MILLIMETER WAVE MIC BANDPASS FILTERS AND MULTIPLEXERS

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ABSTRACT

Using low dielectric constant substrates (Duroid, $\varepsilon = 2.22$), various millimeter wave filters, diplexers, and triplexers have been fabricated. Originally constructed on open microstrip, circuits exhibited considerably lower losses when enclosed in channels and integrated with printed circuit to waveguide transitions.

Introduction

Millimeter-wave receivers which use MIC "front ends" invariably either have waveguide filtering or direct mixer inputs. Usual MIC bandpass filters are known to be lossy and a combination of such filters, as might be used for multiplexing, should give rather poor results. Furthermore, it might be thought that the fabrication of such devices at frequencies in the 26-60 GHz range might require a good deal of experimentation.

In this paper we will show that millimeter-wave MIC bandpass filters and multiplexers can be designed rather accurately. Most important, we will show how the use of printed circuit to microstrip transitions, together with filter channelization, can greatly reduce the losses of these devices.

Filters on Open Microstrip

Various 5 and 6 section edge coupled filters were constructed on Duroid in the frequency range 28-60 GHz. The Tchebycheff designs used the formulas of Cohn,[1] together with the coupled-line even and odd mode impedances and effective dielectric constants of Bryant and Weiss.[2] Using the above data, the length of each coupled line section was compensated for the different even and odd mode propagation velocities by the Dell-Imagine formula:[3]

$$L = \frac{\lambda_o}{4} \; \frac{Z_{oe} + Z_{oo}}{Z_{oe}\sqrt{\varepsilon_{oe}} + Z_{oo}\sqrt{\varepsilon_{oo}}}$$

λ_o = free space wavelength

ε_{oe} = even mode effective dielectric constant

ε_{oo} = odd mode effective dielectric constant

Analysis of the filters utilized our own MIC network analysis program which treats the edge coupled sections as two-port devices in ABCD matrix form[4] and multiplied together. As suggested by Childs[5], a decided improvement in accuracy could be obtained if the above matrices were modified to account for the end capacities of the open ends of the coupled line sections. Figure 1 shows the experimental bandpass plot of a six section Tchebycheff filter on open microstrip. Calculated bandpass characteristics (assuming no losses) with and without end capacitance modifications are shown in the same diagram. The actual capacities used were taken from the empirical curve matching equations of Silvester and Benedek[6] for dielectric constant 2.5.

Note that in this figure, as in all others, losses include those of the transitions. Also, in order to reduce radiation losses in open microstrip, a small metal bridge having an inverted "U" shape cross section is suspended across the filter. The bridge used was about 1/4 wavelength above the microstrip. The size, shape and height of such bridges are relatively insignificant. The design method for all bandpass filters was to:

1. Calculate the even and odd mode impedances needed for the various sections for the Tchebycheff desired.
2. Find the closest Z_{oe} and Z_{oo} and effective dielectric constant values on a tabulation which we made from the Bryant and Weiss MSTRIP program[2] for dielectric constant 2.22 (tabulation available on request). Use lengths found from Dell-Imagine formula.
3. Find the Silvester and Benedek end capacities, from another tabulation, for the various strip widths required in (2).
4. Calculate the performance of the filter. These results are displayed on a graphic terminal.
5. Note the percentage shift in frequency from the center of the bandpass desired. Each section length is then decreased by the above amount.
6. The bandpass characteristic is computed using the new section lengths. Generally these come out very close to the desired bandpass.

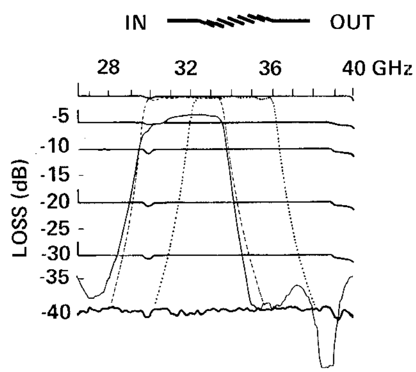

Figure 1. 6 section Chebycheff filter response
.... calculated without end capacitance
- - - - - calculated with end capacitance
———— measured

Diplexers on Open Microstrip

Figure 2a shows the form of a two channel MIC diplexer.[7] For lossless filters, each bandpass filter appears as a pure reactance out of band. At the input of each filter an additional transmission line is added to make the out of band reactance appear as an open circuit. That is to say, at 32 GHz the higher frequency bandpass filter appears as an open circuit to the input line, and at 36 GHz the low frequency bandpass appears as open circuit. Although losses are excessive using the open form of microstrip, the bandpass calculations proved out very well, and as will be shown, the diplexer works quite well when used in reduced width waveguide with printed circuit transitions.

Figure 3 shows another form of diplexing in which the quadrature characteristics of 3 dB branch couplers were utilized. For ideal couplers of this type, if the direct and coupled ports are terminated in equal reactances, input signals will appear unattenuated at the fourth port. The two bandpass filters used in this diplexer are identical and, as mentioned previously, ideal bandpass filters appear as pure reactances out of band. Hence out-of-band frequencies appear at the fourth port of the first hybrid, in-band frequency appear 90 degrees out of phase at the input terminals of the second hybrid. The additional phase shift of the second hybrid recombines the in-band frequencies in phase at one of the outport ports.

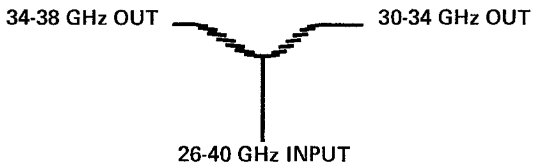

Fig. 2a. Two channel diplexer

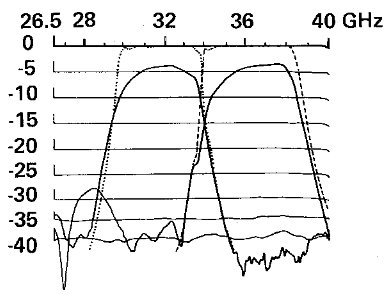

Fig. 2b. Measured vs computed diplexer bandpass outputs. Much less loss was obtained with printed circuit transitions and channelized filters. This illustrates the good correlation between measured and computed frequency behaviour.

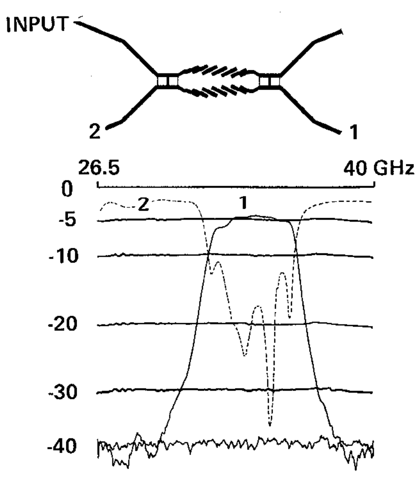

Figure 3. Diplexer using quadrature couplers which recombine bandpassed signals.

Low Loss Printed Circuit Transitions

The Van Heuven printed circuit transition[8] was modified considerably to produce wide bandwidth transitions with very low loss. Although long length transitions were built which had low (1.2) VSWR over full waveguide bandwidths, short step transitions such as shown in Figure 4 had extremely low loss (0.3 dB per transition) along with adequate VSWR for all practical purposes.

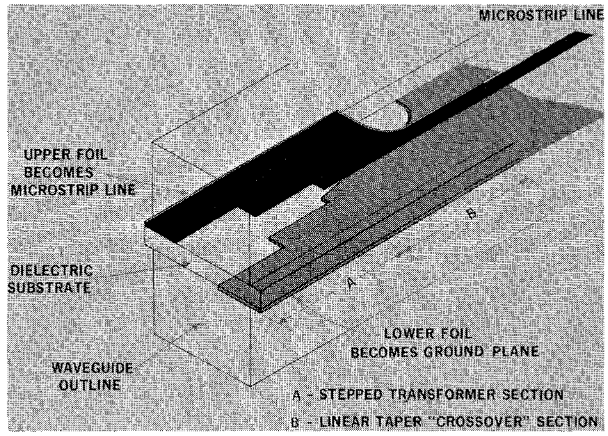

Figure 4a. Printed Circuit Waveguide to Microstrip Transition.

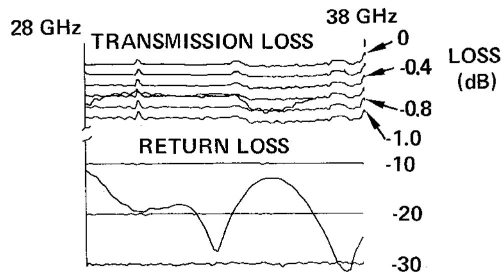

Figure 4b. Transmission and Return Loss of Transitions.

Figure 4. Waveguide to Microstrip Printed Circuit Transitions. Losses shown for two transitions plus 0.60" of microstrip line.

Figure 5 shows the bandpass characteristics of a six section, 1 dB ripple filter designed for 44-48 GHz. The 2 percent frequency discrepancy could not be resolved using Bryant and Weiss computations for covered microstrip. The success of the two port printed circuit transitions led to the fabrication of transitions for four port devices. It was necessary to fabricate channels which had height H (Fig. 4) 10-15% less than standard waveguide. Also, it was necessary to surround the entire dielectric with metal, i.e., inserting the microstrip in open slots or slots which had shorts 1/4 wavelength away (choke flanges) led to spurious responses.

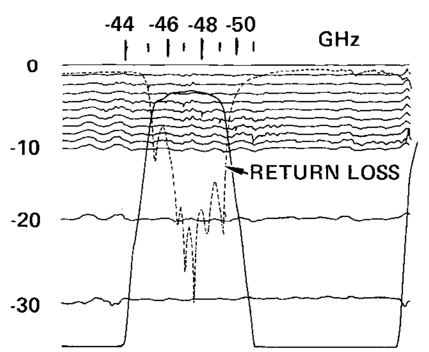

Figure 5. Six section 44-48 GHz filter using printed circuit transitions.

Multiplexers with Printed Circuit Transitions

The two forms of diplexing indicated above were combined to form the triplexer shown in Figure 6. All but the mid-band frequencies are diverted to the fourth port of the input hybrid coupler. The two branch diplexer is then used to split the high and low bands. The center band frequencies are recombined at one of the output ports of the second hybrid, the other port is terminated by using resistive Mylar film over a length of transmission line. All of the filters were channelized, the two mid-band filters confined to the same channel. It was a simple matter to test the two branch diplexers by themselves in this housing, the mid-band channel is simply removed and the input connected to the remaining diplexer. Figure 7 and 8 show the bandpass characteristics of both contiguous and non-contiguous diplexers of this type.

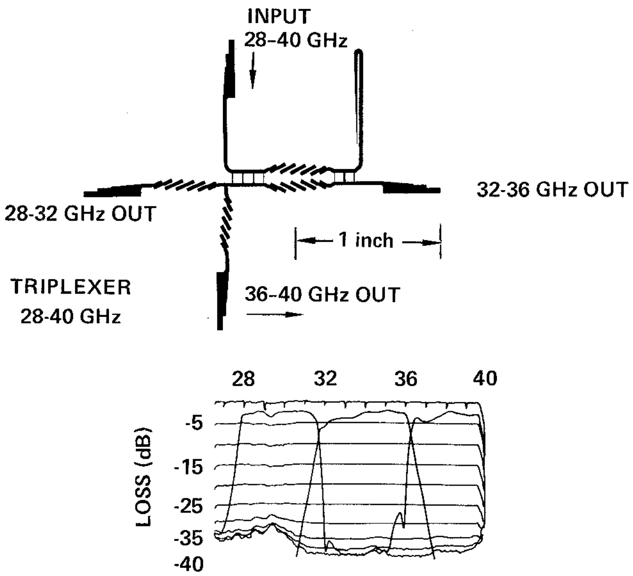

Figure 6. 28-40 GHz Triplexer. Filters are 0.5 dB Tchebycheff.

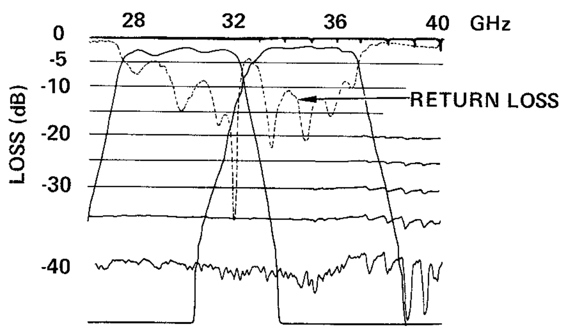

Figure 7. Bandpass characteristics of contiguous diplexer using printed circuit transitions.

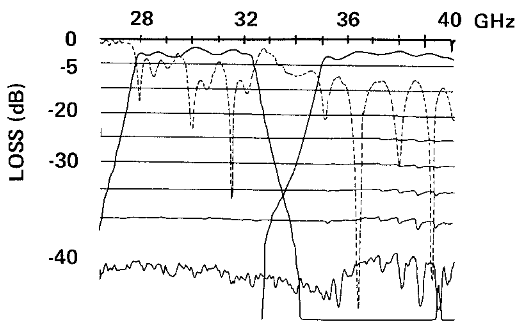

Figure 8 Bandpass characteristics of non-contiguous diplexer using printed circuit transitions.

Fabrication

Rogers type 5880 RT/duroid was used for these filters, 0.010" substrates for less than 40 GHz, 0.005" substrates for above 40 GHz. Copper cladding was pre-etched to about 0.0002" before photoresist was applied. Pre-etching was required to reduce undercutting since most of the filters required approximately a 0.002" gap for the first and last coupled sections. "Rolled copper" cladding has somewhat lower conductive losses than "electrodeposited" copper and is preferable for this use.

Conclusions

Previous to doing the reported work, the authors had used low dielectric constant microstrip to build a variety of millimeter wave MIC components such as mixers, bandpass filters, and oscillators.[7] We believed that microstrip at these frequencies was very useful, but waveguide type diplexers and multiplexers were the only reasonable methods for channelizing input signals. With the development of the new low loss/printed circuit transitions and using the analysis methods described, we now feel that the extreme low cost and simple fabrication of microstrip multiplexers should be considered for many millimeter wave applications.

References

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