APPLICATION NOTE 1

NARROW BAND MICROWAVE BANDPASS FILTER

1. Introduction

The major objection to using exact synthesis methods for the design of microwave (commensurate line length) filters is the difficulty of obtaining realizable component values using this method. The problem stems from the fact that practically all realizable microwave components must have impe- dances that fall into a much narrower range than in any other realization method.

This application note proves the fallacy of this objection. The many degrees of freedom inherent in nearly all filter synthesis methods, coupled with the large number of manipulation methods built into S/FILSYN and a few tricks of the trade, enable us to design *any* feasible filter, while keeping element values in a narrow, realizable range.

2. Problem Specification

We select a narrow band (2% bandwidth) bandpass example, which is the kind likely to cause difficulties. We center the band at 1 GHz which is also going to be the quarter-wave frequency. The specification calls for a 0.05 dB passband ripple (a maximum VSWR of 1.25) and a 35 dB suppression about 3% away from the band-center.

This filter is to be realized in an edge-coupled stripline form, shown below in Fig. AN1.1.

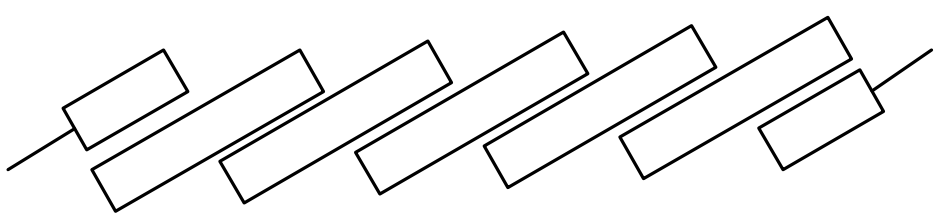

Fig. AN1.1 Physical structure of edge-coupled stripline filter

One pair of coupled lines has an electrical equivalent (see ref. [53]) shown below in Fig. AN1.2

Therefore the electrical design must contain series open stubs separated by unit elements. Because all the series open stubs cab be combined into a single series stub by the repeated use of the ap- propriate Kuroda's identity, the design must contain a single series open stub and as many unit elements as needed to meet the stopband rejection requirement.

Please note that on the personal computer we have a batch file, called EMC.BAT, that performs all of these steps completely automatically. The reason for this application note is to enable our users, who run the program on mainframe or workstation systems, to perform this type of design.

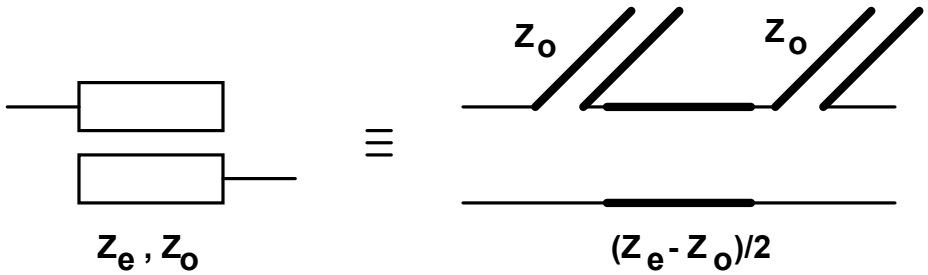

Fig. AN1.2 Electrical equivalent of coupled line pair

3. Electrical Design

The design is started as a highpass, because in terms of the Richard's transformation, the quarter-wave frequency corresponds to infinite frequency in the transformed frequency variable. The series open stub represents a single transmission zero at zero frequency, and there are no finite transmission zeros; therefore the only variable parameter is the number of unit elements. A previous run has already indicated that 3 unit elements will suffice to meet the stopband requirements, hence the session with S/FILSYN starts as shown:

```
C:\>sfilsyn
         ***** S/FILSYN *****
    RELEASE 3.2  VERSION 1  4/1/94

          ** ROOT SEGMENT **

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            All Rights Reserved.

READ DATA FROM FILE: Y/N
>  n
SMAIN: S, PLACER: P OR END: E
>  s
ENTER TITLE
>  microwave demonstration example
FILTER KIND - LUMPED: 0, DIGITAL: 1 OR MICROWAVE: 2
>  2
ENTER QUARTER WAVE FREQUENCY IN HZ
>  1GHz
FILTER TYPE - LOWPASS: 1, HIGHPASS: 2 OR BANDPASS: 4
>  2
LOWER EDGE OF THE PASSBAND IN HZ
>  9.9e8
PASSBAND - MAX.-FLAT: 0, EQUAL-RIPPLE: 1, FUNCTIONAL INPUT: 2
>  1
WHAT IS THE BAND EDGE LOSS IN DB
>  0.05
STOPBAND - MONOTONIC: 0, EQUAL-MINIMA: 1 OR SPECIFIED: 2
>  2
ENTER NO. OF UNIT ELEMENTS
IF IMPEDANCE MATCHING, ENTER -1
>  3
ENTER MULTIPLICITY OF TRANSMISSION ZERO AT ZERO
>  1
```

```
ENTER NO. OF FINITE TRANSMISSION ZEROS
>  0
ENTER INPUT TERMINATION IN OHMS
>  50
ENTER OUTPUT TERMINATION (0. INDICATES OPEN OR SHORT)
>  50
```

The summary printout does not contain anything new. We proceed to the synthesis and select the computer-generated configuration, because the structure is unique:

```
LATTICE: L, COMPUTER CONFIG.: C, INPUT SIDE: IN, OUTPUT SIDE: OUT OR END: END
>  c
WISH TO SEE INTERMEDIATE RESULTS: Y/N
>  n
** EVEN NUMBERED BRANCHES ARE SERIES, ODD ONES SHUNT **

microwave demonstration example

**** ALL VALUES ARE IMPEDANCES ****

   1   ├──R──┤       50.000000  ohm
       |       |
       *       *
   3   *  U E  *        3.052131 kohm
       *       *
       |       |
       *       *
   5   *  U E  *       15.382185 Mohm
       *       *
       |       |
       *       *
   7   *  U E  *      129.988090 Gohm
       *       *
       |       |
  10   |       C      655.038728 Tohm
       |       |
  11   ├──R──┤       10.732970 Tohm
       |       |
```

These values are clearly unacceptable, but several methods are available to improve this, including the use of partial Kuroda's identities (splitting the series open stub into two and shifting one of these over to the other side of the adjacent unit element), and inserting additional unit elements at either or both ends of the structure.

Both of these steps will be employed, but first we make the circuit symmetrical by using the TR (impedance transform) command, requesting 50 ohms output termination. The program performs a full and a partial Kuroda's identity transformation automatically, yielding the circuit:

```
COMMAND:
>  tr 50.
ENTER SERIAL NO.'S OF BRANCHES TO BE USED
ENTER TWO ZEROS FOR COMPUTER SELECTION
>  0 0
LARGEST TRANSFORMATION RATIO:   3.9364145D-08
TRANSFORMATION RATIO USED:      3.9364145D-08
   8   |       C      129.962300 Gohm
       |       |
       *       *
  11   *  U E  *       25.790156 Mohm
       *       *
       |       |
  15   ├──R──┤       422.494204 kohm
```

```
        |       |
LARGEST TRANSFORMATION RATIO:   1.4005496D-08
TRANSFORMATION RATIO USED:      1.1834482D-04
   6    |       C       15.214848 Mohm
        |       |
        *       *
   9    *  U E  *      167.337263 kohm
        *       *
        |       |
  14    |       C       15.214848 Mohm
        |       |
        *       *
  17    *  U E  *        3.052131 kohm
        *       *
        |       |
  21    |---R---|       50.000000  ohm
        |       |

COMMAND:
>  pri
microwave demonstration example

**** ALL VALUES ARE IMPEDANCES ****

   1    |---R---|       50.000000  ohm
        |       |
        *       *
   3    *  U E  *        3.052131 kohm
        *       *
        |       |
   6    |       C       15.214848 Mohm
        |       |
        *       *
   9    *  U E  *      167.337263 kohm
        *       *
        |       |
  14    |       C       15.214848 Mohm
        |       |
        *       *
  17    *  U E  *        3.052131 kohm
        *       *
        |       |
  21    |---R---|       50.000000  ohm
        |       |
```

As we can see, the circuit became completely symmetrical, but this is just an accident, related to the fact that we have exactly three unit elements. In any case, this symmetry is not important.

We insert a 50 ohm unit element next at each end of the circuit, which will not change the loss, it will only add to the phase. Next, the dual of the circuit is requested because the ECM command we will use works only with shorted shunt stubs, rather than open series stubs. At the end of the design, we shall restore the circuit to its original form. Finally, we shift the two stubs to one end of the circuit and combine them into a single stub. This is necessary to prepare for the ECM command.

```
COMMAND:
>  ins 2 ue 50.
        *       *
   4    *  U E  *       50.000000  ohm
        *       *
        |       |
        *       *
   7    *  U E  *        3.052131 kohm
```

```
        *       *
        |       |
  10    |       C       15.214848 Mohm
        |       |
        *       *
  13    *  U E  *      167.337263 kohm
        *       *
        |       |
  18    |       C       15.214848 Mohm
        |       |
        *       *
  21    *  U E  *        3.052131 kohm
        *       *
        |       |
  25    |---R---|       50.000000  ohm
        |       |

COMMAND:
>  ins 22 ue 50.
        *       *
  24    *  U E  *       50.000000  ohm
        *       *
        |       |
  27    |---R---|       50.000000  ohm
        |       |

COMMAND:
>  dual
microwave demonstration example

**** ALL VALUES ARE IMPEDANCES ****

   1    |---R---|       50.000000  ohm
        |       |
        *       *
   5    *  U E  *       50.000000  ohm
        *       *
        |       |
        *       *
   8    *  U E  *      819.099735 mohm
        *       *
        |       |
  11    |---L---|      164.313176 uohm
        |       |
        *       *
  14    *  U E  *       14.939888 mohm
        *       *
        |       |
  19    |---L---|      164.313176 uohm
        |       |
        *       *
  22    *  U E  *      819.099735 mohm
        *       *
        |       |
        *       *
  25    *  U E  *       50.000000  ohm
        *       *
        |       |
  27    |---R---|       50.000000  ohm
        |       |

COMMAND:
>  ib 14 19
  13    |---L---|       15.104201 mohm
        |       |
        *       *
  16    *  U E  *        1.373323  ohm
        *       *
```

```
        |       |
        *       *
   24   *  U E  *        6.921298 kohm
        *       *
        |       |
        *       *
   27   *  U E  *      422.494204 kohm
        *       *
        |       |
   29   |---R---|      422.494204 kohm
        |       |
```

A few more steps like these and the final circuit before the ECM step is as shown below:

```
microwave demonstration example

**** ALL VALUES ARE IMPEDANCES ****

    1   |---R---|       50.000000  ohm
        |       |
    3   |---L---|       50.819262  ohm
        |       |
        *       *
    5   *  U E  *        3.101526 kohm
        *       *
        |       |
        *       *
    7   *  U E  *       15.885364 Mohm
        *       *
        |       |
        *       *
    9   *  U E  *      134.240232 Gohm
        *       *
        |       |
        *       *
   11   *  U E  *      676.546275 Tohm
        *       *
        |       |
        *       *
   13   *  U E  *      4.129816228D+16
        *       *
        |       |
   15   |---R---|      4.129816228D+16
        |       |
```

Our objective is to obtain a structure, where all series open stubs have identical impedances except the end ones, which have half the impedances of those in the middle. This is similar to the LCE command, except for the end elements. In the case of the LCE command, *all* elements end up having the same value. Since we need end elements half that size, we modified the LCE command just for this purpose and call it ECM; otherwise, the command works in an identical manner.

The preamble is as usual, having five unit elements and a shunt stub, resulting in a total of six branches:. The shunt stub branch number must be first, the rest are in the proper sequence:

```
COMMAND:
>  ecm 6
ENTER  6 BRANCH NUMBERS
>  3 5 7 9 11 13
PROCESS CONVERGED, USE TRANSFORMATIONS:

T( 1) =  8.7063969D-03
```

```
T( 2) =  2.1297415D-04
T( 3) =  1.1834482D-04
T( 4) =  1.8483062D-04
T( 5) =  2.9850441D-02
```

These transformation ratios will have to be used in subsequent TR steps to obtain the structure we need. The first one is as follows:

```
COMMAND:
>  tr -1 3 5
LARGEST TRANSFORMATION RATIO:   2.5988978D-04
TRANSFORMATION RATIO USED:      8.7063969D-03
   3   ├──L──┤       60.442887  ohm
       |       |
       *       *
   7   *  U E  *      289.397405  ohm
       *       *
       |       |
   9   ├──L──┤       29.782018  ohm
       |       |
       *       *
  11   *  U E  *      138.304283 kohm
       *       *
       |       |
       *       *
  13   *  U E  *        1.168749 Gohm
       *       *
       |       |
       *       *
  15   *  U E  *        5.890280 Tohm
       *       *
       |       |
       *       *
  17   *  U E  *      359.558192 Tohm
       *       *
       |       |
  19   ├──R──┤       359.558192 Tohm
       |       |
```

Performing the four additional steps (just like the one above), followed by obtaining its dual again, we quickly reach the final electrical design shown below:

```
COMMAND:
>  dual
microwave demonstration example

**** ALL VALUES ARE IMPEDANCES ****

   1   ├──R──┤       50.000000  ohm
       |       |
   4   |       C       41.361360  ohm
       |       |
       *       *
   8   *  U E  *        8.638640  ohm
       *       *
       |       |
  10   |       C       82.722720  ohm
       |       |
       *       *
  14   *  U E  *        1.238628  ohm
       *       *
       |       |
  16   |       C       82.722720  ohm
       |       |
       *       *
```

```
20   *  U E  *      923.245789 mohm
     *       *
     |       |
22   |       C       82.722720  ohm
     |       |
     *       *
26   *  U E  *        1.238628  ohm
     *       *
     |       |
28   |       C       82.722720  ohm
     |       |
     *       *
32   *  U E  *        8.638640  ohm
     *       *
     |       |
34   |       C       41.361360  ohm
     |       |
35   |──R────|       50.000000  ohm
     |       |
```

As can be readily seen, the series stubs are all of equal impedance, except the end ones, which have exactly half that value. The values are now very reasonable and the whole procedure was quite simple and painless.

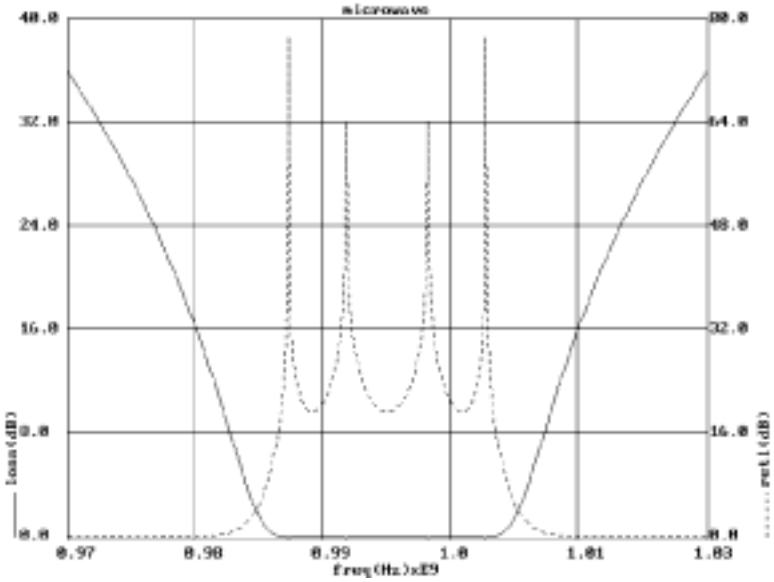
Converting these values to even- and odd-mode impedances according to the equations of Fig. AN1.2 above, we obtain the following set of values:

Section	Z_e (ohms)	Z_o (ohms)
1	58.63	41.36
2	43.79	41.32
3	43.21	41.36
4	43.79	41.32
5	58.63	41.36

Table A1.1. Even and odd mode impedances

These are now all practical values and the last step is to convert them to physical dimensions. This can be done by the use of graphical procedures or approximate expressions which can be easily programmed. A more accurate and convenient way is to use our ECM Postprocessor program.

Finally, the circuit was analyzed in the frequency domain assuming ideal, lossless components, and the loss values are shown below. The print was obtained on the personal computer and a graphics printer by the following procedure. The analysis results were first written to a file with the name AN7.TAB (where the extension need not be specified, the program does that itself). We called the GRAPH utility next, selected the AN7.TAB file (the program displays only the files with .TAB extension), and selected the loss and the return loss to be displayed. When the screen shows the plot, the F5 function key sends it to the printer.


microwave
40.0
32.0
24.0
16.0
8.0
0.0
80.0
64.0
48.0
32.0
16.0
0.0
loss(dB)
refl(dB)
0.97
0.98
0.99
1.0
1.01
1.03
freq(Hz)xE9

Notes:

Notes: