POWER ANALYSIS Module

The power analysis module is used to estimate the voltage and current carrying requirements for components used in building filters intended for high power applications. It will display the voltage across every parallel and series connected branch in any circuit, and the current entering and leaving each point for any given input power level. The results are displayed using a box to symbolize a parallel or series component.

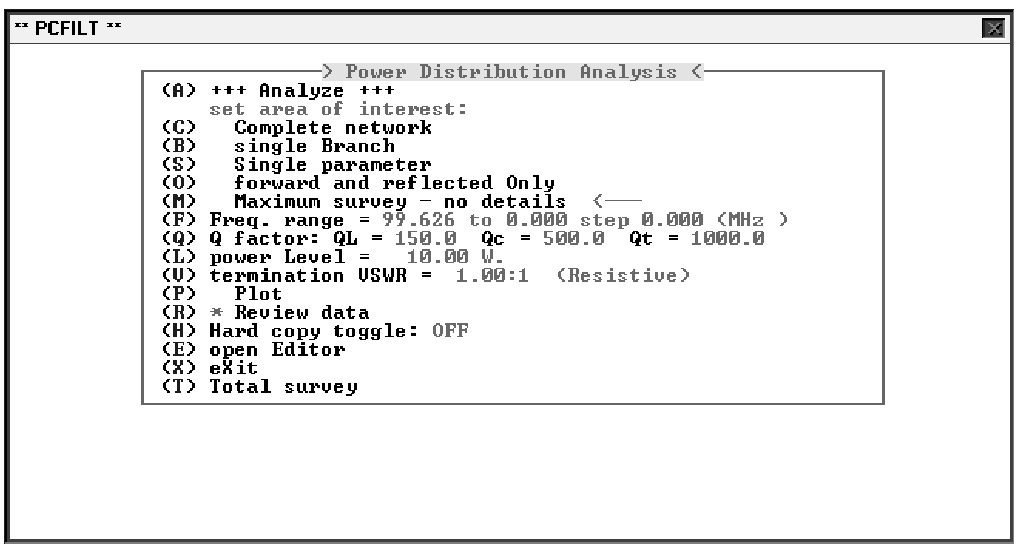
Any design that is to be evaluated to find the extremes of current or voltage levels should be evaluated near the edges of the passband, this is where the extreme conditions will develop.

The shunt elements are numbered on the display using the same branch numbers as used by the editor circuit drawing module. Each shunt number corresponds directly to each parallel component. Note that in the case of a multiplexer, each side port is displayed as only one shunt branch.

The current taken from the source is also displayed

```
  ******************************************************************
***    ALL VOLTAGE AND CURRENT LEVELS ARE GIVEN IN R.M.S. VALUES    ***
***  To get Peak values, multiply each voltage or current by 1.414  ***
  ******************************************************************
```

The power analysis module is entered from the Utilities menu and will show the following menu immediately on entry:



The menu options are:

(A) +++ Analyze +++

Causes analysis to be performed.

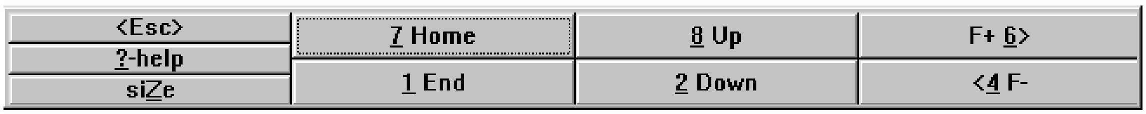
set area of interest:

The following 5 options control the analysis allowing detailed data on a single area of the network, or covering the levels throughout the entire network.

Before doing a detailed analysis of a specific branch or component, the program must make an internal map of all the shunt branches in the network. To do this, the user must make an analysis of the entire network at a minimum of 1 frequency point. The "Maximum survey - no details" is the default "area of interest". You should use this first to find the worst case (maximum level) areas within the network. The "area of interest" that is selected is identified by an arrow (<—).

(C) Complete network

This causes a display of all shunts and series elements to be presented by moving the network up or down. If data is going to the screen, one of these two menus will appear depending on the frequency range that is set up. More than one frequency point results in extra buttons to control the frequency.



The up and down numeric keypad arrow keys (1,2,8,) move the display of each shunt up or down. The <7 Home> key jumps the display to the termination end of the network. The <1 End> key jumps to the source end.

Frequency may be changed up or down using the right and left numeric keypad arrow keys (4 and 6) if a frequency range and step have been set.

(B) single Branch

After the "maximum survey" has been done, this option will display a list of all the valid shunt branches and prompt for the single branch and associated series branch you wish to concentrate on.

(S) Single parameter

After selecting a single branch, another menu will display the selected shunt branch and request a single parameter be selected. Once this has been set, the output will resemble a typical tabulated analysis done with the normal analysis module but with the added parameter on the right.

(O) forward and reflected Only

This option can be selected in the event only the information about the power going in and out of a network is needed. This option is best used for making hard copies to a printer.

(C) Maximum survey - no details

This is the default setting and will be active when the power analysis module is first entered. Use this at any time to make a survey of the maximum voltage, current and power loss level locations throughout the network over the entire frequency range set.

(F) Freq. range = ###.### to #.### step #.### (MHz.)

The frequency range over which the analysis will be done is set by this option. Initially, the starting frequency is set to the Fo or Fc (reference frequency) of the design. Because the "to" and "step" frequencies are set to 0, only one frequency point will be analyzed. This is usually good for an initial full network analysis. When setting the frequency range for more than 1 point, the step frequency may be specified by the number of points given as a negative (-) integer. Up to 150 points may be analyzed.

(Q) Q factor: QL = ###.## Qc = ####.## Qt = ####.##

This is the same "Q" values as shown in the window on the main control menu and may be changed here.

(L) power Level = ##.## W.

This is used to set the power level being fed into the source end of the network. Initially, 10 W. is assumed.

(V) termination VSWR = 1.00:1

Use this to set the termination VSWR the filter is to operate into.

(P) * Plot

This option is used to display the results of a single parameter analysis over a frequency range. It uses the main high resolution graphics module. The parameter of interest will be option "X" on the D-Display menu.

(P) * Review data

Selects tabulated output of data on a single parameter of a single branch over a wide frequency range. The function called is identical to the hard copy menu review to screen option (from the UTILITIES menu). The data can be scrolled up or down by line or page using the keypad arrow and page keys.

(H) Hard copy toggle: OFF

This selection determines where the analysis data is sent. There are two possible destinations.

```
Send data to:
(P)-Printer (F)-File.
```

Hard copy toggle is normally OFF - No hard copy. All data goes to the screen (Default).

(P)-Printer - All data goes to the printer.

(F)-File: File_name.AHC - This allows data to be sent to one or more disk files. The file name will be the same file name shown on the main control menu and will initially have the extension ".AHC". The output will continue being sent to this file until the next selection of the (H) Hard copy option which will close the file. The next time a file is opened, the first letter in the extension will be incremented to name.BHC if an analysis was actually done under the previous extension. Each time the file is written to and closed, the extension increments up 1 letter. If the file is NOT written to, the extension will remain unchanged. When the output destination is selected a channel is opened. The channel remains open until the (H) Hard copy menu option is selected again. This closes the channel and printing will actually begin or the file will be closed.

(E) open Editor

Brings up the circuit editor and the schematic drawing module. You can use this to print the schematic to identify branch numbers at any time. If the editor is used to change the circuit, the initial "Maximum survey" of the entire network must be repeated to up-date the internal map of shunt numbers. A test is made to compare the length of the network before and after each analysis run. If any change in length is found, a warning is displayed and the internal record of the valid shunt branch numbers is cleared.

(X) eXit

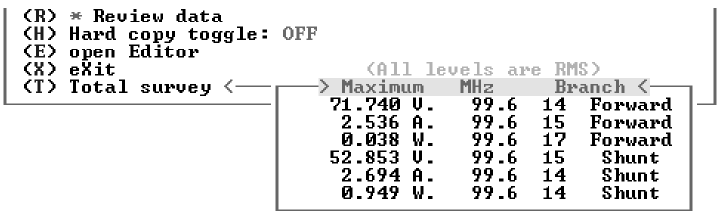
Exit the program.

(T) Total survey

This displays a tabulation of the maximum voltage and current levels for **every branch** in the network over the entire frequency range analyzed. The branches having the worst cases are marked with an asterisk (*).

Maximum value display

The power analysis module automatically records the worst case voltage, current and loss points encountered during the "Maximum survey" over the frequency range set. The frequency and branch where the maximum levels occur is displayed in the window located to the lower right of the screen. The maximum level window appears after the "Maximum survey" is complete. Whenever the selected single branch and parameter is the same as one of these 6 maximum points on the display, it will be intensified.



If you are using a mouse pointing device, you can select any one of the 6 displayed maximum points to be "the area of interest" simply by selecting it with the mouse. The frequency range set is not changed allowing details about this specific area in the network to be plotted or tabulated.

*** Examples ***

Below is the schematic diagram of a simple contiguous L-C highpass - lowpass diplexer with a crossover at 100 MHz (note the shunt branch numbers):

```
  0 ┌─ Termination ─┐            50 Ohms  <-,
  1 ├────── L ──────┤        129.85 nHy.    |
    │               │                       |
  2 │               C        22.584 pFd.    |
    │               │                       |     "Forward" port.
  3 ├────── L ──────┤        45.721 nHy.    |
    │               │                       |
  4 │               C        20.934 pFd.    |
    │               │                     <-'
    └──────>        └─── to Source ──>
  5 ┌── port term ──┐            50 Ohms  <-,
  6 ├────── C ──────┤        19.507 pFd.    |
    │               │                       |
  7 │               L        112.16 nHy.    |
    │               │                       |     "Side port"
  8 ├────── C ──────┤        55.402 pFd.    |
    │               │                       |
  9 │               L           121 nHy.  <-'
    │               │
 10 └───── Source ──┘            50 Ohms
 11  Fc = 100 MHz.
```

The results of the analysis at 100 MHz (the crossover frequency) with 10 Watts into the common port is shown below. Note that each shunt element is shown as a box marked by the branch number corresponding to the schematic drawn by the edit module. The entire side port is displayed as a single box marked 10a. Any branch that has multiple parts (like the primary and secondary winding of a transformer) will have an "a" or a "b" designation.

```
Inductor Q=150 Cap. Q=1500 Trans. Q=1000
   Frequency   Rtn. loss    Atten.       Delay       Phase
    (MHz.)       (dB)       (dB)        (nSec)       (Deg.)
    100.000      43.516       3.162        8.144    -214.020
                              ┌──────────────┐
      10.0000 W. ──────>│     Loss     │──────>
       0.0004 W. <──────│  5.17127 W.  │   4.8283 W.
                              └──────────────┘
    ┌────── Termination ──────┐
    │ <────── 15.538 V.──────> │
    │          0.311 A.───────X
    │                          │
    │      ┌──────────┐       │
  1 ├──────┤  0.020 W.├──X───┤ <-- Parallel inductor.
    │      └──────────┘  │    │
    │          0.190 A.───┘    │
    │ <────── 15.538 V.──────> │
    │                          │
    │          ┌──────────────> │
    │          │          ┌────┴────┐
    │          │          │ 0.006 W.│ <-- The series cap at branch 2.
    │         25.761 V.   └────┬────┘
    │          └──────────────> │
    │          0.366 A.───────X
    │                          │
    │      ┌──────────┐       │
  3 ├──────┤  0.113 W.├──X───┤ <-- Parallel inductor.
    │      └──────────┘  │    │
    │          0.769 A.───┘    │
    │ <────── 22.101 V.──────> │
    │          ┌──────────────> │
    │          │          ┌────┴────┐
    │          │          │ 0.014 W.│ <-- The series cap at branch 4.
    │         40.098 V.   └────┬────┘
    │          └──────────────> │
    │          0.527 A.───────X <-- Notice that the current into both ports is
    │                          │     the same (.527 Amp.) at the crossover freq.
    │      ┌──────────┐       │
10a ├──────┤  5.018 W.├──X───┤  <-- The entire lowpass port!
    │      └──────────┘  │    │
    │          0.527 A.───┘    │
    │ <────── 22.213 V.──────> │
    │                          │
    │          0.450 A.────────┤
    │                          │
 10 └────── Source (~) ───────┘
```

It is not possible to display the entire chart of all shunt and series branches to the screen at once as is shown throughout this section of the manual without printing out the analysis on your printer. The (C) Complete network option can be used instead to scroll the display up or down to see one shunt at a time.

In addition to the ability to generate a display of all the parameters associated with a single shunt branch at one or more frequencies, a method is also provided to tabulate or graph, one parameter over any range of frequencies.

Let's suppose we would like to know the voltage requirements for the capacitor at branch 4 of our multiplexer when 10 W. is applied to the source. From our complete network display we see that we want to select the series branch above shunt branch 10a.

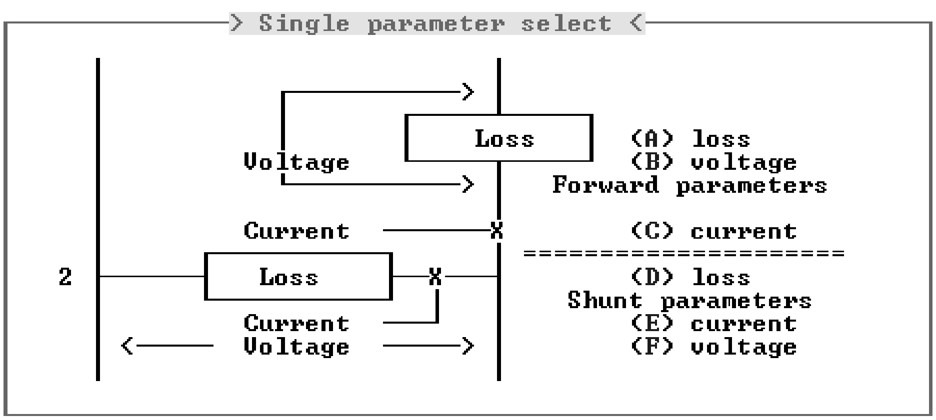
```
Using the (*) single Branch option:
Valid branches: 1 3 10
What shunt branch number? 10
```

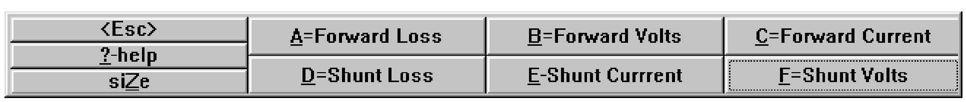
Next we need to select the desired parameter. In this case there is two shunts numbered 10, The program needs to know which one you are interested in.

Using the (S) Single parameter option:

```
Branch 10 is a dual shunt branch, Pick A or B? A
```

Now the individual parameter can be selected:





The capacitor we have chosen to examine is part of the highpass port, so we will have to set the frequency range to sweep the high frequency side of the multiplexer crossover.

Use the (F) Freq. range option.

```
Analyze from, to , step (MHz.) ? 90,120,2
```

Now do the analysis: (A) +++ Analyze +++

```
Inductor Q=150 Cap. Q=1500 Trans. Q=1000
   Frequency   Rtn. loss    Atten.       Delay       Phase    Forward voltage
    (MHz.)       (dB)       (dB)        (nSec)       (Deg.)      Branch 10
     90.000     31.907       6.818       6.809    -241.533      36.521 V.
     92.000     33.343       5.962       7.203    -236.488      37.495 V.
     94.000     35.351       5.159       7.568    -231.167      38.395 V.
     96.000     38.144       4.419       7.867    -225.605      39.162 V.
     98.000     41.714       3.751       8.066    -219.863      39.743 V.
```

100.000	43.516	3.162	8.144	-214.020	40.098 V.
102.000	40.755	2.652	8.097	-208.166	--> 40.211 V.
104.000	37.563	2.220	7.939	-202.387	40.086 V.
106.000	35.215	1.858	7.692	-196.755	39.748 V.
108.000	33.544	1.559	7.383	-191.325	39.235 V.
110.000	32.349	1.313	7.040	-186.132	38.589 V.
112.000	31.496	1.112	6.683	-181.191	37.849 V.
114.000	30.896	0.948	6.328	-176.508	37.051 V.
116.000	30.489	0.813	5.985	-172.076	36.223 V.
118.000	30.232	0.702	5.660	-167.885	35.386 V.
120.000	30.093	0.610	5.356	-163.920	34.556 V.

The capacitor at branch 4 must handle 40.2 Volts R.M.S at 102 MHz.

At this point the results may be plotted, or another branch evaluated.

Reactive loads - VSWR

Quite often the problem of predicting the effects of operating a filter into a mismatched or reactive load under power will come up. It will be necessary to determine the voltage and current levels throughout the network under these conditions. This encompasses an infinite number of possible conditions. Evaluation must be done over the operating frequency range considering every possible combination of complex impedances that represent the VSWR level anticipated.

In order to accomplish this, the termination impedance of the network is internally changed to reflect a resistive mismatch equivalent to the VSWR level set. For example, a termination Zo of 100 Ohms in a 50 Ohm system would be used represent a 2:1 VSWR. In addition, a series transmission line having a Zo equal to the ideal termination Zo of the filter under test is automatically inserted between the filter and the mismatched termination. By varying the length of this line in 1 degree increments from 0 to 360 degrees, the "Maximum survey" feature will evaluate almost all of the possible reactive loads that can occur for a given VSWR level. This is a time consuming operation and will take a while even on a fast computer.

NOTE: The only time the filter is evaluated over the entire range of complex termination impedances is when a "Maximum survey" is done. The "Complete network" option will perform an analysis assuming only the single complex impedance displayed next to the VSWR on the menu. So, perform the maximum survey before you evaluate the details of specific branches or after you change anything.

After a "Maximum survey" is performed, the complex termination impedance that yielded the worst case VOLTAGE is set and displayed for detailed evaluation. The complex termination for the 6 worst case conditions displayed will likely be different. Selecting each of the 6 worst cases individually with your mouse will set the recorded complex termination for that case. Doing this will allow each case to be analyzed over the operating frequency range and tabulated or plotted.

When the VSWR is set to be greater then 1.0:1, the series transmission line "[SWR] mismatch simulator" is automatically added. When the VSWR is set to 1.0:1, the mismatch simulator is removed. It is also removed when exiting from the power analysis module. This line is special in that it is assumed to be lossless and has the same Zo as the termination. It has been given the special symbol "[SWR]" to indicate that it is a mismatch simulator. The termination Zo (at branch 0) will show as equal to that of the filter, but its actual value internally will be multiplied by the VSWR level. The schematic of a typical lowpass filter under power test into a termination VSWR of 1.5 to 1, as drawn by the circuit editor, looks like this:

```
  0 ┌─ Termination ─┐            50 Ohms
    │               │
  1.│             [SWR]     1.5 :1      <-- Mismatch simulator line
    │               │
  3 ├────── C ──────┤       3.5833 pFd.
    │               │
  4 │               L       12.442 nHy.
    │               │
  5 ├────── C ──────┤       6.8014 pFd.
    │               │
  6 │               L       13.994 nHy.
    │               │
  7 ├────── C ──────┤       6.8014 pFd.
    │               │
  8 │               L       12.442 nHy.
    │               │
  9 ├────── C ──────┤       3.5833 pFd.
 10 └──── Source ───┘            50 Ohms
 11  Fc = 1000 MHz.
```

The [SWR] mismatch simulator branch must be located ONLY at branch number 1. When using the circuit editor, Any command that moves it (like >REverse, for example) will generate an error warning. If it is necessary to do something that moves the [SWR] branch, simply delete it. The program inserts and deletes it automatically as needed and will simply replace it when you exit from the editor back to the power analysis menu. When the [SWR] mismatch simulator branch is removed an inevitable “dummy” branch is added to take its place. This keeps the branch numbers the same. **This means that once the [SWR] simulator is added the branch numbers will be permanently changed from those before entering the power analysis module.** When examining the levels throughout a network, remember that the shunt numbers indicated will be adjusted to include the added [SWR] mismatch simulator at branch number 1. This will change all the other branch numbers from those shown when the schematic was drawn from outside the power analysis module, that is, the way you saw it during the initial design.

Complex Branches.

When voltage or current levels must be determined for an element that is part of a complex branch like the series branch composed of parts 3 and 5 in the elliptic function zig-zag filter shown below, some manual calculations will be required. The voltage and current display generated will only show the voltage between branch 2 and the shunt notch section branch 6. The current through this branch is all that is required to calculate the voltage across the capacitor at branch 5, But, let's say we need to know the current flowing through the 9.463 pFd. capacitor at branch 4 at Fo with 10 W. applied.

```
 0  ┌─ Termination ─┐          66.42 Ohms
 1  ├─────── L ─────┤         45.286 nHy.
 2  ├─────── C ─────┤         53.155 pFd.
    │              ┌┴┐
 3. │              L C        107.27 nHy.       9.4636 pFd.  Fx = 157.96 MHz.
    │              └┬┘
    │               │
 5  │               C         13.748 pFd.
    │               │
 6. ├─── C ── L ────┤          83.95 pFd.       81.691 nHy.  Fx = 60.774 MHz.
 8  ├─────── C ─────┤         57.787 pFd.
    │               │
 9  │               C         14.946 pFd.
    │               │
10  │               L         193.51 nHy.
    │               │
11  └──── Source ───┘             50 Ohms
12  Fc = 97.98 MHz.
```

To do this, we must fool the program into giving us the voltage across the series notch section alone. This can be done by adding an "open" parallel branch using the circuit editor. In the circuit shown below, a 1 mHy. inductor was added so as to separate the notch section from the series capacitor at branch 6 (a 0 pFd. cap will not work here). The newly added part is at branch 5 in the circuit shown below:

```
 0  ┌─ Termination ─┐          66.42 Ohms
 1  ├─────── L ─────┤         45.286 nHy.
 2  ├─────── C ─────┤         53.155 pFd.
    │              ┌┴┐
 3. │              L C        107.27 nHy.       9.4636 pFd.  Fx = 157.96 MHz.
    │              └┬┘
 5  ├─────── L ─────┤          1e+06 nHy. <-- Added "open" shunt branch.
    │               │
 6  │               C         13.748 pFd.
    │               │
 7. ├─── C ── L ────┤          83.95 pFd.       81.691 nHy.  Fx = 60.774 MHz.
 9  ├─────── C ─────┤         57.787 pFd.
    │               │
10  │               C         14.946 pFd.
    │               │
11  │               L         193.51 nHy.
    │               │
12  └──── Source ───┘             50 Ohms
13  Fc = 97.98 MHz.
```

Below is the power analysis at branch 5 of this sample filter after the extra "open" parallel branch was added. Before the single branch 5 could be selected, the entire network had to be reanalyzed, as there was no shunt element at branch 5 in the original circuit or in the programs internal map if the shunt branches. Note that the new "open" inductor shows in the analysis but is drawing no current, it is serving only to force the program to give us the needed information about the voltage across the 9.4636 pFd. capacitor at the series branch 4.

```
Inductor Q=150 Cap. Q=1500 Trans. Q=1000
   Frequency   Rtn. loss    Atten.       Delay       Phase
    (MHz.)       (dB)       (dB)         (nSec)      (Deg.)
     97.980      19.739       0.377      16.712      -0.007

                           +---------------+
        10.0000 W. ------->|     Loss      |------->
         0.1062 W. <-------|   0.72577 W.  |   9.1680 W.
                           +---------------+

    |           +-------------------> |
    |           |                     |
    |           |         +-----------+
    |           |         |   0.180 W.|
    |         41.414 V.   +-----------+
    |           +-------------------> |
    |          0.386 A.---------------X
    |                                 |
  5 |------ +-----------+             |
    |       |  0.000 W. |-----X-------|  <-- The big inductor draws no current.
    |       +-----------+     |       |
    |          0.000 A.-------+       |
    | <------ 52.513 V.-------->      |
    |                                 |
```

Now, knowing that we have 41.414 V across a 9.463 pFd. capacitor at 97.98 Mhz, it is very easy to calculate the capacitive reactance using one of these two well known reactance formulas:

```
Xl = 2*Pi*F*L     -or-    Xc =  1/(2*Pi*F*C)
```

```
In this case: Xc = 1/(6.28319 * 97.98 E+6 * 9.463 E-12) = 171.65 Ohms.
```

$$\text{By Ohm's law:} \quad I = \frac{E}{Xc} = \frac{41.414}{171.65} = .241 \text{ Amps.}$$

The power lost in each part can be found from the resistive part of the impedance given by the component "Q".

$$R = \frac{X}{Q} = \frac{171.65}{1500} = .114 \text{ Ohms}$$

And:

$$\text{Power} = I^2 * R = .241 * .241 * .114 = 6.621 \text{ mW.}$$

Transmission line filter power analysis

Power distribution analysis can also be performed on transmission line designs with one limitation:

```
Power loss in forward lines is not calculated
    and is always displayed as ZERO W!
```

This should not be a problem because the area of interest is usually the voltage at the top of the resonators. It is possible get around this deficiency however by the process of elimination. The example to follow is of an SCTL combline filter.

```
File name = default
Design = Combline bandpass
Equal resonator zo. (Y or N) Y
order N                      2
passband Ripple (0=Butt. dB) 0.05
Define pass / stop      (dB) 3
arithmetic Fo.          MHz. 1000
Bandwidth               MHz. 10
design Zo.                   75
 Source zo.                  50
confIg: S=SCTL T=Tap C=Cap   S
tYpe: 1=sing 2=doub 3=ratio  2
electrical Length     (Deg.) 45
```

The circuit editor schematic drawing of the filter is shown below with the forward transmission lines identified.

```
 0 ┌─ Termination ─┐         50 Ohms
 1 │               │    Ref. freq. = 1000.03 MHz.
 2 ╞════[ N:1 ]════╡        13.52 :1 turns
   │               │
 3.║ + + + + + + + ║       9135.8 Ohms            45 Deg.  <---
   │               │
 5.╞═════:───:═════╡       75.541 Ohms            45 Deg.
 7 ├────── C ──────┤       2.1262 pFd.
   │        ┌:═════┘
 8.│        └:═════╗       8205.4 Ohms            45 Deg.
   │               │
10.╞═════:───:═════╡       75.541 Ohms            45 Deg.
12 ├────── C ──────┤       2.1262 pFd.
   │               │
13.║ + + + + + + + ║       9135.8 Ohms            45 Deg.  <---
   │               │
15 ╞════[ N:1 ]════╡     0.07398 :1 turns
16 └──── Source ───┘         50 Ohms
17  Fc = 1000 MHz.
```

The power analysis on this design at Fo is shown below with the default 10W. applied. Take note of the total loss of the network shown in the heading. This loss is computed by subtracting the reflected power from the total forward loss and will include the forward line loss.

```
Inductor Q=150 Cap. Q=1500 Trans. Q=500
   Frequency   Rtn. loss    Atten.       Delay       Phase
    (MHz.)       (dB)       (dB)         (nSec)      (Deg.)
   1000.035      19.184       2.189      44.700     179.993
                                   ┌──────────────┐
         10.0000 W. ─────>│      Loss      │─────>
          0.1207 W. <─────│   3.83787 W.   │    6.0415 W.
                                   └──────┃───────┘
                                          `----------- Total network loss
```

```
   ┌─────── Termination ───────┐
   │ <──────  17.380 V.─────>  │
   │           0.348 A.───────X
   │                           │
   │                           │
   │      ┌───────────┐        │
2a ├──────┤  0.000 W. ├──X─────┤  <-,    <-- Transformer secondary
   │      └───────────┘  │     │    |
   │           0.348 A.──┘     │    |
   │ <──────  17.380 V.─────>  │    |    A perfect transformer is assumed
   │                           │    |    which has no loss.
   │           0.000 A.───────X     |
   │                           │    |
   │      ┌───────────┐        │    |
2b ├──────┤  0.000 W. ├──X─────┤  <-'    <-- Transformer primary
   │      └───────────┘  │     │
   │           0.026 A.──┘     │
   │ <────── 234.931 V.─────>  │
   │                           │
   │           0.026 A.───────X
   │                           │
   │      ┌───────────┐        │
3a ├──────┤  0.000 W. ├──X─────┤ <--- "Out" end of line
   │      └───────────┘  │     │
   │           0.000 A.──┘     │
   │ <────── 234.931 V.─────>  │
   │                           │
   │           ┌────────────>  │
   │           │         ┌─────┴─────┐
   │           │         │  0.000 W. │<-- Not really zero!
   │        179.879 V.   └─────┬─────┘
   │           └────────────>  │
   │           0.026 A.───────X
   │                           │
   │      ┌───────────┐        │
3b ├──────┤  0.000 W. ├──X─────┤ <--- "In" end of line
   │      └───────────┘  │     │
   │           0.000 A.──┘     │
   │ <────── 235.115 V.─────>  │
   │                           │
   │           0.026 A.───────X
   │                           │
   │      ┌───────────┐        │
5  ├──────┤  1.149 W. ├──X─────┤ <-- Second resonator
   │      └───────────┘  │     │
   │           3.112 A.──┘     │
   │ <────── 235.115 V.─────>  │ <-- Voltage at second resonator
   │                           │
   │           3.113 A.───────X
   │                           │
   │      ┌───────────┐        │
7  ├──────┤  0.492 W. ├──X─────┤ <-- Loading (tuning) capacitor
   │      └───────────┘  │     │
   │           3.141 A.──┘     │
   │ <────── 235.115 V.─────>  │
   │                           │
   │           ┌────────────>  │
   │           │         ┌─────┴─────┐
```

```
   │            │       │   0.024 W.│
   │        356.883 V.  └─────┬─────┘
   │            └──────────>  │
   │          0.043 A.───────X
   │                          │
   │      ┌───────────┐       │
10 ├──────│   1.503 W.│──X───┤
   │      └───────────┘  │   │
   │          3.559 A.───┘   │
   │ <───── 268.840 V.─────>  │  <-- Voltage at second resonator
   │                          │
   │          3.592 A.───────X
   │                          │
   │      ┌───────────┐       │
12 ├──────│   0.644 W.│──X───┤
   │      └───────────┘  │   │
   │          3.592 A.───┘   │
   │ <───── 268.840 V.─────>  │
   │                          │
   │          0.037 A.───────X
   │                          │
   │      ┌───────────┐       │
13a├──────│   0.000 W.│──X───┤
   │      └───────────┘  │   │
   │          0.000 A.───┘   │
   │ <───── 268.840 V.─────>  │
   │                          │
   │            ┌──────────>  │
   │            │       ┌─────┴─────┐
   │            │       │   0.000 W.│<-- Not really zero!
   │        250.066 V.  └─────┬─────┘
   │            └──────────>  │
   │          0.037 A.───────X
   │                          │
   │      ┌───────────┐       │
13b├──────│   0.000 W.│──X───┤
   │      └───────────┘  │   │
   │          0.000 A.───┘   │
   │ <───── 303.703 V.─────>  │
   │                          │
   │          0.033 A.───────X
   │                          │
   │      ┌───────────┐       │
15a├──────│   0.000 W.│──X───┤
   │      └───────────┘  │   │
   │          0.033 A.───┘   │
   │ <───── 303.703 V.─────>  │
   │                          │
   │          0.000 A.───────X
   │                          │
   │      ┌───────────┐       │
15b├──────│   0.000 W.│──X───┤
   │      └───────────┘  │   │
   │          0.450 A.───┘   │
   │ <─────  22.468 V.─────>  │
   │                          │
   │          0.450 A.───────X
   │                          │
16 └─────── Source (~) ──────┘
```

To estimate the loss occurring in the forward lines, total up all of the losses given (1.149+.492+.024+1.503+.644=3.812) then subtract that from the total loss shown in the heading (3.83787-3.812=.026) to get the total loss in both forward lines. In this case, we have about 13 milliwatt in each forward line.