Appendix B
Microwave microstrip lowpass filter
Using Kuroda transforms and the L-C -to-> stub Generator

Two different methods will be described for the design of a 4 Ghz. microstrip lowpass filter. The first method will use the Kuroda identity transform (>KT) command of the circuit editor to generate a theoretically "correct" filter. The second method uses direct substitution of microwave element for lumped components. This method is very fast but not totally accurate.

We will begin both examples by designing a lumped component lowpass filter using the lowpass reference pole placer. All-pole or elliptic function filters could also be used if the performance is acceptable for the specification requirements.

For the first example, we will select a standard lumped component lowpass filter from the new design menu with the lowpass placer as the reference lowpass. Key in these specifications and [CALCULATE]:
Design file:

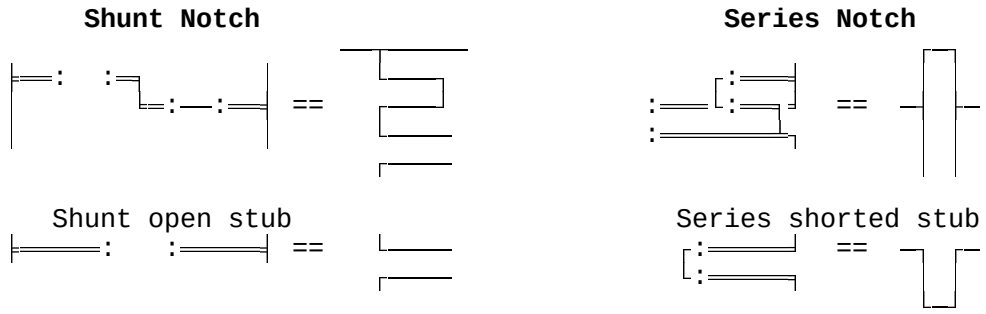
```
default ... Design parameters
Design = L-C Lowpass
passband Ripple (0=Butt. dB) 0.05
design Zo.                   50
Cutoff freqency fc.     MHz. 4000
confIg: (input)  Ser.  Par.  P
tYpe: 1=sing 2=doub 3=ratio  2
  --- POLE PLACER DATA ---
Zeros at Infinity = 3
Finite transmission zero frequencies:
    1.300
Finite transmission zero sequence: 1
Placer specification mask:

Lowpass reference used:
   ├────── R ──────┤       1
   │               L       1.02809
   ├────── C ──────┤       1.02771
   │               │
   │             ┌─┴─┐
   │             L   C     0.919927  0.643221  f = 1.3
   │             └─┬─┘
   │               │
   ├────── C ──────┤       1.02771
   │               L       1.02809
   ├────── R ──────┤       1
```

The resulting L-C design is shown below:

```
0  ┌─ Termination ─┐              50 Ohms
1  ├──────── C ────┤         0.81813 pFd.
   │               │
2  │             L │          2.0446 nHy.
   │               │
3. ├─── C ─── L ───┤         0.73205 pFd.        1.2796 nHy.  Fx = 5200 MHz.
   │               │
5  │             L │          2.0446 nHy.
   │               │
6  ├──────── C ────┤         0.81813 pFd.
7  └──── Source ───┘              50 Ohms
8   Fc = 4000 MHz.
```

Notice that the single notch section is a shunt notch (branches 3 and 4). Series notches are not realizable on microstrip. The parallel input configuration (confIg: (input) Ser. Par. P) chosen on the parameters menu determines which one of the two "dual" topologies is generated and therefore selects series or parallel notch sections.

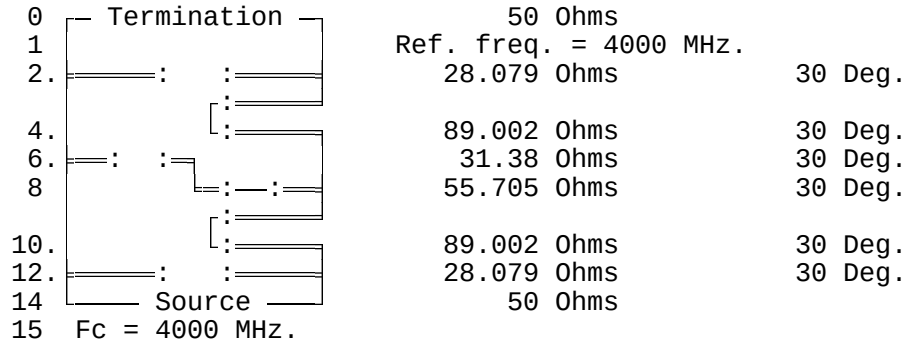
Kuroda transforms can be performed only on transmission line stub sections of the types show below:



The L-C -to-> stub generator will next be programmed to replace each lumped component directly with an equivalent transmission line stub. This is done by displaying the stub generator menu from the Utilities menu and choosing options F, J and N. The electrical length required can be chosen to control the anomalous responses in the stopband which will occur at the frequency where each stub becomes 90 degrees long. 30 degrees is picked here placing the 90 degree point at 12 GHz. (4 GHz. times 90 / 30). It is important that all the electrical lengths be equal for Kuroda equivalents to be applied. When correctly set, the "Constants" window on the L-C -to-> stub generator menu will look like this:

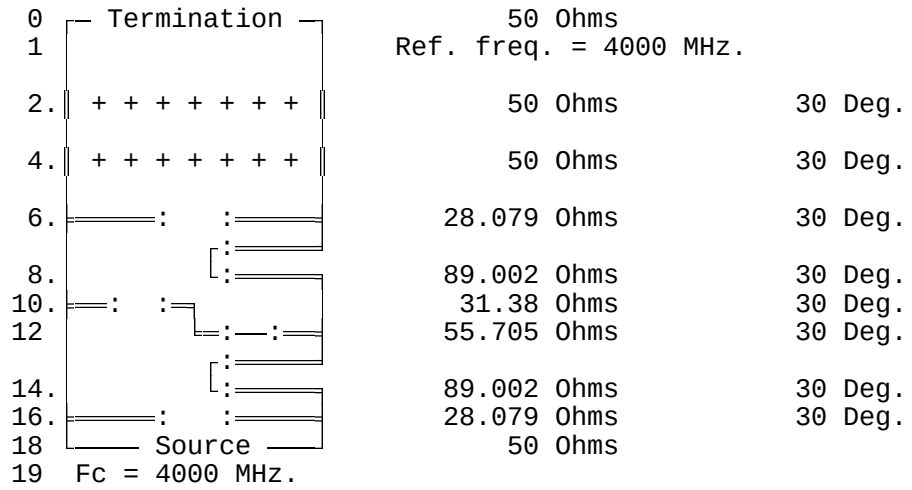
```
┌──> Constants <──┐
│ (1) L/C  0.00   │
│ (D) Θ = 30.00 °<─┼── All stubs must be of equal (30.00°) length.
│ (G) Θ = 30.00 °<─┤
│ (J) Θ = 30.00 °<─┘
│ (5) L/C  0.00   │     (The constants marked "L/C  0.00" are for elements
│ (6) L/C  0.00   │      not present in this filter and are irrelevant.)
│ (7) L/C  0.00   │
│ (8) L/C  0.00   │
└─────────────────┘
```

Calculate again results in this network:



Enter the circuit editor (the line-edit mode is being used) and insert two series transmission lines directly before the first element at the termination end of the filter, after the reference frequency at branch 1. These two lines are often referred to as "Unit Elements" and must be equal to the termination impedance and have the same length as the stubs to be transformed (30 Degrees in this example)

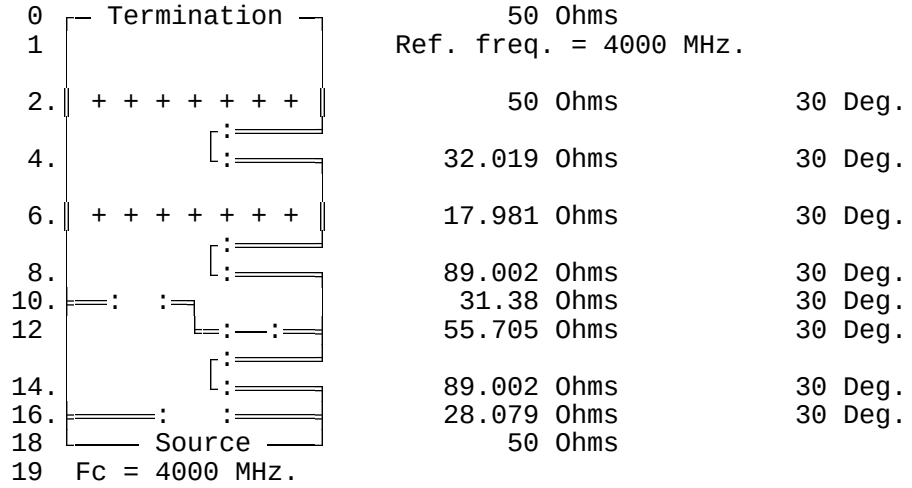
[MIS1:] Insert
After branch 1



Begin the transformations by inverting the open stub at branch 6:

[MIS3:] Kuroda

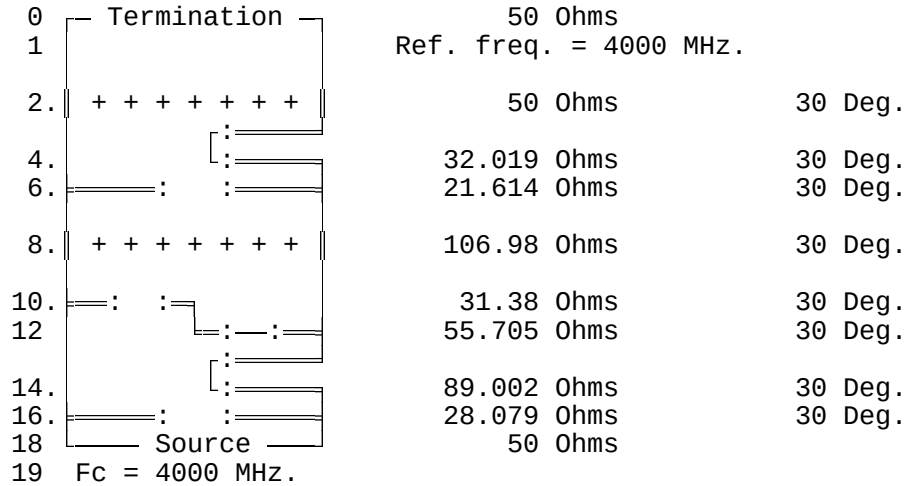
At branch 4



Move the same Unit Element on to invert the stub at branch 8:

[MIS3:] Kuroda

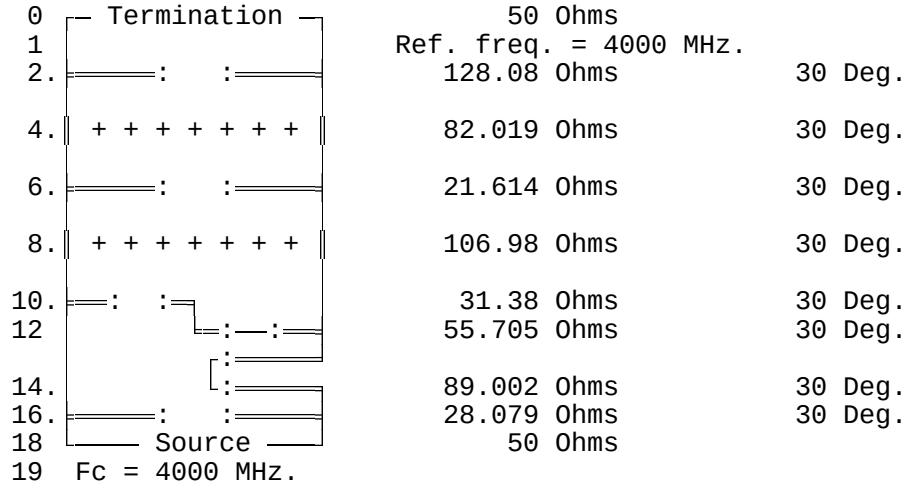
At branch 6



One more transform inverts the stub at branch 4 to complete one end:

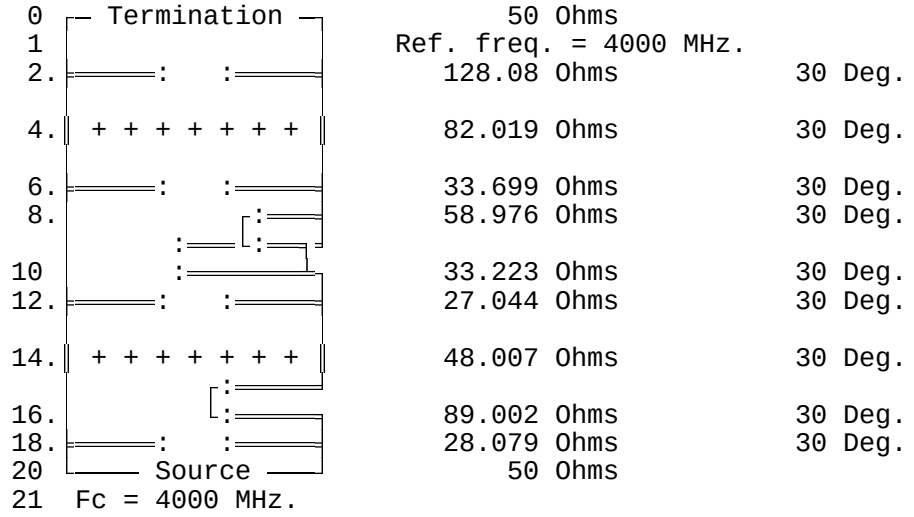
[MIS3:] Kuroda

At branch 2



Notch sections may also be inverted in the same manner if necessary. Although it is not needed or desirable in this design, the shunt notch at branch 10 may be inverted to become a series notch by one more transformation, like this:

Kuroda at branch 8



Since the series notch configuration cannot be realized on a microstrip, we must back up to the original shunt notch topology by using the un-do or "Oops" command:

Oops (Mouse right button menu)

We could transform the source end of the filter by reversing the entire filter end-for-end using the >RE command and then repeating the same procedure. To illustrate how the Kuroda transforms may be done from the source end toward the termination, we will do it by inserting two more transmission line Unit Elements after the last branch.

[MIS1:] Insert After branch 16

```
  0 ┌─ Termination ─┐          50 Ohms
  1 │               │     Ref. freq. = 4000 MHz.
  2.╞═══:   :═══╡       128.08 Ohms          30 Deg.
    │               │
  4.╟ + + + + + + + ╢       82.019 Ohms          30 Deg.
    │               │
  6.╞═══:   :═══╡       21.614 Ohms          30 Deg.
    │               │
  8.╟ + + + + + + + ╢       106.98 Ohms          30 Deg.
    │               │
 10.╞══:  :═╗           31.38 Ohms          30 Deg.
 12          ╚═:═:═══╡       55.705 Ohms          30 Deg.
              :═══════╡
 14.          ╚:══════╡       89.002 Ohms          30 Deg.
 16.╞═══:   :═══╡       28.079 Ohms          30 Deg.
    │               │
 18.╟ + + + + + + + ╢           50 Ohms          30 Deg.
    │               │
 20.╟ + + + + + + + ╢           50 Ohms          30 Deg.
    │               │
 22 └──── Source ────┘           50 Ohms
 23  Fc = 4000 MHz.
```

Three more Kuroda transforms completes the transformation process. This time we will move the Unit Elements in the opposite direction. >KT 16

Kuroda at branch 14

Kuroda at branch 18

```
  0 ┌─ Termination ─┐          50 Ohms
  1 │               │     Ref. freq. = 4000 MHz.
  2.╞═══:   :═══╡       128.08 Ohms          30 Deg.
    │               │
  4.╟ + + + + + + + ╢       82.019 Ohms          30 Deg.
    │               │
  6.╞═══:   :═══╡       21.614 Ohms          30 Deg.
    │               │
  8.╟ + + + + + + + ╢       106.98 Ohms          30 Deg.
    │               │
 10.╞══:  :═╗           31.38 Ohms          30 Deg.
 12          ╚═:═:═══╡       55.705 Ohms          30 Deg.
    │               │
 14.╟ + + + + + + + ╢       106.98 Ohms          30 Deg.
    │               │
 16.╞═══:   :═══╡       21.614 Ohms          30 Deg.
    │               │
 18.╟ + + + + + + + ╢       82.019 Ohms          30 Deg.
    │               │
 20.╞═══:   :═══╡       128.08 Ohms          30 Deg.
 22 └──── Source ────┘           50 Ohms
 23  Fc = 4000 MHz.
```

The shunt notch at branch 10 can now be transformed to a more reasonable configuration using the stub generator directly from the circuit editor:

[MIS3:] Prog stuber

Program the stub generator to substitute shunt L/C notch sections with stub type "g" from the alternate menu ((P) swap menu) rather than option "F". The electrical length must remain the same as the length of the stubs we transformed to be valid. The "Constants" window will look as shown below. **[exiT]** takes you back to the circuit editor.

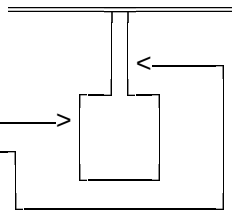
```
> Constants <
(1) L/C  0.00
(e) Θ = 30.00 °<---- The length must remain the same as the old stub.
(G) Θ = 30.00 °
(J) Θ = 30.00 °
(5) L/C  0.00
(6) L/C  0.00
(7) L/C  0.00
(8) L/C  0.00
```

By using the **Stub** command twice, the stub is first converted back to an L/C notch and then to the alternate type stub:

[MIS3:] Stub at branch 10

[MIS3:] Stub at branch 10

```
 0  Termination          50 Ohms
 1                  Ref. freq. = 4000 MHz.
 2.    :   :          128.08 Ohms          30 Deg.
 4.  + + + + + + +      82.019 Ohms          30 Deg.
 6.    :   :          21.614 Ohms          30 Deg.
 8.  + + + + + + +      106.98 Ohms          30 Deg.
10.     : :           49.058 Ohms          30 Deg.
12    :     :         87.085 Ohms          30 Deg.
14.  + + + + + + +     106.98 Ohms          30 Deg.
16.   :   :           21.614 Ohms          30 Deg.
18.  + + + + + + +     82.019 Ohms          30 Deg.
20.   :   :           128.08 Ohms          30 Deg.
22    Source             50 Ohms
23  Fc = 4000 MHz.
```



Branch 10 and 12 are now in a more convenient form.

Mechanical dimensions for the microstrip can be determined by using the mechaNical dimensions & spacings option from the Utilities menu.

```
>  MECHANICAL DIMENSIONS and SPACING  <          Stub Generator enabled
     ** General microstrip **       Substrate  ╔═══════> Control <═══════╗
Branch    Line Zo    Width    Length    K=2.1   ║ (S) Substrate thick = 0.031 ║
number      Ohms      In.      In.    thick=0.031 ║ (D) Dielectric k = 2.100 ║
   2      128.079  0.0139   0.1800              ║ (G) L-C ──> stub Generator ║
   4       82.019  0.0414   0.1867              ║ (C) + Calculate design +   ║
   6       21.614  0.2975   0.1608              ║ (P) Parameters             ║
   8      106.983  0.0229   0.1889              ║ (A) Analyze                ║
  10       49.058  0.0999   0.1674              ║ (E) Edit                   ║
  12       87.085  0.0366   0.1872              ║ (O) Optimize               ║
  14      106.983  0.0229   0.1889              ║ (X) eXit to main menu      ║
  16       21.614  0.2975   0.1608              ║ (N) Next screen            ║
  18       82.019  0.0414   0.1867              ╚═══ (?) for help ═══════════╝
  20      128.079  0.0139   0.1800
```

Using the L-C -to-> stub Generator alone

A very quick but approximate design for the same filter may be done by using the L-C -to-> stub generator to convert each element of the original L-C filter to the final form directly. Usually, this will make a filter with quite adequate performance and having many less elements then the Kuroda transformed filter.

Begin by designing the same L-C filter as the previous example, but this time, set the stub generator to options G, K and N. When using this method, the line and stub lengths do not all have to be equal. The stub impedance may also be specified rather than their lengths. This allows varying lengths and a constant impedance and therefore a constant microstrip width. This example will retain all of the lengths equal to 30 degrees for comparison with the other Kuroda transformed design. The stub generator "Constants" window will show these settings:

```
╔═> Constants <═╗
║ (1) L/C  0.00 ║
║ (e) Θ = 30.00 ° ║
║ (H) Θ = 30.00 ° ║
║ (J) Θ = 30.00 ° ║
║ (5) L/C  0.00 ║
║ (6) L/C  0.00 ║
║ (7) L/C  0.00 ║
║ (7) L/C  0.00 ║
╚═══════════════╝
```

After Calculate, the network immediately looks like this:

```
 0  ┌─ Termination ─┐          50 Ohms
 1  │               │     Ref. freq. = 4000 MHz.
 2. ╞═══════:   :═══╡        28.079 Ohms          30 Deg.
    │               │
 4. ╟ + + + + + + + ╢        102.77 Ohms          30 Deg.
 6. │      ╔═: :═╗  │        49.058 Ohms          30 Deg.
 8  ╞══════:┘   └:══╡        87.085 Ohms          30 Deg.
    │               │
10. ╟ + + + + + + + ╢        102.77 Ohms          30 Deg.
    │               │
12. ╞═══════:   :═══╡        28.079 Ohms          30 Deg.
14  └──── Source ──┘            50 Ohms
15   Fc = 4000 MHz.
```

The mechanical dimensions for the design are:

```
>  MECHANICAL DIMENSIONS and SPACING  <          Stub Generator enabled
     ** General microstrip **       Substrate  ═══════> Control <═══════
Branch   Line Zo   Width   Length    K=2.1      (S) Substrate thick = 0.032
number     Ohms     In.      In.   thick=0.032  (D) Dielectric k = 2.100
   2      28.079  0.2206   0.1622               (G) L-C ──> stub Generator
   4     102.771  0.0260   0.1886               (C) + Calculate design +
   6      49.058  0.1025   0.1670               (P) Parameters
   8      87.085  0.0376   0.1872               (A) Analyze
  10     102.771  0.0260   0.1886               (E) Edit
  12      28.079  0.2206   0.1622               (O) Optimize
                                                (X) eXit to main menu
                                                (N) Next screen
                                               ──── (?) for help ──────────
```

This method of direct substitution of microwave elements for lumped components, although quick and easy, will often require some optimization. The menu provided in the microstrip mechanical dimensions screen provides all the facilities necessary to do the needed optimization without exiting to other menus. This particular example needs almost no optimization however.