MANIFOLD MULTIPLEXING

PHASE DIPLEXING

Consider three bandpass Chebyshev filters, as shown in **Error! Reference source not found.**, with the following characteristics:

- Bandwidth = 10 MHz for all three filters
- Centre frequencies: Filter A = 900 MHz, Filter B = 1000 MHz, and Filter C = 1100 MHz
- Passband return loss = 25 dB.

Responses of these three filters are shown in Figure 1. These three filters are modelled as inverter-coupled lumped-element resonators. In this model, all filter characteristics are determined by the centre frequency and coupling bandwidths.

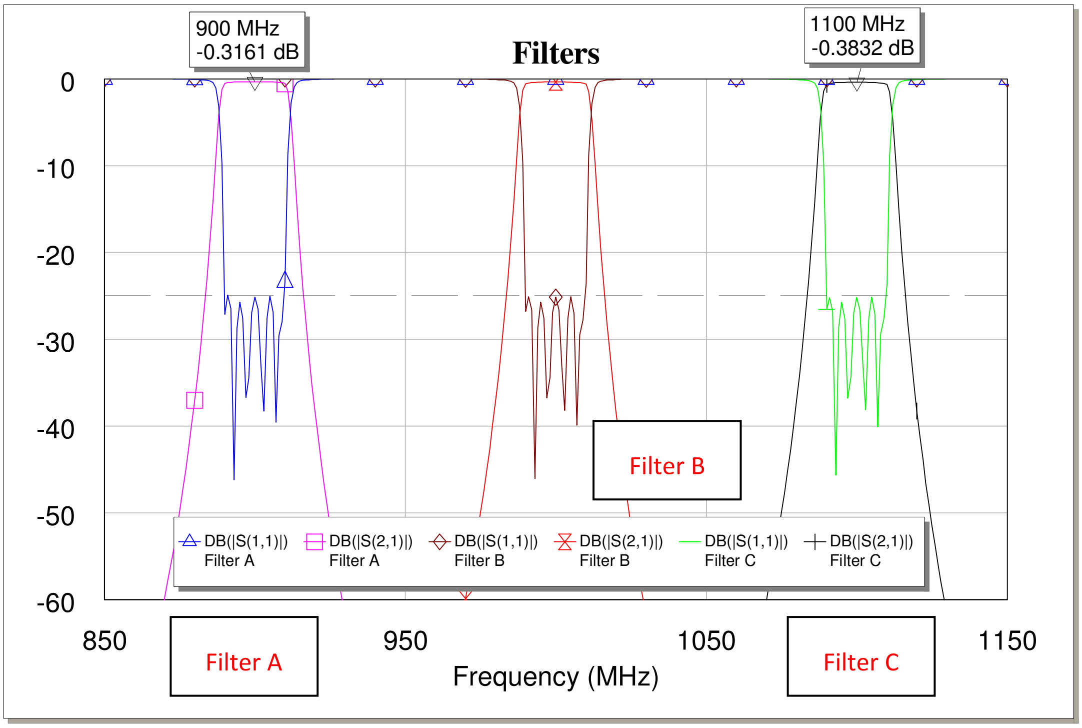

Figure 1

Phase responses of these three filters are shown in Figure 2. Outside their pass band, all three filters asymptote to a phase of 0˚. This value is arbitrary and primarily depends on the nature of the lumped-element model used. A filter, like the one in Microwave Library of General elements (BPFC = Chebyshev Bandpass Filter in Closed Form) asymptote to 180˚ which has been chosen to represent an ideal filter. In this case a phase length of $\lambda/4$ is required to diplex two ideal filters which are far away in frequency. Lumped element model used here can easily be modified so that it asymptotes to any desired phase value.

In practice, the value to which the phase asymptotes is determined by the physical nature of the filter implementation (microstrip, combline, stripline filter, etc) and in particular the way in which coupling to the first resonator is achieved (direct tap coupling, transformer coupling, etc).

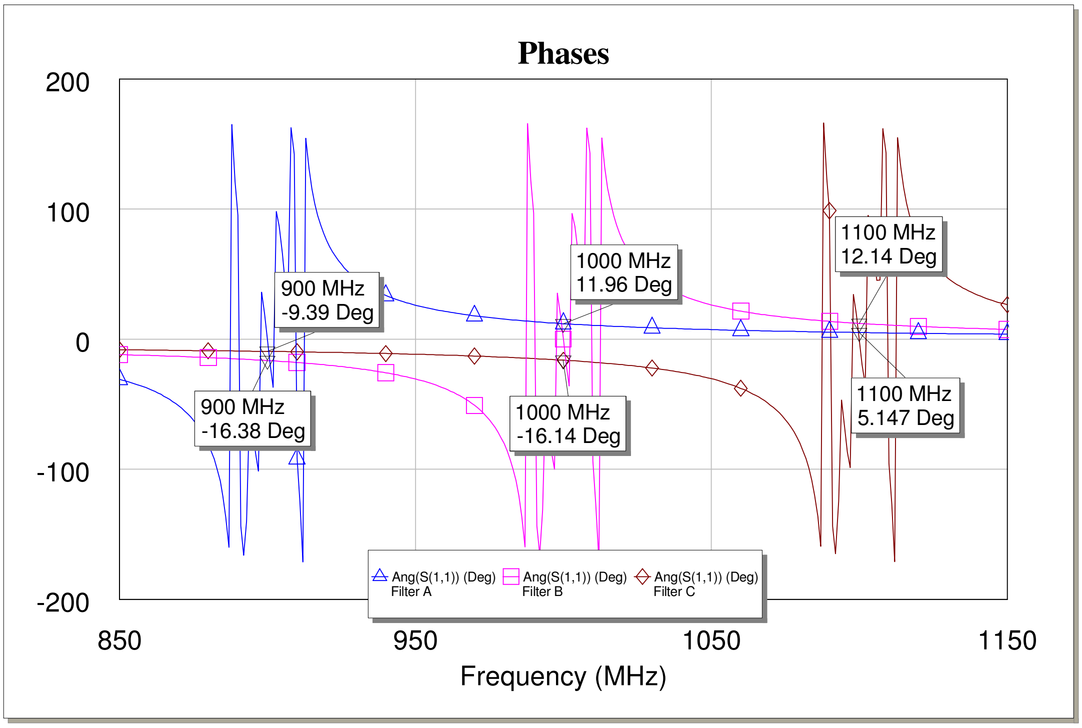

Figure 2

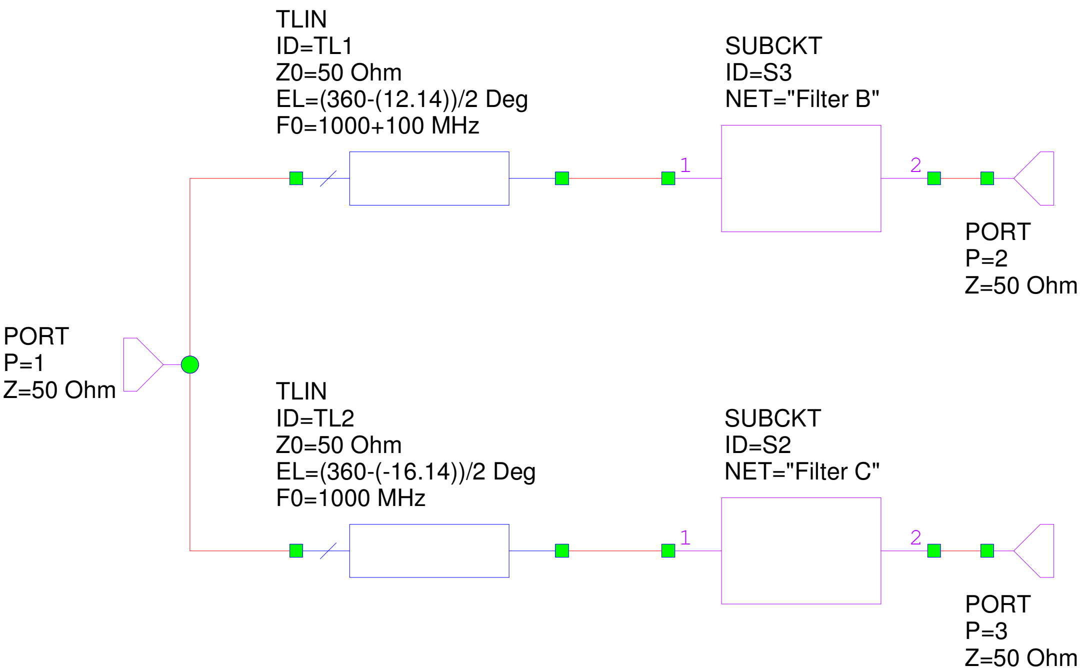

Figure 3

Circuit used for diplexing is shown in Figure 3. Phase length in front of Filter B:

$$\frac{[360° - (12.14°)]}{2}$$

is calculated as follows. Signals in Filter C passband entering from Port 1 into the upper branch will suffer the following phase shifts:

- (360°-(12.14°))/2 when entering the branch
- reflected phase shift of Filter B at Filter C centre frequency, as no signal at Filter C frequency will go through Filter B
- (360°-(12.14°))/2 when exiting the branch through Port 1

The total round-trip phase shift of Filter C signals in Filter B branch has to be a multiple of 360° (or really 0°) so that Filter C signal entering Port 1 and going directly to the lower branch, and Filter C signal entering the lower branch after being reflected back from Filter B, cannot be told apart.

Phase shift suffered by Filter C signals being reflected from Filter B can be read off from Figure 2. We use only the centre-frequency value (12.14° at 1100 MHz on Filter B magenta line), as the phase slope of a Filter outside and far away from its pass band is very small.

The total round-trip phase equation is:

$$\frac{[360° - (12.14°)]}{2} + (12.14°) + \frac{[360° - (12.14°)]}{2} = 360°$$

Using exactly the same argument, we find that the length of the transmission line in front of Filter C should be

$$\frac{[360° - (-16.14°)]}{2}$$

as this is the phase shift of Filter C at Filter B centre frequency.

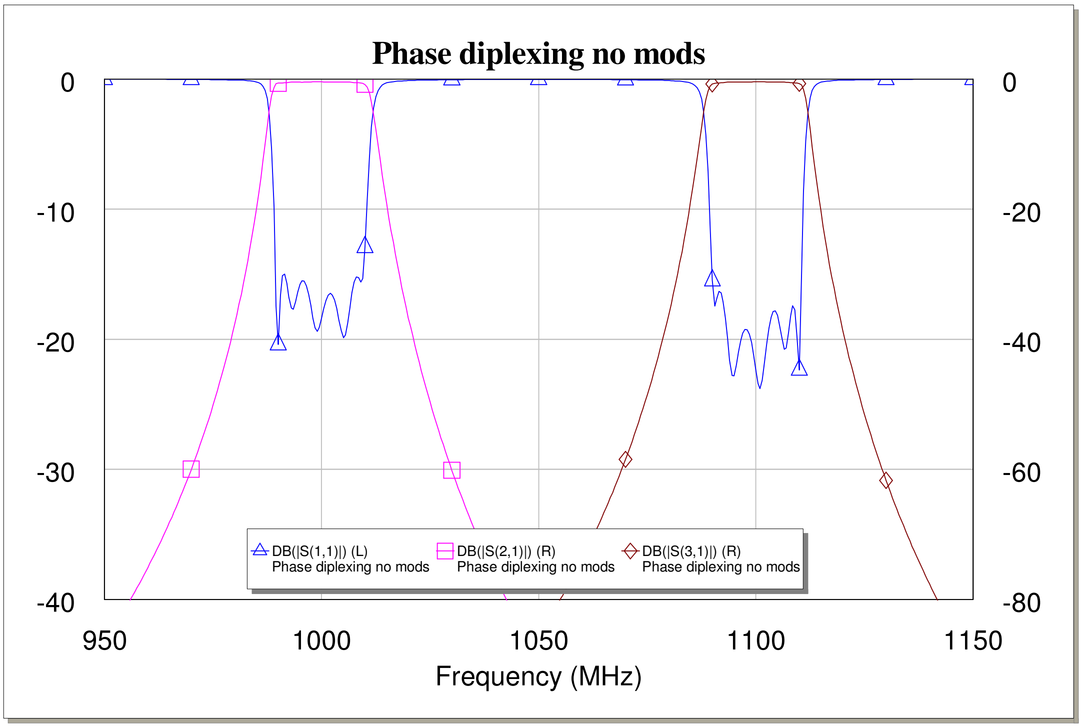

Figure 4

Response of the circuit of Figure 3 is shown in Figure 4. We immediately notice the degradation in the return loss of the two filters. From the starting value of 25 dB, the circuit is now only showing a return loss of about 15 dB.

Since the two filters are not infinitely far away, they load each other, thus changing their performances when compared to those of the individual filters. This change in performance can be observed by the different reflected phase responses of the two filters in two different states (Figure 5).

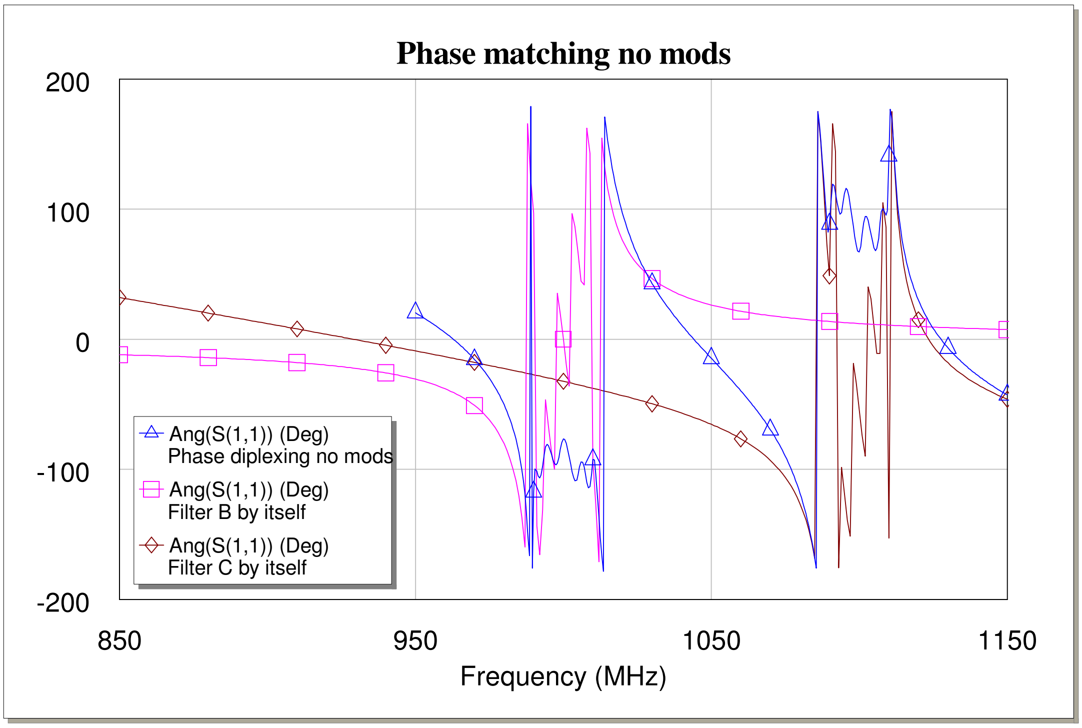

Figure 5

Blue line ("Phase diplexing no mods", shows varying phases over both passbands) shows the reflected phase response of the two filters when they are in the circuit of Figure 3, i.e. with two joined phase lengths in front of them.

Magenta ("Filter B by itself) and brown ("Filter C by itself") lines show the reflected phase responses of the two filters by themselves, without any additional elements. The two sets of responses are clearly different. This difference is due to the interaction of the two filters, and it is the cause of the observed return loss degradation.

In order to correct this problem, the parameters of the two filters need to be modified. The reflected phase response of a filter is primarily determined by the initial few elements in the filter (initial few resonators and adjacent coupling bandwidths). Therefore, we change the following values:

- filter input coupling
- resonant frequency of the first resonator
- first-to-second resonator coupling bandwidth

Optimised response of the two diplexed filters is shown in Figure 6. The amount by which each of the three values changed is shown in Table 1.

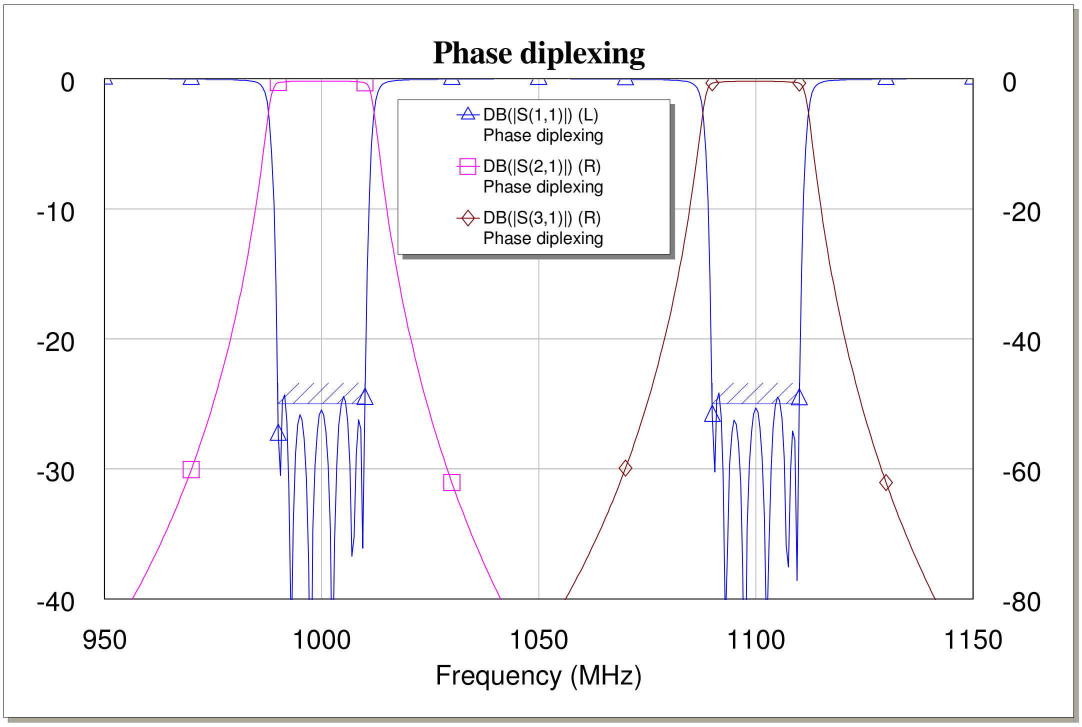

Figure 6

Parameter	Filter B original value	Filter B modified value	% change	Filter C original value	Filter C modified value	% change
Input coupling [MHz]	24.37	20.12	-17.4	24.37	20.21	-17.1
First resonator resonant frequency [MHz]	1000	997.5	-0.25	1100	1101.4	0.13
First-to-second resonator coupling bandwidth [MHz]	18.82	18.21	-3.24	18.82	18.31	-2.7

Table 1

The input coupling bandwidth changed the most, as expected, and the other two values changed very little. Since the first resonator frequency and first-to-second resonator coupling changed little, and since the goal was achieved, there was no need to change any other filter values.

Figure 7 shows that now the diplexed filters exhibit the same (or very close to) reflected phase response as the individual filters. This way, the effect of the two filters loading each other due to proximity in frequency was compensated by modifying filter parameters, in order to obtain the same response.

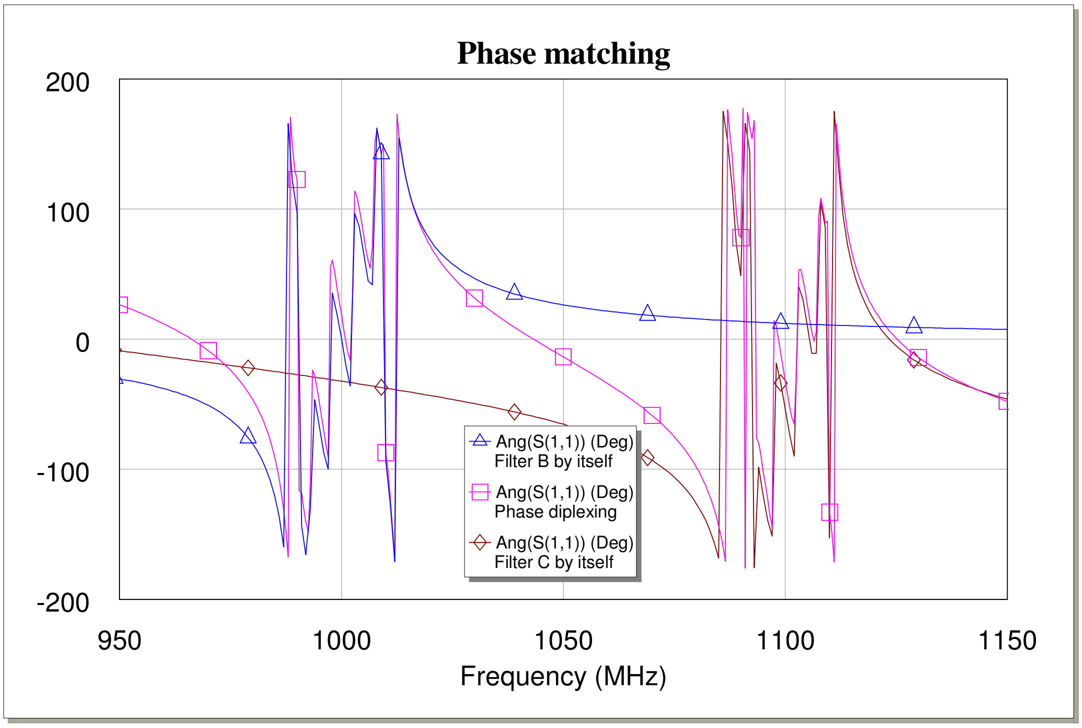

Figure 7

MANIFOLD DIPLEXING

The two filters can also be diplexed by using a manifold approach, as shown in **Error! Reference source not found.**. Here:

- Elements 1, 2, and 3 fixed 180˚ phase elements, arbitrarily chosen to be at the average of the two centre frequencies.
- Elements 4 and 5 are the main phase shifters.

As it can be seen from the values of phase shifters 4 and 5, the same basic 360˚ degree phase shift condition applies here, as the phase shift values of elements 4 and 5 are the same as before. Adjustment shifters 6 and 7 still have small values, as in the case of phase diplexing.

There are, however, two additional paths that each of the two signals (one at Filter B centre frequency, and the other one at Filter A centre frequency) can go through in this circuit.

At Junction 1, Filter B can go to the right or it can continue going down. If it goes right it is absorbed by Filter B. If it continues going down, it suffers a 180˚ phase shift when going to Junction 2.

At Junction 2 there are two options: going to the right, or going down. The signal going to the right will be reflected from Filter C and back at Junction 2 it will have the total phase shift of 360˚. At Junction 2 it can go down, or it can go back up. If it goes back up, it will suffer another 180˚ phase shift until it gets to Junction 1. With the original phase shift of 180˚ (suffered by going down from Junction 1 to Junction 2), this is a total phase shift of 360˚ at Junction 1.

Once reflected back from Filter C, the signal going down at Junction 2 will suffer a 90˚ shift, then it will shift another 180˚ due to being reflected from the short, and in the end it will shift another 90˚ coming back up from the short to Junction 2. By going back (as other paths have been looked at) to Junction 1 it will suffer another 180˚ of phase shift. With the original 180˚ (going from Junction 1 to Junction 2), this is a total phase shift of 180˚ + 90˚ + 180˚ + 90˚ + 180˚ = 720˚ = 3 x 360˚ = 360˚.

So, all paths in this circuit satisfy the total 360˚ phase shift condition.

The 180˚ phase shift immediately after Port 1 does not affect phase relationships in this circuit.

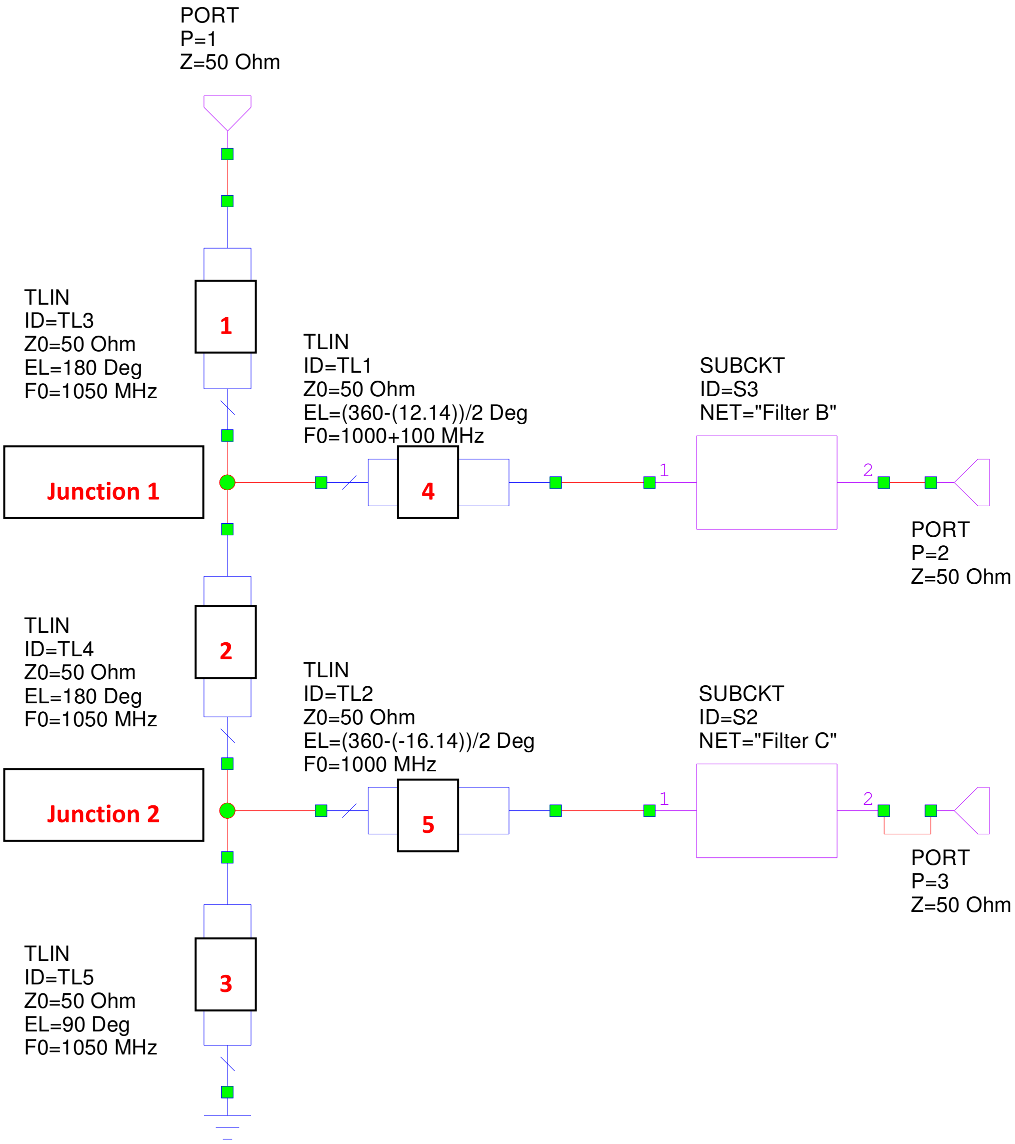

Figure 8

Figure 9 shows the performance of the circuit in Figure 8, that is without Filters B and C being modified in any way. Again, we see some degradation in return loss performance, although it is not as pronounced as in the case of phase diplexing.

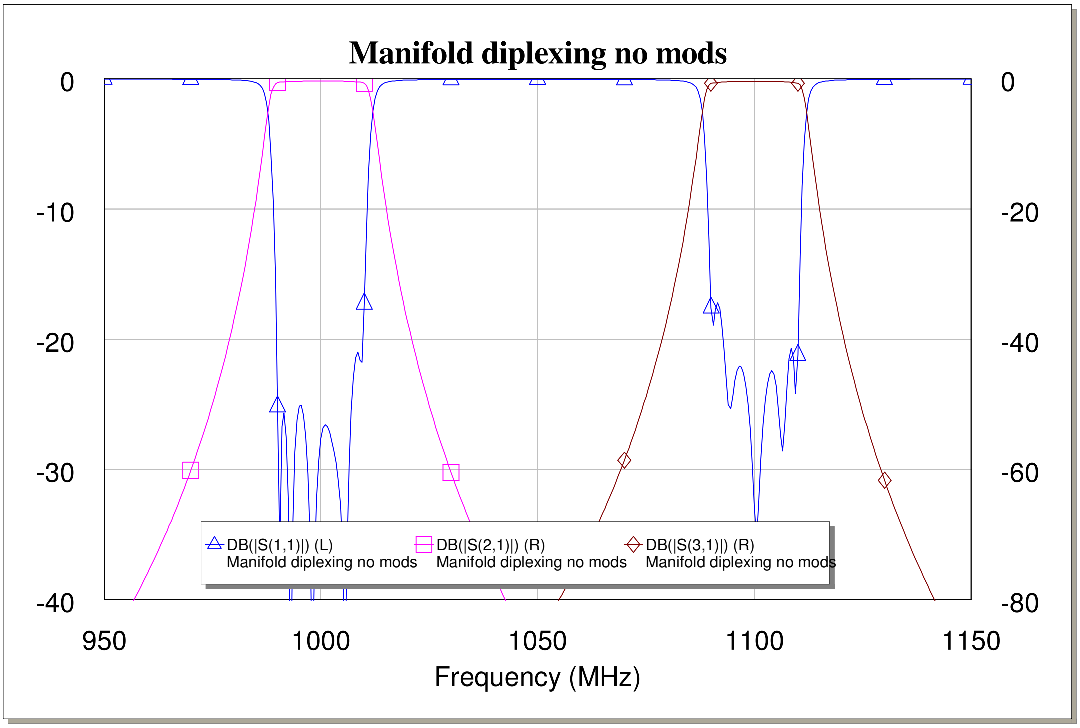

Figure 9

After optimising the same parameters as before, we obtain the performance shown in Figure 10.

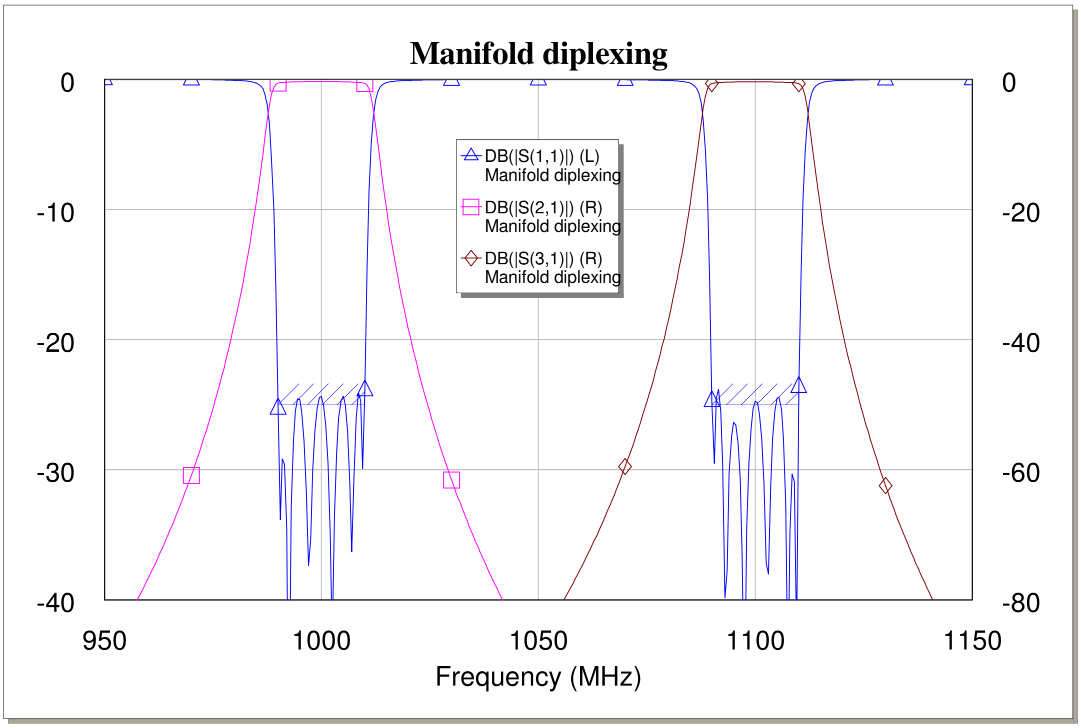

Figure 10

Parameter changes are shown in Table 2; the range of changes in the same as in the phase diplexing case.

Parameter	Filter B original value	Filter B modified value	% change	Filter C original value	Filter C modified value	% change
Input coupling [MHz]	24.37	21.58	-11.4	24.37	20.34	-16.5
First resonator resonant frequency [MHz]	1000	999.5	-0.05	1100	1100	0
First-to-second resonator coupling bandwidth [MHz]	18.82	18.01	-4.3	18.82	18.36	-2.4

Table 2

PHASE TRIPLEXING

The above concept can easily be extended to a triplexing arrangement, where Filter A is present in addition to Filters B and C, as shown in Figure 11.

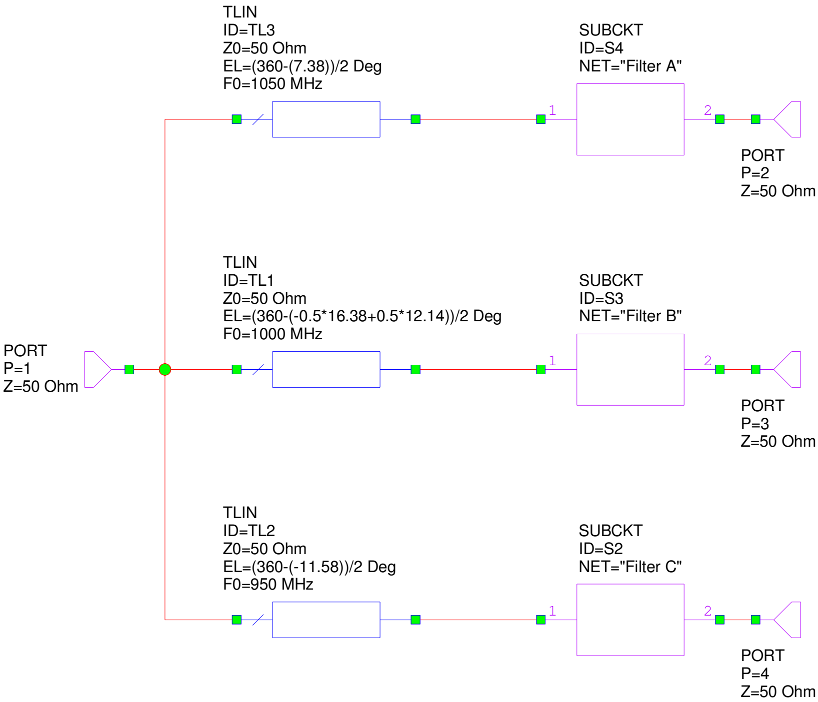

Figure 11

As discussed previously, phase shifting element is specified at one frequency only. Otherwise, a phase equalising element would be required. Specifying the phase shift at one frequency only is justified by the fact that the phase of a filter outside its passband changes slowly, and mostly in a linear manner.

Phase shift in front of Filter A is specified at 1050 MHz, which is the middle point between Filter B and Filter C centre frequencies. Similarly, phase shifting element in front of Filter B is specified at 1000 MHz, while the phase shifting element in front of Filter C is specified at 950 MHz. See Figure 12 for reference.

On the basis of the same logic, the length of the shifting element in front of Filter A is chosen to be (360-(7.38˚))/2. 7.38˚ is the reflected phase of Filter A at 1050 MHz, frequency in between Filter B and Filter C centre frequencies. An alternative would have been to use (11.96 + 5.147)/2 = 8.6˚, which is the average of Filter A reflected phase at Filter B and Filter C centre frequencies.

Phase shift at 950 MHz, in front of Filter C, has been calculated in the same way.

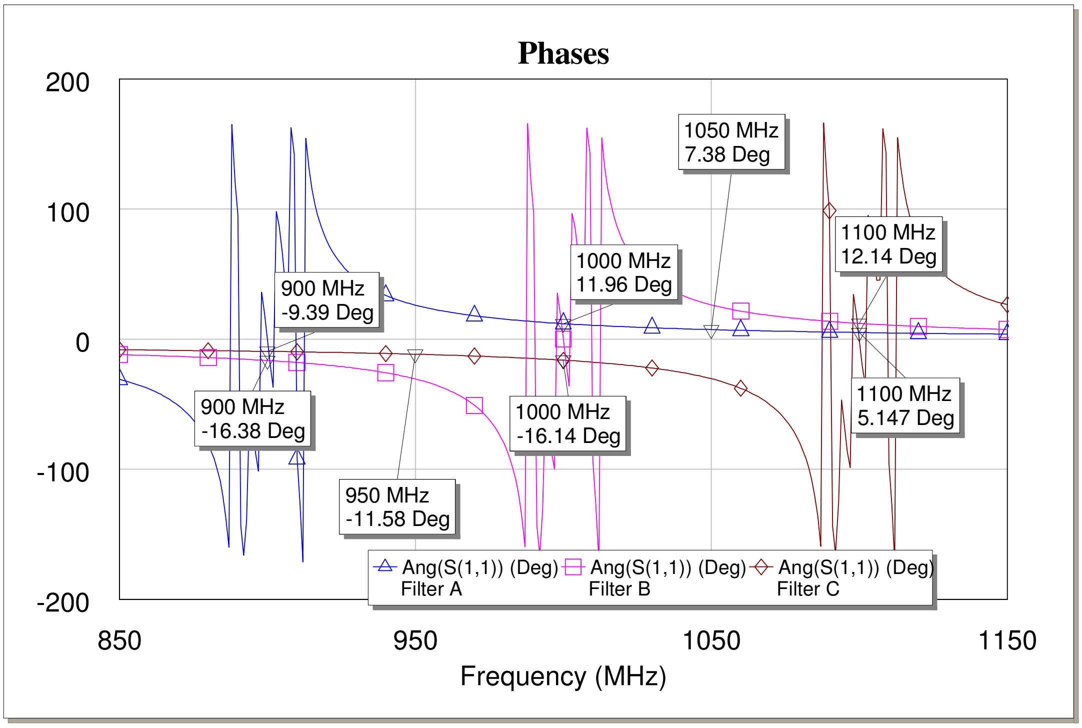

Figure 12

In the case of phase shift at 1000 MHz, in front of Filter B, an average of Filter B reflected phase at Filter A centre frequency (-16.38˚) and Filter B reflected phase at Filter C centre frequency (12.14˚) is used, for obvious reasons.

The performance of this triplexer, where the individual filters have not been optimised, is shown in Figure 13. Again, we see some degradation in the return loss.

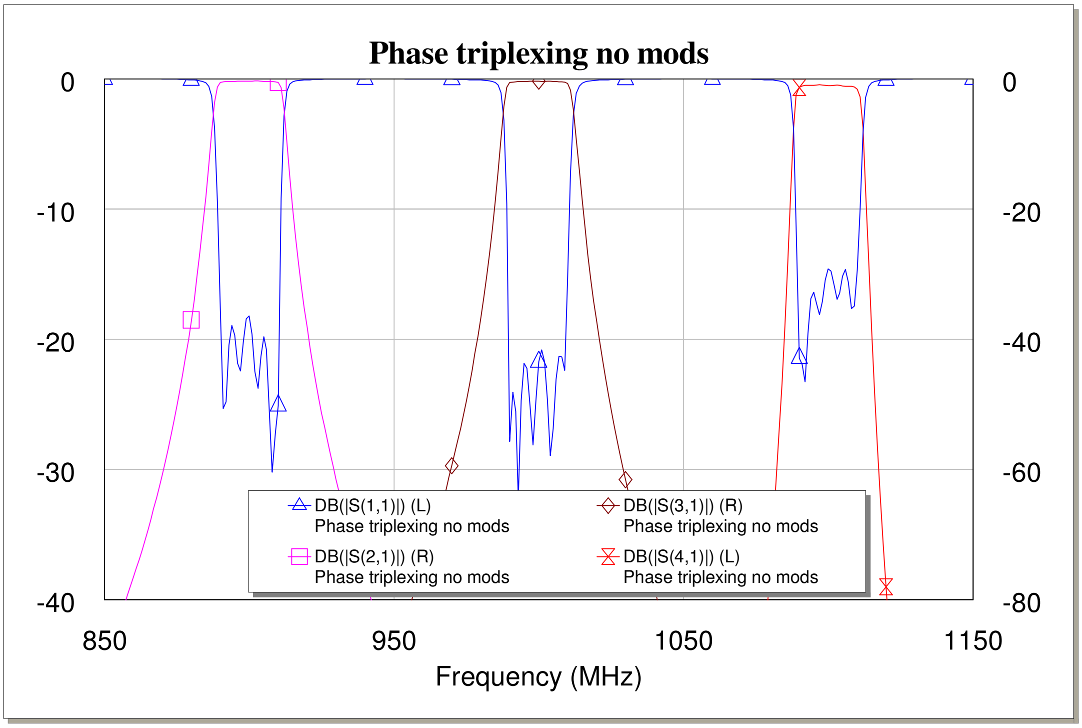

Figure 13

The response after optimisation is shown in Figure 14.

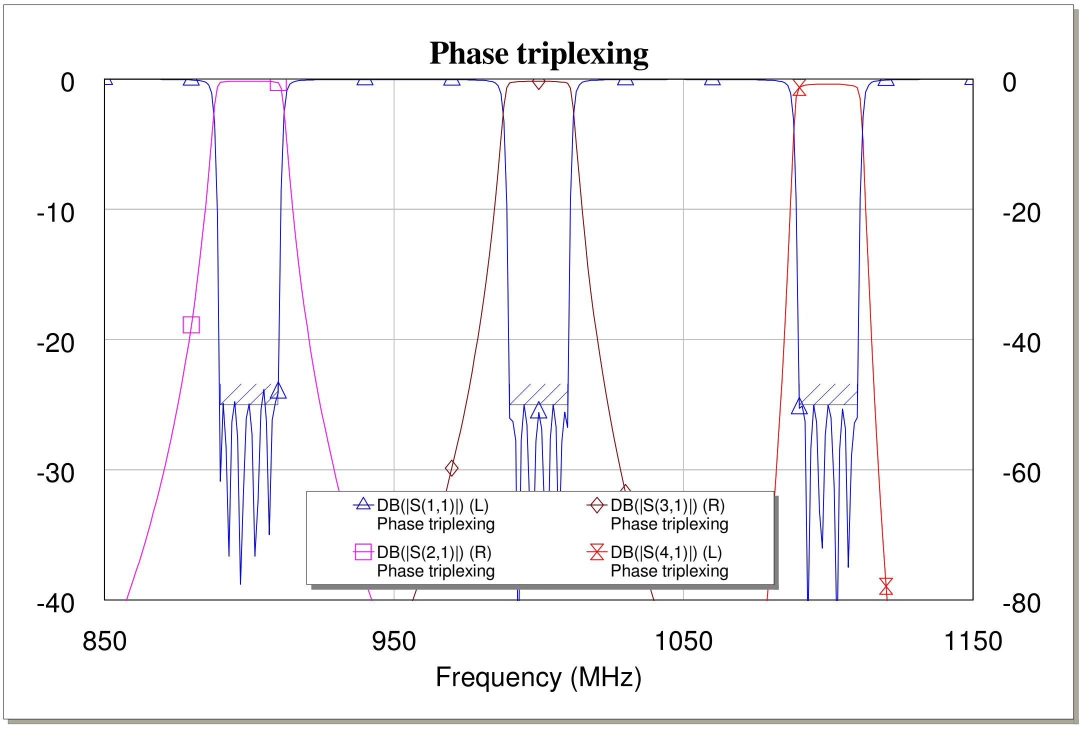

Figure 14

The degree to which filter parameters changed is as before.

MANIFOLD TRIPLEXING

Manifold triplexing is a simple extension of manifold diplexing. As in the diplexing case, manifold branch phase shifts are the same as in the phase triplexer case (Figure 15).

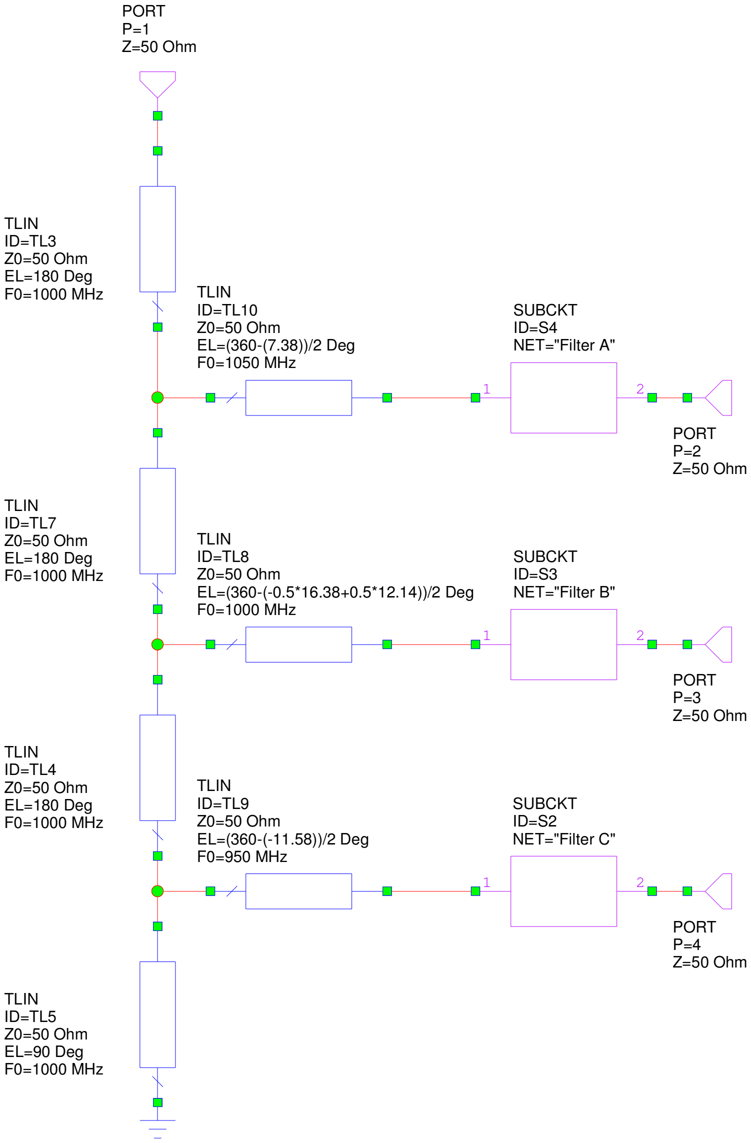

Figure 15

Circuit response without optimisation is shown in Figure 16, while the response after optimisation is shown in Figure 17.

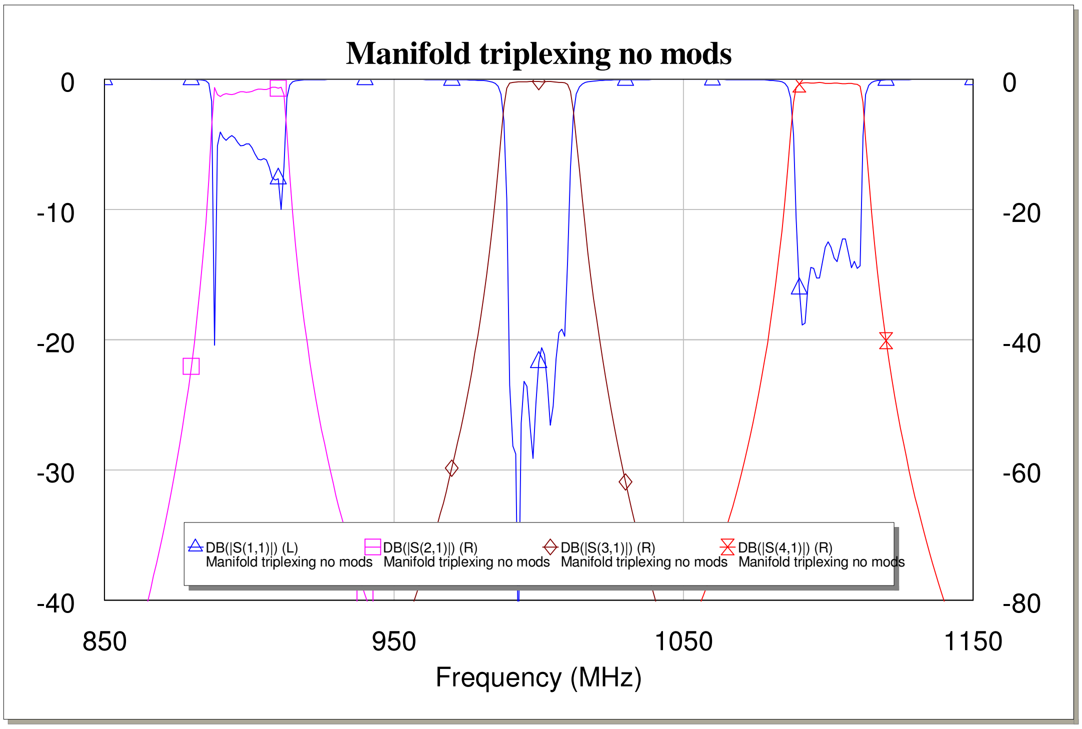

Figure 16

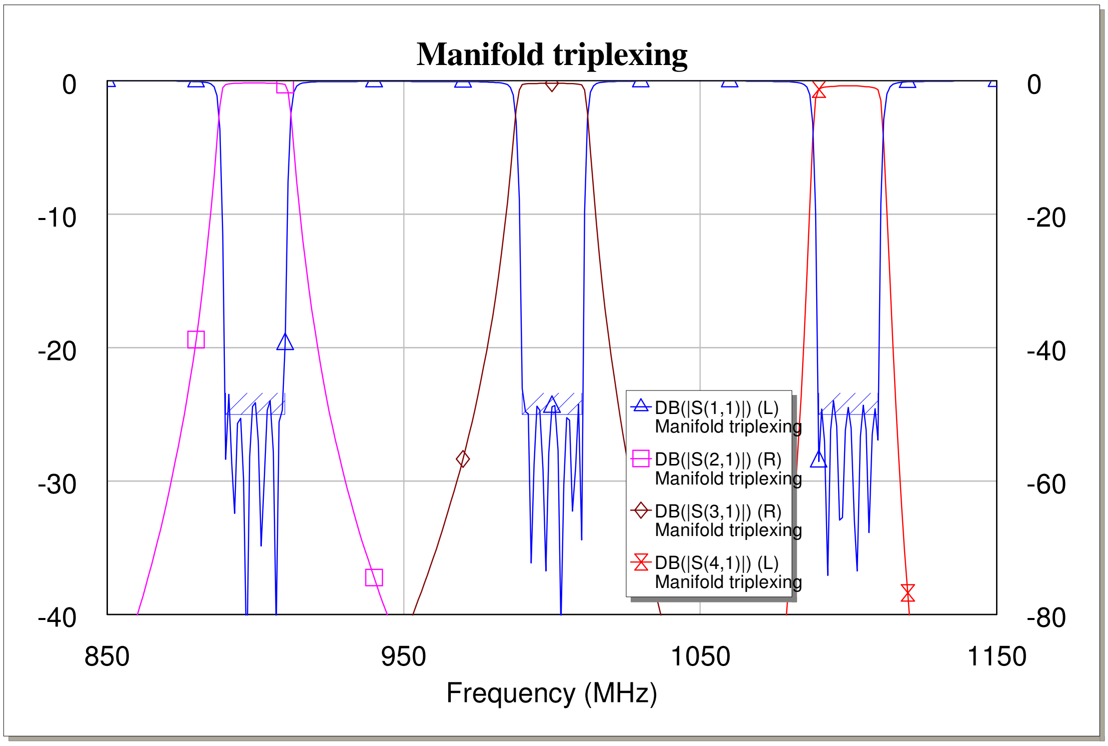

Figure 17

VERSION HISTORY

Version 1 (02 APRIL 2009): First release