDE		PORT 3 SIDE		ISOLATION	COUPLING
NUM	ZO EVEN	ZO ODD	ZO EVEN	ZO ODD	RESISTOR	COEFFICIENT
1	1.11590	.99955	1.11590	.99955	16.34442	.05500
2	1.29582	.99970	1.29582	.99970	7.01162	.12900
3	1.54342	.99928	1.54342	.99928	3.29854	.21400
4	1.79228	.99943	1.79228	.99943	1.39045	.28400

B.

data

```
3.0      1.7      1.3      1.1

.061     .111     .188
```

results

```
                HYBRID T SYNTHESIS

   POWER DIVISION RATIO (R-PORT3/R-PORT2)   1.700
   IMPEDANCE RATIO (R-PORT1/R-PORT2)        1.300
    3 SECTIONS      MAX VSWR AT PORT1       1.100
   RELATIVE BANDWIDTH OF EVEN MODE           .971

         ALL IMPEDANCES NORMALIZED TO PORT 1
```

SECT NUM	PORT 2 SIDE ZO EVEN	ZO ODD	PORT 3 SIDE ZO EVEN	ZO ODD	ISOLATION RESISTOR	COUPLING COEFFICIENT
1	.88667	.78472	1.50735	1.33402	11.87813	.06100
2	1.10531	.88445	1.87903	1.50357	3.79320	.11100
3	1.37787	.94177	2.34238	1.60102	1.69715	.18800

SECTION IV

DESIGN AIDS

1.0 INTRODUCTION

Component design programs tend to produce very specific devices for very specific requirements, yet not every application has the same requirements. It is useful, therefore, to provide the designer with added capabilities which allow him to characterize or modify his designs and to interface with other components. Three design aids are presented in this section to meet these needs by providing the designer with time delay and phase response of Chebyshev filters, the spurious harmonic levels involved in mixer systems, and a general network analysis and optimization program capable of handling diode models and transmission line elements.

1.1 PROGRAM C100 - CHEBYSHEV RESPONSE

PURPOSE: The program computes the amplitude, phase and time delay response of a Chebyshev bandpass filter at a number of equally spaced frequency points between the center frequency and the upper 3dB band edge.

INPUT: (Format 9F8.2)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
FCENT	1-8	GHZ	Center Frequency of Filter Response.
BANWTH	9-16	GHZ	Bandwidth of Filter.
SECTS	17-24		Number of Chebyshev Sections in the Filter.
RIPPLE	25-32	DB	Ripple Factor in dB.
STEPS	33-40		Number of Frequency Increments to be Printed in Output (less than 100).

OUTPUT:

1. Repetition of input data: FCENTR, BANWTH, SECTS, RIPPLE.
2. Loss in dB, phase in degrees, and delay in nanoseconds, in addition to the frequency at which they occur.

METHOD: The 3dB bandwidth of the filter is computed and then the phase, delay and amplitude are calculated at each frequency.

$$\text{DELAY} = \epsilon^2 \frac{\sum_{m=0}^{n-1} \dfrac{U_{2m}(w)\,\text{Sinh}(2n-2m-1)\phi_2}{\text{Sin}(2m+1)\gamma}}{1 + \epsilon^2 T_n^2(w)}$$

$$\text{PHASE} = \frac{360}{\pi} \sum_{m=0}^{\infty} \frac{\epsilon^{-(2m+1)\phi_2} T_{2m+1}(w)}{(2m+1)\ \text{Sin}(2m+1)\gamma}$$

$$\text{LOSS} = 10.\text{Log}_{10}\left[1 + (\epsilon\, T_n(w))^2\right]$$

METHOD:
(cont'd.)

where $T_n(w)$ is the Chebyshev function

$U_n(w)$ is the Chebyshev function of the second kind

$$\phi_2 = \frac{1}{n} \sinh^{-1} \frac{1}{\epsilon}$$

$$\gamma = \frac{\pi}{2n}$$

n is the number of sections

G is the ripple factor

w is the radian frequency

MISCELLANEOUS:

Program C100 uses Routines S97, F98 and F99

References: Weinberg, L., <u>Network Analysis and Synthesis</u>, McGraw-Hill, 1962, pp. 519-521.

Sample Problem:

data

1.0 0.1 5.0 0.01 20.0

results

CHEBYSHEV FILTER RESPONSE

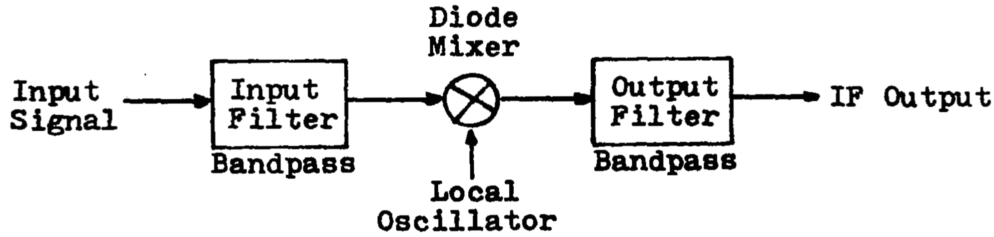
1.000 GHZ CENTER FREQUENCY .100 GHZ BANDWIDTH
5 SECTIONS .010 DB RIPPLE

FREQUENCY GHZ	LOSS DB	PHASE DEGREES	DELAY NANOSEC
1.0000	0.000	-.00	9.072
1.0032	.001	-10.54	9.077
1.0065	.004	-21.10	9.094
1.0097	.007	-31.69	9.128
1.0129	.009	-42.32	9.184
1.0161	.010	-53.04	9.268
1.0194	.008	-63.88	9.384
1.0226	.005	-74.87	9.533
1.0258	.002	-86.05	9.714
1.0291	.000	-97.46	9.926
1.0323	.001	-109.13	10.167
1.0355	.005	-121.10	10.449
1.0387	.009	-133.44	10.799
1.0420	.009	-146.25	11.268
1.0452	.004	-159.71	11.935
1.0484	.001	-174.10	12.900
1.0516	.037	-189.83	14.231
1.0549	.200	-207.30	15.836
1.0581	.645	-226.59	17.245
1.0613	1.553	-246.58	17.624
1.0646	3.010	-262.85	16.481

1.2 PROGRAM C132 - SPURIOUS INTERMODULATION PRODUCTS

PURPOSE: The program computes the input frequencies (and harmonic frequencies) which, when combined with harmonics of the local oscillator, will produce a spurious response in the receiver output or IF network.

STRUCTURE:



INPUT: (Format 7F8.4)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
FCLO	1-8	MHZ	Local Oscillator Frequency
FCIF	9-16	MHZ	IF Center Frequency
BANDIF	17-24	MHZ	Bandwidth of IF Filter
FCIN	25-32	MHZ	Center Frequency of Input Filter
BANDIN	33-40	MHZ	Bandwidth of Input Filter
SECIN	41-48		Number of Sections in Input Filter for Maximum Flat Skirt Selectivity
Next Card			
VBIAS	1-8	Volts	Diode Bias Voltage
RO	9-16	OHMS	Diode Effective Resistance
CLOSS	17-24	DB	Conversion Loss of Receiver Primary Response
ALPHA	25-32	1./Volts	Diode Exponential Voltage Constant
PSIGIN	33-40	DBM	Assumed Input Power Level
VLO	41-48	Volts	Local Oscillator Voltage Amplitude
TESTPW	49-56	DB	Reject All Frequencies Whose Spurious Response is Greater Than TESTPW DB Down From Input

OUTPUT:

1. Repetition of input data.

2. Equivalent diode leakage current (to produce specified conversion loss).

3. A table of input frequency ranges together with their harmonic numbers and the resulting spurious response level in dBM of the worst single frequency.

4. Another table containing basically the same data rearranged in order of power level with respect to the input signal in dB.

METHOD: The range of input frequencies which will produce signals in the pass band of the output can be found by repeatedly solving the following equations for various harmonic numbers, m and n.

$$FCIF - \frac{BANDIF}{2} \leqslant \left| n*F_{IN} + m * FCLO \right| \leqslant FCIF + \frac{BANDIF}{2}$$

The power of the output signal in the IF band is computed as follows for an input signal whose frequency satisfies the equation above and whose amplitude has been reduced by input filtering:

$$\text{Power} = \frac{2}{R_o}\left[\left(I_o \epsilon^{a*VLO} R_o\right) I_m\ (a*VLO)\ I_n\ (a*V_{sig})\right]^2$$

where I_o is calculated from the conversion loss
a = Alpha
I_m and I_n are modified Bessel functions of order m and n

$$V_{sig} = \sqrt{\frac{2\ R_o\ P_{in}}{1+(FIN/FCIN)^{2k}}}$$

k = SECIN

LIMITATIONS: The equations are valid approximately for low level mixing with the input signal at least 10 dB below the local oscillator power.

MISCELLANEOUS:

C132 uses Subroutine S133

Reference: Orloff, L.M., "Intermodulation Analysis of Crystal Mixers," Proc. of the IEEE, February 1964, pp. 173-179.

Sample Problem:

data

450.0	60.0	1.0	840.0	1600.0	1.0	
0.0	126.0	8.0	14.6	-30.0	0.3	100.0

results

RECEIVER SPURIOUS RECEPTION ANALYSIS
FREQUENCY DATA

	INPUT FILTER	OUTPUT FILTER	LOCAL OSCILLATOR
CENTER FREQ.(MHZ)	840.0	60.0	450.0
BANDWIDTH(MHZ)	1600.0	1.0	
SIGNAL STRENGTH	-30.0 DBM		.3000 VOLTS

REJECT SPURIOUS RESPONSES WHICH ARE
OVER 100.0 DB. DOWN

DIODE MIXER DATA
BIASED AT 0.000 VOLTS
LEAKAGE CURRENT = 15.586 MICROAMPS
AVERAGE RESISTANCE = 126.000 OHMS
EXPON. VOLTAGE COEF. = 14.600 1/VOLTS

SPURIOUS RECEPTION FREQUENCIES

NUMBER	M TH HARMONIC (L.O.)	N TH HARMONIC (INPUT)	SPURIOUS-RANGE LOW EDGE (MHZ)	SPURIOUS-RANGE HIGH EDGE (MHZ)	WORST SPUR (MHZ)	MAGNITUDE WORST SPUR (DBM)
1	-1	1	509.5	510.5	510.5	-38.69
2	-1	2	254.8	255.3	255.3	-66.49
3	-1	3	169.8	170.2	170.2	-97.96
4	1	-1	389.5	390.5	390.5	-39.21
5	1	-2	194.8	195.3	195.3	-67.12
6	1	-3	129.8	130.2	130.2	-98.61
7	-2	1	959.5	960.5	959.5	-41.40
8	-2	2	479.8	480.3	480.3	-67.66
9	-2	3	319.8	320.2	320.2	-98.93
10	2	-1	839.5	840.5	840.0	-41.30
11	2	-2	419.8	420.3	420.3	-68.18
12	2	-3	279.8	280.2	280.2	-99.53
13	-3	1	1409.5	1410.5	1409.5	-48.31
14	-3	2	704.8	705.3	705.3	-71.52
15	3	-1	1289.5	1290.5	1289.5	-47.72
16	3	-2	644.8	645.3	645.3	-71.77
17	-4	1	1859.5	1860.5	1859.5	-57.62
18	-4	2	929.8	930.3	929.8	-78.27
19	4	-1	1739.5	1740.5	1739.5	-56.98
20	4	-2	869.8	870.3	869.8	-78.17
21	-5	1	2309.5	2310.5	2309.5	-68.19
22	-5	2	1154.8	1155.3	1154.8	-87.75
23	5	-1	2189.5	2190.5	2189.5	-67.63
24	5	-2	1094.8	1095.3	1094.8	-87.34
25	-6	1	2759.5	2760.5	2759.5	-79.71
26	-6	2	1379.8	1380.3	1379.8	-99.40
27	6	-1	2639.5	2640.5	2639.5	-79.24
28	6	-2	1319.8	1320.3	1319.8	-98.80
29	-7	1	3209.5	3210.5	3209.5	-92.09
30	7	-1	3089.5	3090.5	3089.5	-91.68

SPURIOUS FREQUENCIES
ORDERED BY MAGNITUDE WRT INPUT SIGNAL POWER

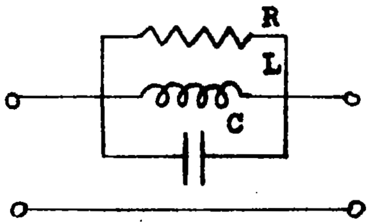
M TH HARMONIC (L.O.)	N TH HARMONIC (INPUT)	SPURIOUS FREQUENCY (MHZ)	MAGNITUDE WRT F-IN (DB)
-1	1	510.5	-8.69
1	-1	390.5	-9.21
2	-1	840.0	-11.30
-2	1	959.5	-11.40
3	-1	1289.5	-17.72
-3	1	1409.5	-18.31
4	-1	1739.5	-26.98
-4	1	1859.5	-27.62
-1	2	255.3	-36.49
1	-2	195.3	-37.12
5	-1	2189.5	-37.63
-2	2	480.3	-37.66
2	-2	420.3	-38.18
-5	1	2309.5	-38.19
-3	2	705.3	-41.52
3	-2	645.3	-41.77
4	-2	869.8	-48.17
-4	2	929.8	-48.27
6	-1	2639.5	-49.24
-6	1	2759.5	-49.71
5	-2	1094.8	-57.34
-5	2	1154.8	-57.75
7	-1	3089.5	-61.68
-7	1	3209.5	-62.09
-1	3	170.2	-67.96
1	-3	130.2	-68.61
6	-2	1319.8	-68.80
-2	3	320.2	-68.93
-6	2	1379.8	-69.40

1.3 PROGRAM C294 - ANALYSIS/OPTIMIZATION

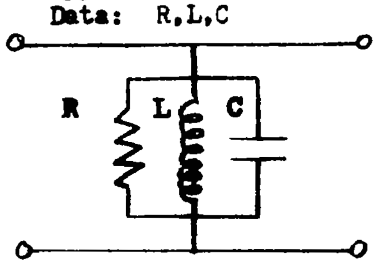
PURPOSE: This program provides for the analysis and optimization of cascaded networks of lumped elements, distributed transmission line elements, and diodes.

STRUCTURE: The program recognizes thirteen distinct element structures and one general purpose user supplied element specified by a user supplied subroutine SUB1. The structures are listed below, together with their required parameters and type identification number in the required order of entry. All dimensions are in pico Farads, nano Henries, Ohms, milli Amperes, and fractional wavelengths referenced to a center frequency in Giga-Hertz. A negative initial value for any parameter value indicates that this parameter is to be varied during optimization (Exception: diode and generator parameters may not be varied).

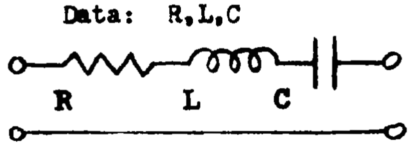
Series Parallel
Type: 1
Data: R,L,C,



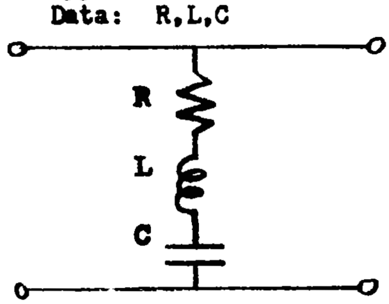
Parallel Parallel
Type: 2
Data: R,L,C



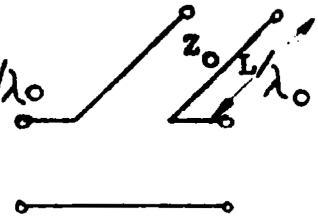
Series Series
Type: 3
Data: R,L,C



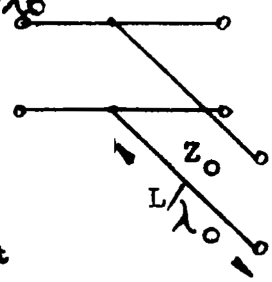
Parallel Series
Type: 4
Data: R,L,C



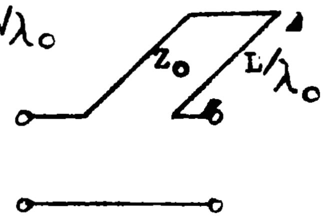
Series Open
Type: 5
Data: $Z_o, L/\lambda_o$



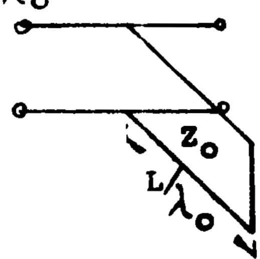
Parallel Open
Type: 6
Data: $Z_o, L/\lambda_o$



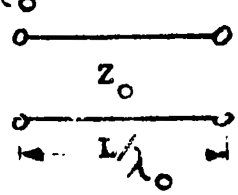
Series Short
Type: 7
Data: $Z_o, L/\lambda_o$



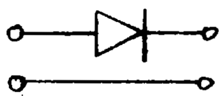
Parallel Short
Type: 8
Data: $Z_o, L/\lambda_o$

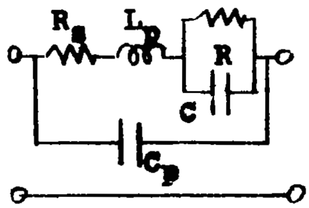


Series Lined
Type: 9
Data: $Z_o, L/\lambda_o$



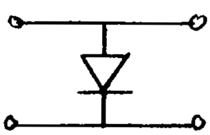
Series Diode
Type: 10
Data: $I, X, K, R_s, L_p, C, C_p$





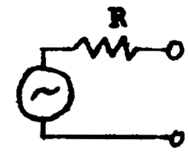
$R = KI^{-X}$

Parallel Diode
Type: 11
Data: $I, X, K, R_s, L_p, C, C_p$

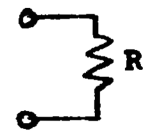


See Model Above

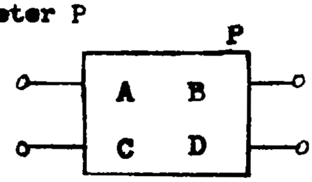
Generator
Type: 12
Data: R



Load
Type: 13
Data: R



User Supplied Element
Type: 14
Data: Parameter P



Subroutine SUB1(A,B,C,D,P,F)

INPUT: (Format 9F8.2)

VARIABLE NAME	CARD COLUMNS	UNITS	DESCRIPTION
	First Card		
TYPE	1-8		First Card Identification Number 15.0
BUFFER(1)	9-16		Function Identification 1.0 Analyze Network 2.0 Optimize Network for VSWR 3.0 Optimize Network for Attenuation 4.0 Optimize Network for Phase
BUFFER(2)	17-24	GHZ	Fractional Wavelength Reference Frequency
BUFFER(3)	25-32	GHZ	Frequency Range Starting Frequency
BUFFER(4)	33-40	GHZ	Frequency Range Last Frequency
BUFFER(5)	41-48	GHZ	Frequency Range Increment Frequency
BUFFER(6)	49-56		Optimization Target Value - if optimization is required. The routine attempts to modify the indicated parameters until the response is uniformly near the target value across the frequency range.
BUFFER(7)	57-64		Absolute Maximum Number of Circuit Modifications to be Allowed.
	Second Card		
TYPE	1-8		Generator Card Identification Number 12.0
BUFFER(1)	9-16	OHMS	Generator Resistance
Rest of Network Cards in Order Corresponding to Network Order			
TYPE	1-8		Network Element Identification Number
BUFFER(1) thru BUFFER(7)	9-16 thru 57-64		Parameter Cards as Required by Network Element
	Last Card		
TYPE	1-8		Load Card Identification Number 13.0
BUFFER(1)	9-16	OHMS	Load Resistance

OUTPUT:

1. Input data is repeated in order input.
2. If the task is optimization the program will display the new values of the parameters which were identified as variables and then initiate an analysis of that network.

OUTPUT: (cont'd.)

3. The VSWR, output power in dB, phase angle in degrees and input impedance of the network under consideration is displayed at each frequency point in the frequency range.

METHOD: The program computes the equivalent transfer matrix representation of each section at each frequency and sequentially multiplies them together to formulate the overall transfer matrix of the network. The insertion loss, phase, VSWR, and input impedance are calculated from this overall transfer matrix.

In the optimization mode, the program optimizes the circuit by repeated network analysis with new circuit values selected by a conjugate gradient pattern search technique. The function to be minimized is the fourth root of the average fourth power of the deviation of the response from the target over the range of frequencies.

When the search technique fails, a limited number of random searches are employed to attempt to avoid local minima.

LIMITATIONS: The analysis program is limited to a maximum of 100 sections, a total of 400 parameters, and a maximum of 50 variable parameters for the optimizations. Actual numeric accuracy is solely dependent on round-off errors in the matrix multiplication. As with virtually all optimization problems, there is practically no guarantee that the minimum found is indeed the global minimum and, therefore, the real criteria to be applied is simply whether the design goals were met.

MISCELLANEOUS:

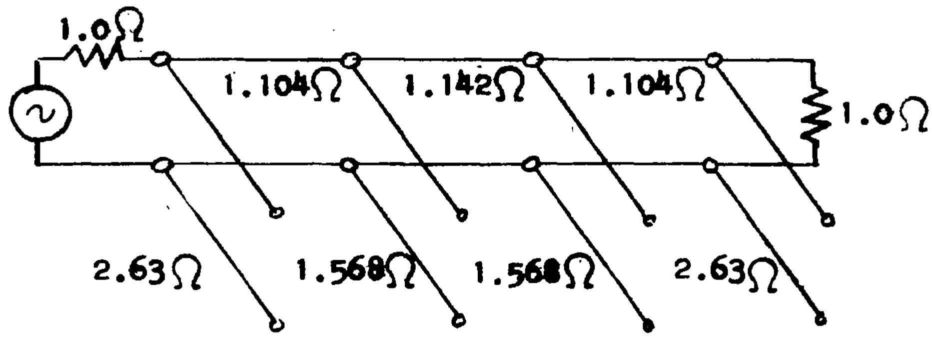
C294 uses Routines S295, S296, S297, S298, S299, F300 and F301

References: Pierre, Donald A., Optimization Theory with Applications, John Wiley & Sons, Inc. New York, 1969, pp. 296-321.

Watson, H.A., Microwave Semiconductor Devices and Their Circuit Applications, McGraw-Hill, 1969, pp. 309-313, 335-339.

Sample Problem:

A.



STOP BAND FILTER EXAMPLE

ALL LENGTHS = $\lambda_o/4$

data

15.0	1.0	1.0	0.3	3.5	0.1	0.0	0.0
12.0	1.0						
6.0	2.63	0.25					
9.0	1.104	0.25					
6.0	1.568	0.25					
9.0	1.142	0.25					
6.0	1.568	0.25					
9.0	1.104	0.25					
6.0	2.63	0.25					
13.0	1.0						

results

MICROWAVE NETWORK ANALYSIS/OPTIMIZATION

INPUT DESCRIPTION OF NETWORK CONFIGURATION

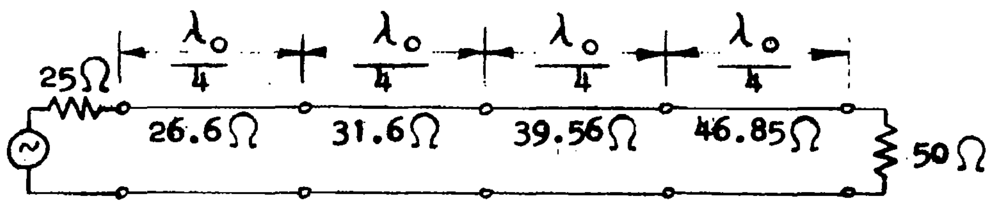
SECT	TYPE	PARAMETERS	
1	12	1.0000	
2	6	2.6300	.2500
3	9	1.1040	.2500
4	6	1.5680	.2500
5	9	1.1420	.2500
6	6	1.5680	.2500
7	9	1.1040	.2500
8	6	2.6300	.2500
9	13	1.0000	

FREQUENCY RESPONSE

FREQUENCY GHZ	VSWR	POWER DB	PHASE DEGREES	IMPEDANCE REAL	IMPEDANCE IMAG
.3000	1.282	.07	109.53	.79	.07
.4000	1.045	.00	149.17	.98	.04
.5000	1.236	.05	-167.52	.94	-.20
.6000	1.356	.10	-118.58	.76	-.11
.7000	1.051	.00	-54.03	1.04	-.03
.8000	1.826	.39	68.49	1.69	.40
.9000	999.000	33.07	-142.72	.00	-.50
1.0000	.000	2378.24	-90.00	0.00	-.00
1.1000	999.000	33.07	-37.28	.00	.50
1.2000	1.826	.39	111.51	1.69	-.40
1.3000	1.051	.00	-125.97	1.04	.03
1.4000	1.356	.10	-61.42	.76	.11
1.5000	1.236	.05	-12.48	.94	.20
1.6000	1.045	.00	30.83	.98	-.04
1.7000	1.282	.07	70.47	.79	-.07
1.8000	1.351	.10	107.56	.75	.07
1.9000	1.219	.04	143.74	.88	.14
2.0000	1.000	0.00	-180.00	1.00	.00
2.1000	1.219	.04	-143.74	.88	-.14
2.2000	1.351	.10	-107.56	.75	-.07
2.3000	1.282	.07	-70.47	.79	.07
2.4000	1.045	.00	-30.83	.98	.04
2.5000	1.236	.05	12.48	.94	-.20
2.6000	1.356	.10	61.42	.76	-.11
2.7000	1.051	.00	125.97	1.04	-.03
2.8000	1.826	.39	-111.51	1.69	.40
2.9000	999.000	33.07	37.28	.00	-.50
3.0000	.000	2378.24	90.00	0.00	-.00
3.1000	999.000	33.07	142.72	.00	.50
3.2000	1.826	.39	-68.49	1.69	-.40
3.3000	1.051	.00	54.03	1.04	.03
3.4000	1.356	.10	118.58	.76	.11
3.5000	1.236	.05	167.52	.94	.20

END OF ANALYSIS

B.



STEPPED IMPEDANCE TRANSFORMER EXAMPLE

CENTER FREQUENCY = 1 GHZ

BANDWIDTH = 0.8 GHZ

Stepped impedance transformer example

C294 Continued

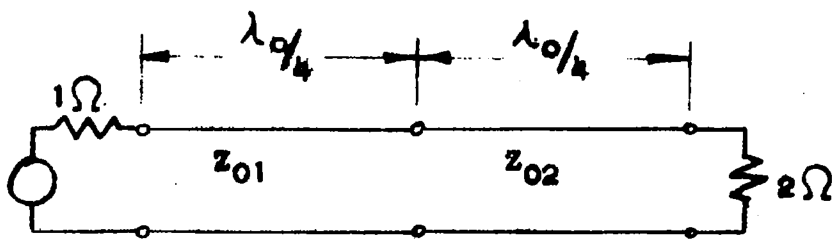
data

```
15.0    1.0     1.0    0.5    1.5    0.1    0.0    0.0
12.0   25.0
 9.0   26.6    0.25
 9.0   31.6    0.25
 9.0   39.56   0.25
 9.0   46.86   0.25
13.0   50.0
```

results

```
MICROWAVE NETWORK ANALYSIS/OPTIMIZATION

INPUT DESCRIPTION OF NETWORK CONFIGURATION

SECT  TYPE        PARAMETERS

 1    12         25.0000
 2     9         26.6000         .2500
 3     9         31.6000         .2500
 4     9         39.5600         .2500
 5     9         46.8600         .2500
 6    13         50.0000


                    FREQUENCY RESPONSE

FREQUENCY      VSWR      POWER      PHASE         IMPEDANCE
  GHZ                     DB       DEGREES      REAL      IMAG

   .5000      1.106      .01      178.89       22.60     -.11
   .6000      1.019      .00     -144.73       24.57      .17
   .7000      1.016      .00     -108.49       25.00     -.39
   .8000      1.013      .00      -72.30       24.80     -.26
   .9000      1.004      .00      -36.15       25.01      .09
  1.0000      1.010      .00         .00       25.25     -.00
  1.1000      1.004      .00       36.15       25.01     -.09
  1.2000      1.013      .00       72.30       24.80      .26
  1.3000      1.016      .00      108.49       25.00      .39
  1.4000      1.019      .00      144.73       24.57     -.17
  1.5000      1.106      .01     -178.89       22.60      .11


END OF ANALYSIS
```

C.



OPTIMIZATION EXAMPLE

STEPPED IMPEDANCE TRANSFORMER

	INITIAL VALUES	FINAL VALUES	
Z_{01}	1.45	1.221	Normalized
Z_{02}	1.55	1.667	
VSWR	1.750	1.096	

Optimization example - Initialized Circuit

C294 Continued

data

15.0	1.0	1.0	0.7	1.3	0.1	0.0	0.0
12.0	1.0						
9.0	1.45	0.25					
9.0	1.55	0.25					
13.0	2.0						

results

MICROWAVE NETWORK ANALYSIS/OPTIMIZATION

INPUT DESCRIPTION OF NETWORK CONFIGURATION

SECT	TYPE	PARAMETERS	
1	12	1.0000	
2	9	1.4500	.2500
3	9	1.5500	.2500
4	13	2.0000	

FREQUENCY RESPONSE

FREQUENCY GHZ	VSWR	POWER DB	PHASE DEGREES	IMPEDANCE REAL	IMAG
.7000	1.374	.11	126.80	1.27	.24
.8000	1.564	.22	144.92	1.45	.30
.9000	1.700	.30	162.60	1.66	.2[illegible]
1.0000	1.750	.34	-180.00	1.75	-.00
1.1000	1.700	.30	-162.60	1.66	-.2[illegible]
1.2000	1.564	.22	-144.92	1.45	-.30
1.3000	1.374	.11	-126.80	1.27	-.24

END OF ANALYSIS

Optimization example - Optimized Circuit

C294 Continued

data

15•0	2•0	1•0	0•7	1•3	0•1	1•03	1000•0
12•0	1•0						
9•0	-1•45	0•25					
9•0	-1•55	0•25					
13•0	2•0						

results

MICROWAVE NETWORK ANALYSIS/OPTIMIZATION

INPUT DESCRIPTION OF NETWORK CONFIGURATION

SECT	TYPE	PARAMETERS	
1	12	1•0000	
2	9	-1•4500	•2500
3	9	-1•5500	•2500
4	13	2•0000	

OPTIMIZED CIRCUIT VALUES

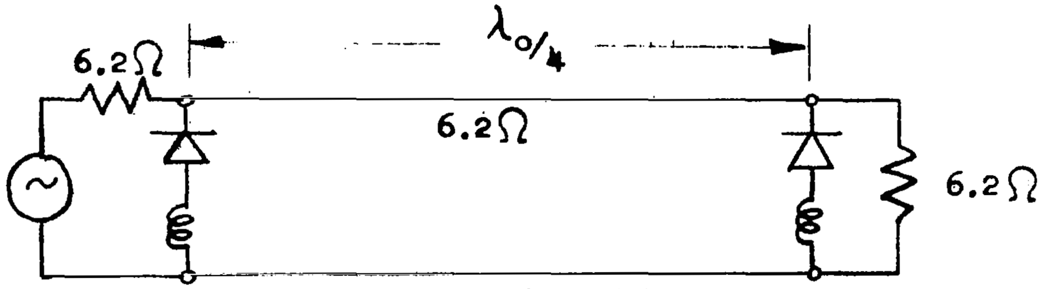
SECT	TYPE	PARAMETERS	
2	9	1•2210	•2500
3	9	1•6674	•2500

FREQUENCY RESPONSE

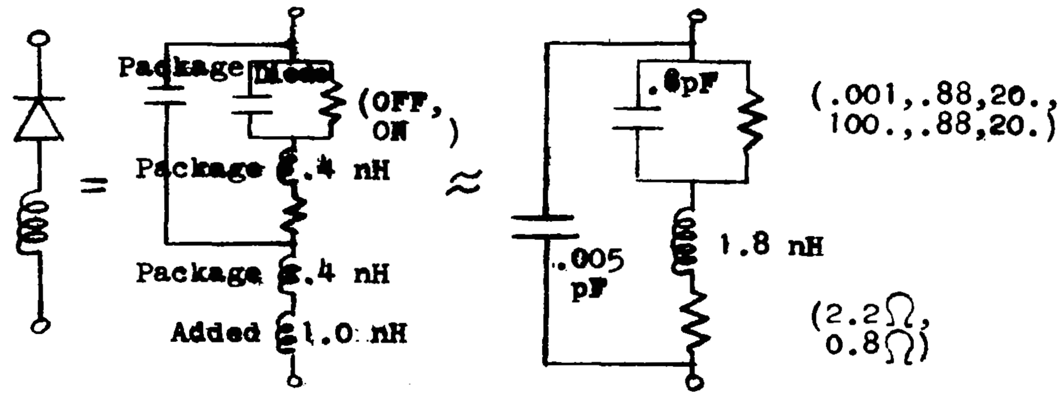
FREQUENCY GHZ	VSWR	POWER DB	PHASE DEGREES	IMPEDANCE REAL	IMAG
•7000	1•096	•01	125•11	•96	-•08
•8000	1•011	•00	143•49	1•00	-•01
•9000	1•053	•00	161•78	1•05	•01
1•0000	1•078	•01	-180•00	1•07	-•00
1•1000	1•053	•00	-161•78	1•05	-•01
1•2000	1•011	•00	-143•49	1•00	•01
1•3000	1•096	•01	-125•11	•96	•0[illegible]

END OF ANALYSIS

D.



INDIVIDUAL PHASE SHIFT SECTION
22½ DEGREES SHIFT
TRANSFORMERS NEEDED TO MATCH DIODE IMPEDANCE LEVELS



DESIRED
IDEAL
ELEMENTS

MODEL

FINAL ANALYSIS
MODEL

Diode phase shifter example - off analysis

C294 Continued

data

15.0	1.0	3.0	2.7	3.3	0.1	0.0	0.0
12.0	6.2						
11.0	.001	0.88	20.0	2.2	1.8	0.8	0.005
9.0	6.2	0.25					
11.0	.001	0.88	20.00	2.2	1.8	0.8	0.005
13.0	6.2						

results

MICROWAVE NETWORK ANALYSIS/OPTIMIZATION

INPUT DESCRIPTION OF NETWORK CONFIGURATION

SECT	TYPE	PARAMETERS			
1	12	6.2000			
2	11	.0010	.8800	20.0000	
		2.2000	1.8000	.8000	.0050
3	9	6.2000	.2500		
4	11	.0010	.8800	20.0000	
		2.2000	1.8000	.8000	.0050
5	13	6.2000			

FREQUENCY RESPONSE

FREQUENCY GHZ	VSWR	POWER DB	PHASE DEGREES	IMPEDANCE REAL	IMAG
2.7000	1.025	.06	89.18	6.05	-.00
2.8000	1.008	.08	92.99	6.15	-.00
2.9000	1.012	.09	96.92	6.27	-.02
3.0000	1.037	.12	101.01	6.42	-.07
3.1000	1.069	.15	105.31	6.59	-.17
3.2000	1.110	.19	109.87	6.79	-.32
3.3000	1.163	.26	114.78	7.02	-.58

END OF ANALYSIS

data

15.0	1.0	3.0	2.7	3.3	0.1	0.0	0.0
12.0	6.2						
11.0	100.0	0.88	20.0	0.8	1.8	0.8	0.005
9.0	6.2	0.25					
11.0	100.0	0.88	20.0	0.8	1.8	0.8	0.005
13.0	6.2						

results

MICROWAVE NETWORK ANALYSIS/OPTIMIZATION

INPUT DESCRIPTION OF NETWORK CONFIGURATION

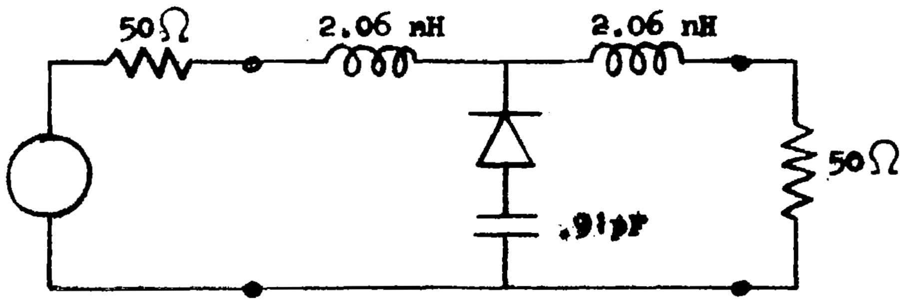
SECT	TYPE	PARAMETERS			
1	12	6.2000			
2	11	100.0000	.8800	20.0000	
		.8000	1.8000	.8000	.0050
3	9	6.2000	.2500		
4	11	100.0000	.8800	20.0000	
		.8000	1.8000	.3000	.0050
5	13	6.2000			

FREQUENCY RESPONSE

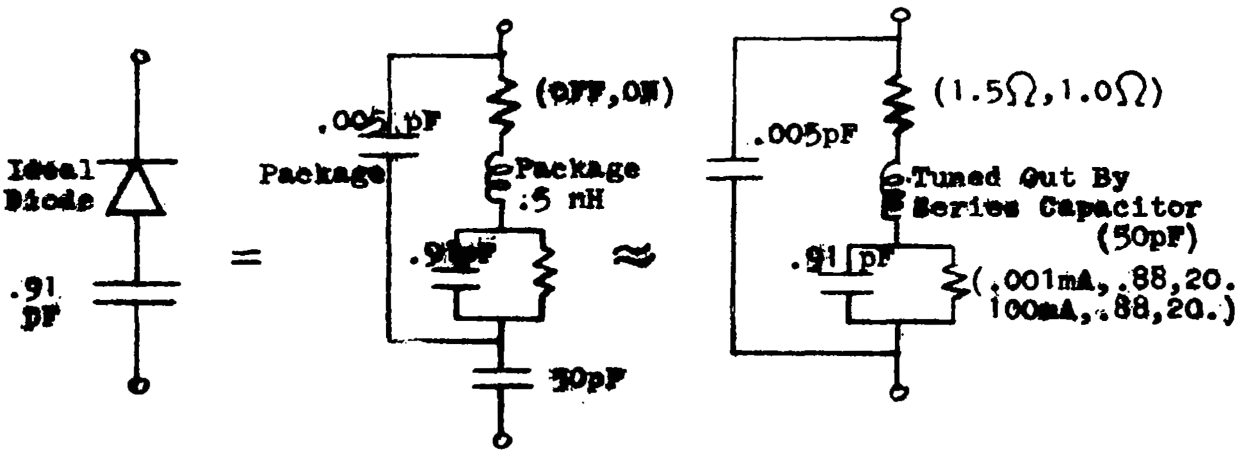
FREQUENCY GHZ	VSWR	POWER DB	PHASE DEGREES	IMPEDANCE REAL	IMAG
2.7000	1.109	.06	69.16	6.81	.27
2.8000	1.081	.05	72.65	6.67	.17
2.9000	1.056	.04	76.10	6.53	.10
3.0000	1.034	.04	79.51	6.40	.05
3.1000	1.013	.04	82.90	6.28	.02
3.2000	1.007	.03	86.26	6.16	.00
3.3000	1.025	.03	89.60	6.05	-.00

END OF ANALYSIS

E.



DIODE ISOLATION SWITCH



DESIRED IDEALIZED ELEMENTS

MODEL
LEAD INDUCTANCE
TUNED OUT BY
ADDED SERIES CAPACITOR
(no effect on .91 pf)

ANALYSIS MODEL

Diode isolator example - off analysis

C294 Continued

<u>data</u>

15.0	1.0	1.0	0.6	2.6	0.1	0.0	0.0
12.0	50.0						
3.0	.000	2.06	1.E+6				
11.0	.001	0.88	20.0	1.5	0.01	0.91	0.005
3.0	.000	2.06	1.E+6				
13.0	50.0						

<u>results</u>

MICROWAVE NETWORK ANALYSIS/OPTIMIZATION

INPUT DESCRIPTION OF NETWORK CONFIGURATION

SECT	TYPE	PARAMETERS			
1	12	50.0000			
2	3	.0000	2.0600	1000000.0000	
3	11	.0010	.8800	20.0000	
		1.5000	.0100	.9100	.0050
4	3	.0000	2.0600	1000000.0000	
5	13	50.0000			

FREQUENCY RESPONSE

FREQUENCY GHZ	VSWR	POWER DB	PHASE DEGREES	IMPEDANCE REAL	IMPEDANCE IMAG
.6000	1.143	.02	13.83	51.14	6.68
.7000	1.167	.03	16.13	51.54	7.69
.8000	1.190	.04	18.42	52.00	8.65
.9000	1.212	.05	20.72	52.52	9.56
1.0000	1.234	.06	23.01	53.09	10.40
1.1000	1.254	.07	25.31	53.71	11.18
1.2000	1.274	.08	27.60	54.37	11.86
1.3000	1.291	.09	29.90	55.06	12.46
1.4000	1.307	.10	32.19	55.78	12.95
1.5000	1.321	.11	34.50	56.52	13.34
1.6000	1.333	.12	36.80	57.27	13.60
1.7000	1.342	.13	39.11	58.00	13.74
1.8000	1.349	.14	41.43	58.72	13.74
1.9000	1.353	.15	43.76	59.38	13.60
2.0000	1.354	.15	46.11	59.99	13.32
2.1000	1.352	.16	48.47	60.51	12.90
2.2000	1.346	.16	50.85	60.91	12.33
2.3000	1.338	.17	53.25	61.18	11.64
2.4000	1.325	.17	55.68	61.29	10.84
2.5000	1.310	.17	58.13	61.21	9.94
2.6000	1.291	.17	60.62	60.93	8.96

END OF ANALYSIS

C294 Continued

data

```
15.0     1.0     1.0     0.6     2.6     0.2     0.0     0.0
12.0    50.0
 3.0     0.0     2.06    1.E+6
11.0   100.0     0.88   20.0     1.0     0.5     0.91    0.05
 3.0     0.0     2.06    1.E+6
13.0    50.0
```

results

MICROWAVE NETWORK ANALYSIS/OPTIMIZATION

INPUT DESCRIPTION OF NETWORK CONFIGURATION

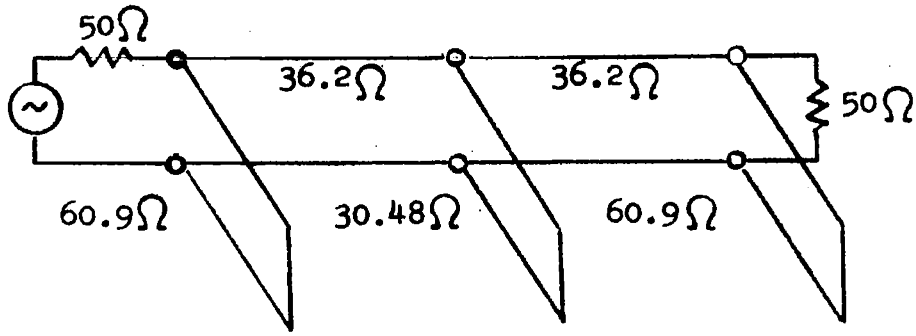
SECT	TYPE	PARAMETERS			
1	12	50.0000			
2	3	.0000	2.0600	1000000.0000	
3	11	100.0000	.8800	20.0000	
		1.0000	.5000	.9100	.0500
4	3	.0000	2.0600	1000000.0000	
5	13	50.0000			

FREQUENCY RESPONSE

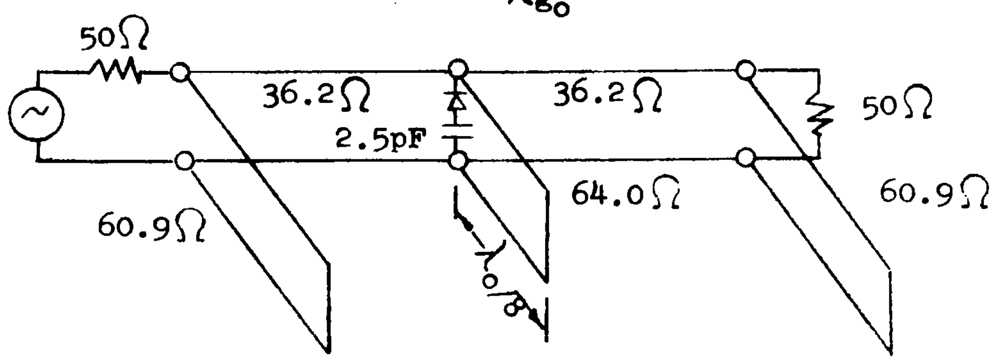
FREQUENCY GHZ	VSWR	POWER DB	PHASE DEGREES	IMPEDANCE REAL	IMPEDANCE IMAG
.6000	50.054	22.03	-40.71	1.04	9.57
.8000	49.495	20.20	-40.11	1.08	12.75
1.0000	48.957	18.77	-37.52	1.12	15.93
1.2000	48.519	17.65	-33.93	1.18	19.09
1.4000	48.241	16.77	-29.87	1.24	22.25
1.6000	48.165	16.08	-25.60	1.31	25.40
1.8000	48.313	15.54	-21.29	1.37	28.54
2.0000	48.698	15.12	-17.04	1.44	31.67
2.2000	49.321	14.81	-12.91	1.51	34.80
2.4000	50.177	14.58	-8.92	1.57	37.92
2.6000	51.260	14.41	-5.11	1.63	41.04

END OF ANALYSIS

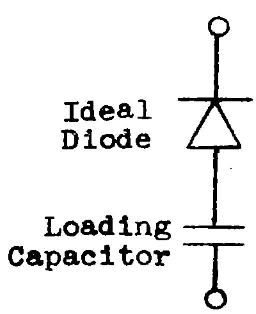
F.



FILTER PROTOTYPE
ALL LENGTHS $\lambda_{g_o}/4$

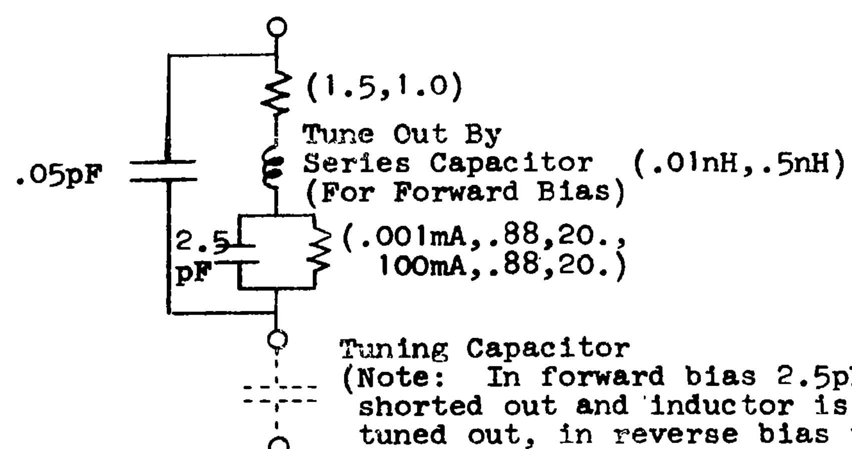


SAME FILTER WITH FISHER CAPACITIVELY
FORESHORTENED STUB
AND DIODE ATTENUATION EXAMPLE



Desired
Ideal
Elements

Use actual diode capacity to realize loading capacity.



Tuning Capacitor
(Note: In forward bias 2.5pF is shorted out and inductor is tuned out, in reverse bias tuning capacitor is negligible due to 2.5pF series capacitor.)

Diode attenuator example - off analysis

data C294 Continued

15.0	1.0	1.0	0.4	1.8	0.1	0.0	0.0
12.0	50.0						
8.0	60.9	0.25					
9.0	36.2	0.25					
11.0	.001	0.88	20.0	1.5	0.01	2.5	0.5
8.0	64.0	0.125					
9.0	36.2	0.25					
8.0	60.9	0.25					
13.0	50.0						

results

MICROWAVE NETWORK ANALYSIS/OPTIMIZATION

INPUT DESCRIPTION OF NETWORK CONFIGURATION

SECT	TYPE	PARAMETERS			
1	12	50.0000			
2	8	60.9000	.2500		
3	9	36.2000	.2500		
4	11	.0010	.8800	20.0000	
		1.5000	.0100	2.5000	.5000
5	8	64.0000	.1250		
6	9	36.2000	.2500		
7	8	60.9000	.2500		
8	13	50.0000			

FREQUENCY RESPONSE

FREQUENCY GHZ	VSWR	POWER DB	PHASE DEGREES	IMPEDANCE REAL	IMPEDANCE IMAG
.4000	23.864	8.14	-30.35	2.78	28.56
.5000	5.799	3.03	3.95	17.84	50.09
.6000	1.535	.23	51.84	66.56	18.59
.7000	1.405	.16	93.10	35.62	.97
.8000	1.730	.36	124.34	30.77	10.22
.9000	1.498	.21	153.04	39.58	14.81
1.0000	1.089	.05	-177.59	50.49	4.23
1.1000	1.262	.11	-148.19	43.86	-9.04
1.2000	1.459	.24	-119.58	35.74	-7.42
1.3000	1.242	.18	-89.56	40.31	-1.11
1.4000	1.448	.34	-53.54	63.04	-16.33
1.5000	3.871	2.12	-12.77	28.72	-51.04
1.6000	11.746	5.75	20.92	6.14	-33.09
1.7000	33.169	9.91	44.22	1.76	-20.52
1.8000	91.707	14.27	61.26	.58	-12.43

END OF ANALYSIS

data

15.0	1.0	1.0	0.4	1.8	0.1	0.0	0.0
12.0	50.0						
8.0	60.9	0.25					
9.0	36.2	0.25					
11.0	100.0	0.88	20.0	1.0	0.5	2.5	0.05
8.0	64.0	0.125					
9.0	36.2	0.25					
8.0	60.9	0.25					
13.0	50.0						

results

MICROWAVE NETWORK ANALYSIS/OPTIMIZATION

INPUT DESCRIPTION OF NETWORK CONFIGURATION

SECT	TYPE	PARAMETERS			
1	12	50.0000			
2	8	60.9000	.2500		
3	9	36.2000	.2500		
4	11	100.0000	.8800	20.0000	
		1.0000	.5000	2.5000	.0500
5	8	64.0000	.1250		
6	9	36.2000	.2500		
7	8	60.9000	.2500		
8	13	50.0000			

FREQUENCY RESPONSE

FREQUENCY GHZ	VSWR	POWER DB	PHASE DEGREES	IMPEDANCE REAL	IMPEDANCE IMAG
.4000	105.663	29.96	-16.60	.53	17.22
.5000	83.794	26.95	-8.38	.73	23.88
.6000	62.805	23.68	4.29	1.15	33.30
.7000	44.844	20.26	22.63	2.17	48.66
.8000	31.628	16.96	48.14	5.68	80.36
.9000	24.092	14.37	81.27	34.35	194.35
1.0000	22.310	13.17	118.94	170.56	-398.81
1.1000	25.833	13.50	154.90	10.66	-105.73
1.2000	33.802	14.78	-175.42	3.47	-58.01
1.3000	44.659	16.30	-152.53	1.77	-38.21
1.4000	56.126	17.65	-134.87	1.15	-26.93
1.5000	65.473	18.61	-120.71	.88	-19.31
1.6000	69.699	19.08	-108.67	.77	-13.52
1.7000	65.349	18.89	-97.50	.79	-8.67
1.8000	47.408	17.51	-85.05	1.06	-4.10

END OF ANALYSIS

SECTION V

MULTIPLIER DESIGN

1.0 INTRODUCTION

The design of a microwave frequency tripler provides an opportunity to illustrate how the various techniques and design programs previously mentioned can be applied to a given task. A microstrip tripler is to be designed to translate a 1.73 GHz signal into a 5.2 GHz signal capable of a minimum of 1 watt of output power. The approach will be to use the basic outline for Varactor Multiplier Design as given by C. B. Burckhardt* and as augmented by the synthesis programs C270 and C276 and the analysis program C294.

The network will consist of an input filter and impedance transformer, followed by a shunt diode, followed by an output transformer, a 2nd harmonic idler, and an output bandpass filter. The output filter will be a parallel coupled microstrip bandpass filter which will provide the output D.C. bias block and the input low pass filter will serve as an impedance transformer in order to form a more compact design.

2.0 DIODE CHARACTERISTICS

The GC-3305 diode from GHz, Inc. was selected for this application based on its high cutoff frequency and breakdown voltage characteristics. The design will be based on a shunt in-line diode mounting in which the published parasitic diode package capacity and inductance are assumed to be the dominant packaging effects.

Typical diode parameters for this application are:

Junction Capacity	C_j @ -6V = 1.5 pF
Breakdown Voltage	V_{BR} = 100V
Cutoff Frequency	f_c @ -6V = 140 GHz
Package Inductance	.4nH

*Burckhardt, C.B., "Analysis of Varactor Frequency Multipliers for Arbitrary Capacitance Variation and Drive Level," Bell System Technical Journal, pp. 675-692, April 1965.

2.0 DIODE CHARACTERISTICS (continued)

Package Inductance	.15 pF
Thermal Resistance	15°C/watt

3.0 DIODE ANALYSIS

Using the tables printed in Burckhardt the significant design parameters of the tripler can be calculated under the assumption of a 1.5 drive level and a step recovery diode:

P_{max} = 12.5 Watts
R_{in} = 9 ohms
R_{load} = 4.26 ohms
ϵ = 77% efficiency
C_1 = 1.88 pF @ fo
C_2 = 2.78 pF @ 2fo
C_3 = 2.08 pF @ 3fo
P_{out} = 4.36 Watts
V_o = -32.3 Volts

The next step is to calculate the effective diode impedance at each of the harmonics by evaluating the diode model together with its packaging effects:

DIODE IMPEDANCE (including parasitics)

	1st Harmonic	2nd Harmonic	3rd Harmonic
R_j	7.845	6.18	4.18 Ohms
C_j	2.24	6.02	17.04 pF

4.0 OUTPUT CIRCUIT

The third harmonic output circuit is composed of a quarter wavelength transformer followed by a 3 section bandpass filter. The transformer has a characteristic impedance of $\sqrt{50*4.2}$ = 14.2 Ohms to match the diode impedance of 4.18 Ohms to an output impedance of 50 Ohms.

Using Table I, provided by Program C270, the strip width of the transformer is .334 inches and the total length would be .202 inches, based on a wavelength at the 3rd harmonic of .807 inches. The output filter was synthesized by Program C276 and the data is listed in Table II.

TABLE I
Table Computed by Program C270

ZO (OHMS)	WIDTH (INCHES)	DIELECTRIC (EFFECTIVE)
8.00	.6553	8.42
8.50	.6117	8.37
9.00	.5730	8.32
9.50	.5384	8.28
10.00	.5068	8.23
10.50	.4792	8.19
11.00	.4537	8.15
11.50	.4304	8.10
12.00	.4089	8.06
12.50	.3897	8.02
13.00	.3717	7.98
13.50	.3550	7.95
14.00	.3396	7.91
14.50	.3252	7.87
15.00	.3118	7.84
15.50	.2993	7.80
16.00	.2876	7.77
16.50	.2767	7.73
17.00	.2663	7.70
17.50	.2566	7.67
18.00	.2475	7.64
18.50	.2368	7.61
19.00	.2307	7.58
19.50	.2229	7.55
20.00	.2156	7.52

TABLE II

PARALLEL COUPLED MICROSTRIP FILTER

5.200 GHZ CENTER FREQUENCY .600 GHZ BANDWIDTH
.050 DB RIPPLE 3 SECTIONS
.050 INCH SUBSTRATE 9.600 DIELECTRIC CONSTANT
50.0 OHM MICROSTRIP INPUT LINE OF WIDTH .0498 INCHES
.610 GHZ BANDWIDTH DUE TO PRE-COMPENSATION

SEC NUM	ELEMENT VALUE	WIDTH INCHES	GAP INCHES	LENGTH INCHES	ZOO OHMS	ZOE OHMS
0	1.0000	.0316	.0103	.226	37.59	83.36
1	.8794	.0456	.0349	.217	42.42	61.05
2	1.1132	.0456	.0349	.217	42.42	61.05
3	.8794	.0316	.0103	.226	37.59	83.36

5.0 IDLER CIRCUIT

A quarter wavelength open circuited stub is to be used as an idler circuit. In order to optimize the performance of the idler, the stub will be attached to the transformer line at the point at which the 2nd harmonic diode capacitance is tuned out.

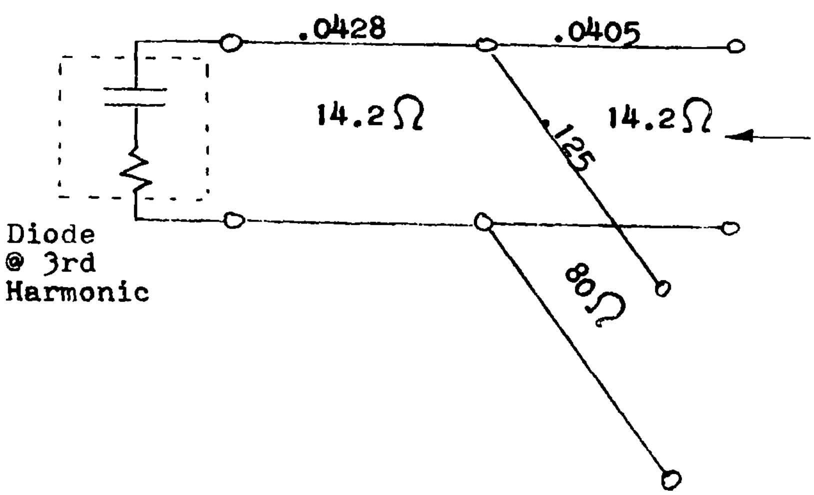
The inductance required to tune out the diode capacity at the 2nd harmonic is .351 nH. A short length of the transformer line will approximately provide this inductance.

$$W_2 L_2 = Z_0 \, 2\pi \, l/\lambda_2$$

Hence, the stub is attached at .1038 inches away from the diode.

The stub itself is to be an 80 ohm line which, on consulting the table on page 20, becomes a line of width .0153 inches and of length .348 inches.

The output circuit can now be analyzed by using the network analysis capabilities of Program C294 to determine if the idler circuit significantly loads the 3rd harmonic output filter.



The results of the analysis appear in Table III and it is clear that the passband has shifted to a higher frequency. Hence, the optimization capabilities of Program C294 were utilized to shift the passband back to 5.2 GHz by adjusting the output arm of the transformer strip to a new length, .1176 inches. The results of this optimization appear in Table IV.

TABLE III

MICROWAVE NETWORK ANALYSIS/OPTIMIZATION

INPUT DESCRIPTION OF NETWORK CONFIGURATION

SECT	TYPE	PARAMETERS		
1	12	50.0000		
2	9	14.2000	.0405	
3	6	80.0000	.1250	
4	9	14.2000	.0428	
5	3	.0000	0.0000	17.0400
6	13	4.1800		

FREQUENCY RESPONSE

FREQUENCY GHZ	VSWR	POWER DB	PHASE DEGREES	IMPEDANCE REAL	IMPEDANCE IMAG
4.5000	4.436	2.22	44.99	14.03	23.95
4.6000	3.960	1.91	48.32	16.09	25.09
4.7000	3.535	1.63	51.69	18.46	26.14
4.8000	3.154	1.36	55.14	21.21	27.05
4.9000	2.812	1.11	58.67	24.39	27.72
5.0000	2.505	.88	62.28	28.04	28.02
5.1000	2.228	.68	65.99	32.15	27.74
5.2000	1.981	.50	69.78	36.65	26.67
5.3000	1.759	.34	73.66	41.36	24.56
5.4000	1.562	.21	77.59	45.97	21.19
5.5000	1.389	.12	81.58	50.01	16.49

TABLE IV

OPTIMIZED CIRCUIT VALUES

SECT	TYPE	PARAMETERS	
2	9	14.2000	.0495

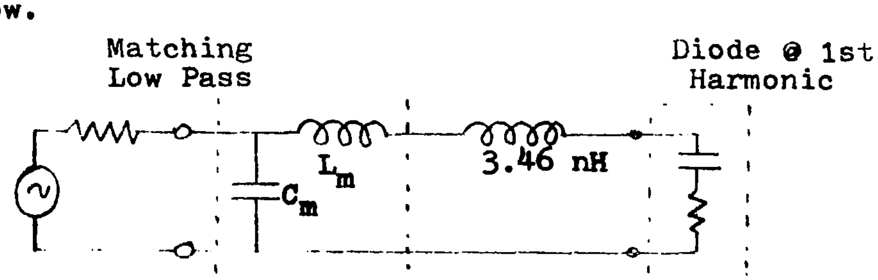
FREQUENCY RESPONSE

FREQUENCY GHZ	VSWR	POWER DB	PHASE DEGREES	IMPEDANCE REAL	IMPEDANCE IMAG
5.0000	1.489	.17	79.56	51.28	20.26
5.1000	1.316	.08	84.11	55.46	13.45
5.2000	1.189	.03	88.65	57.55	5.39
5.3000	1.155	.02	93.15	57.14	-2.92
5.4000	1.242	.05	97.58	54.43	-10.42
5.5000	1.385	.11	101.90	50.09	-16.39

6.0 INPUT CIRCUIT

At the input frequency, the output network and idler do not appreciably load the diode and the input circuit may be designed assuming the diode as its only load.

The first step is to add a short length of line to bring the input impedance to a real value. An inductor equal to 3.46 nH will suffice. The next step is to add a simple two-element low pass impedance transformer to provide input filtering and impedance matching as shown below.



$$L_m = \frac{\sqrt{9 \times 50}}{\omega_o} = 1.96 \text{ nH}$$

$$C_m = \frac{1}{\omega_o \sqrt{9 \times 50}} = 4.34 \text{ pF}$$

Having computed the two-element values L_m and C_m the two inductors may be combined into one 5.42 nH inductor and the resulting L-C combination realized as two short lengths of transmission line. The capacitive line should be low impedance and 10 ohms was selected. From Table I, the strip width is found to be .5068 inches and the relative dielectric constant is 8.23. Conversely, the inductive line should have high impedance and for a 90 ohm line the table in the example for Program C270 in Section II shows a strip width of .0104 inches and a relative dielectric constant of 5.91.

The approximate formulas for the inductive and capacitive effects of short line lengths are shown below:

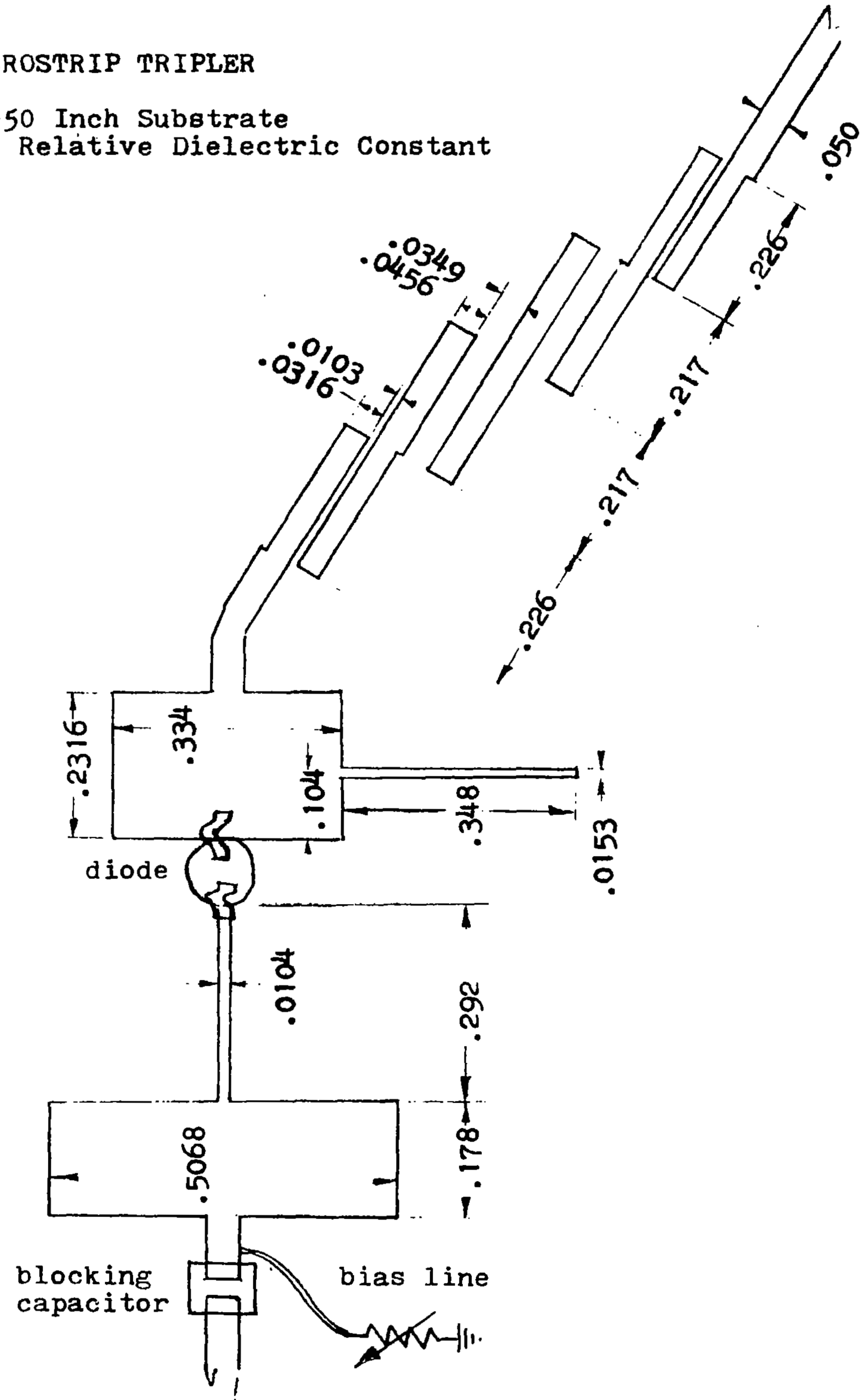
$$\omega_o C = Y_o \quad 2\pi(1/\lambda_{g_o})$$

$$\omega_o L = Z_o \quad 2\pi(1/\lambda_{g_o})$$

Evaluating these expressions, the length of the capacitive line is .178 inches and the inductive line is .292 inches.

7.0 MICROSTRIP TRIPLER

0.050 Inch Substrate
9.6 Relative Dielectric Constant



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APPENDIX

List of Computer Programs and Subprograms

NUMBER	NAME	DESCRIPTION
S73	SIMQ	Finds solution of simultaneous equations by the Gauss pivotal method.
S92	ELMENT	Computes normalized element values for Chebyshev and Butterworth low pass prototype filters.
S96	NSECTN	Computes number of Chebyshev or Butterworth filter sections required to maintain a specified attenuation.
S97	CBRESP	Computes amplitude, phase, and time-delay response of Chebyshev filter between half power frequencies.
F98	CBAMP	Computes Chebyshev filter amplitude response.
F99	CBPHAS	Computes Chebyshev filter phase response.
C100	MAIN RESPONSE	Computes the amplitude, phase, and time-delay response of a Chebyshev bandpass filter at a number of equally spaced frequency points between the center frequency and the upper 3dB edge.
S105	BSTOP	Computes admittances for bandstop filter by exact synthesis method.
S106	DPOLRT	Finds the double precision roots of a polynomial function.
S107	PMPY	Multiplies two double precision polynomials together.
S108	DTAN	Computes double precision tangent value.
C115	MAIN SPLITTER	Computes the even and odd mode impedances and isolation resistors to realize a matched equiphase power divider with coupled lines and intermediate resistors.

NUMBER	NAME	DESCRIPTION
S116	CONGA	Determines values of isolation resistors by conjugate gradient search.
S117	FUNCT	Evaluates figure of merit for optimizing routine by computing a measure of how nearly the coefficients of two numerator polynomials match.
S118	CPMPY	Multiplies two polynomials with complex coefficients together.
S119	PSUB	Subtracts one polynomial from another.
S120	FMCG	Finds the minimum value of a nonlinear junction of several variables by conjugate gradient and pattern search techniques.
S121	DPRQD	Calculates the real and imaginary roots of a given polynomial with real coefficients by the Quotient Difference method.
S122	POLRT	Finds the roots of a polynomial.
S123	PVAL	Evaluates a polynomial at a given argument.
S124	PDER	Finds the derivative polynomial of a polynomial.
S125	SPMPY	Multiplies two polynomials together.
C132	MAIN SPURS	Finds the input frequencies (and harmonic frequencies) which, when mixed with the harmonics of a local oscillator, will produce a spurious output response.
S133	BESSLI	Computes values of the modified Bessel function $I_n(x)$ by backward recursion.
S259	MSTRIP	Computes the width (inches) of a microstrip line for a given impedance level, dielectric constant, and substrate height.
C260	MAIN BANDSTOP	Computes the series and shunt microstrip quarter-wave transmission line impedances as well as the length and width dimensions necessary to realize an optimum bandstop filter.

NUMBER	NAME	DESCRIPTION
C261	MAIN LOW PASS	Computes the lengths and widths for a series of cascaded high and low impedance microstrip lines to realize a lumped equivalent low pass filter.
S262	ZSTRIP	Computes the characteristic impedance of a single microstrip line for a given height, width, and dielectric constant.
S264	QSF	Computes the integral of a function specified by a table of values by modified Simpson integration.
S265	SICI	Computes the values of the modified sine and cosine integrals.
S266	MINI	Computes the dielectric Green's function for the case of coupled microstrip lines.
C267	MAIN MICROSTRIP	Computes the capacity, characteristic impedance, phase velocity and effective relative dielectric constant for coupled or single strip microstrip lines.
C270	MAIN STRIP SYNTHESIS	Computes tables of microstrip widths and effective dielectric constant for a range of impedances.
C276	MAIN PARALLEL	Computes the even and odd mode impedances and dimensions of a parallel coupled microstrip bandpass filter.
S277	CPLMS	Computes width and spacing dimensions required to synthesize a specified pair of even and odd mode impedances.
S278	INVCPL	Finds the width and gap dimensions required to synthesize a pair of coupled microstrip lines with a given coupling coefficient.
C279	MAIN ENDGAP	Computes the gap susceptances and filter dimensions needed to realize an end coupled bandpass filter.
S280	SYNTH	Finds spacing required to realize a given gap susceptance.
C283	MAIN HYBRID RING	Displays the physical dimensions of a microstrip hybrid ring.

NUMBER	NAME	DESCRIPTION
S284	RING	Computes the physical dimensions of a micro-strip hybrid ring.
C288	MAIN CIRCULATOR	Computes the dimensions of a microstrip ferrite circulator, together with matching transformers and magnetic fields strength.
C289	MAIN TRANSFORMER	Computes the impedances and widths of micro-strip quarter wave lines needed to transform from one impedance level to another over a band of frequencies, including the effects of junction discontinuities.
C290	MAIN HIGH PASS	Computes the lumped capacitances and shunt inductances needed to realize a high pass filter and converts the inductors into equal length shorted stubs of varying impedances.
C291	MAIN COUPLER	Computes the even and odd mode impedances needed to realize an asymmetrical directional coupler and the microstrip dimensions of the resulting structure.
S292	RROOTS	Computes the quadratic root factors for a Chebyshev reflection coefficient magnitude function.
S293	POLMPY	Reconstructs a reflection coefficient poly-nomial by multiplication of quadratic root factors.
C294	MAIN OPTANAL	Analyzes and optimizes cascaded networks of lumped elements, distributed transmission lines, and diodes displaying the network's insertion loss, phase, VSWR, and input impedance as a function of frequency.
S295	EVAL	Computes the figure of merit used to deter-mine the quality of a network design for optimization purposes.
S296	GRDNT	Computes the gradient of the figure of Merit function in order to point to a better net-work design.
S297	RESPON	Computes the insertion loss, phase, input impedance, and VSWR of the given network configuration at a particular frequency.

NUMBER	NAME	DESCRIPTION
S298	SUB1	Establishes dummy routine to be replaced by user supplied routine, to allow the user to include network elements of any type in the program.
S299	OPT	Varies selected network parameters until network response agrees with desired response or until no further movement toward better agreement is available.
F300	TTAN	Computes the tangent of any angle including multiples of 90 degrees without error.
F301	RANF	Computes random numbers in the range 0.0 to 1.0 (uniformly distributed). This routine calls a built-in function called RANDOM and a substitute routine should be called if RANDOM is not available.

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