18-30 GHz BROADBAND BANDPASS HARMONIC REJECT FILTER

T.N. Ton, Y.C. Shih, L.Q. Bui

MM-Wave Technology, Inc.
365 Van Ness Way, Bldg. 505 Torrance, California

Abstract

An 18-30 GHz harmonic reject filter has been designed using a distributed prototype. The aspect ratio of the coupled suspended stripline structure is chosen to equalize the even- odd-mode electrical lengths when considering the open-end effects. The measured insertion loss is about 1 dB in the passband and more than 40 dB rejection up to twice the center frequency.

Introduction

Recent advances in microwave and millimeter-wave receivers and measurement systems create a need for broadband harmonic reject filters. For example, using such a filter in a "multiplied" mm-wave source will allow the signal to have a much lower harmonic contents. In this paper, we present the design and measurement of an 18-30GHz bandpass filter. The filter is a parallel-coupled line filter designed on a suspended substrate with built in transitions to waveguide input and output. The measured insertion loss is about 1 dB and return loss is about 15 dB in the passband, better than 40 dB rejection has been measured up to twice the center frequency (2 fo). The printed circuit technology is used to reduce the cost and size in the production of microwave and millimeter wave systems with improved performance and reproducibility.

Design procedures for parallel-coupled line filters have been fully documented (1,2,3,4). However, in the practical realizations at millimeter-wave frequencies, several design iterations are normally required because of the problems associated with the prototypes, the transmission lines and, the discontinuities. To alleviate the problems in the design of 18-30 GHz filter, we have selected a prototype which is capable of broadband design. We have also chosen a transmission line structure, which would approximately equalize the even- and odd-mode electrical lengths when considering the open-end effects. Finally, to integrate the filter with waveguide input and output, we have designed a broadband transition covering 18-30 GHz.

Design Procedure

The parallel coupled suspended-stripline filter is designed using a distributed lowpass prototype. Figure 1 shows a typical filter pattern and its equivalent circuit. The filter consists of, in this example, a cascade of 7 parallel coupled resonators which are open circuited at both ends and a half wavelength long at the mid band frequency fo. It can also be viewed as 8 sections of quarter-wavelength long coupled transmission lines connected in series.

Referring to Figure 1, the following briefly summarizes the design procedure. Given the filter specifications (i.e., bandedge frequencies, passband ripples, and number of cavities), the K inverter values in the prototype are first obtained from synthesis procedures (1,4,5,6). Next, the even and odd-mode impedances of a coupled line are determined from the impedance inverter values. Finally, the line width and spacing of each coupled line section are adjusted for a selected geometry to provide the correct even- and odd-mode impedances.

In the design of the 18-30 GHz filter, we have applied four synthesis procedures to calculate the impedance inverter values and made comparison between them. The procedures are, respectively, those proposed by Cohn (1), Cristal (4), Rhodes (5), and by an exact synthesis (6). Cohn's procedure does not produce correct bandwidth for this 50% filter; iteration is required for bandwidth correction. Cristal's formula gives correct bandwidth for the filter; however, the resulting design requires a tighter coupling for the first resonator than the other designs. This makes the filter more difficult to realize and to reproduce. Rhodes' procedure produces the correct bandwidth, similar to the exact synthesis and both methods result in designs having reasonably loose coupling. Rhodes' approach is prefered because of its simple closed-form formula.

From the impedance inverter values, the even- and odd-mode impedance (Zoe,Zoo) of a coupled line can be calculated for a given characteristic impedance. The line width and spacing of the coupled line are then determined from the given even- and odd-mode impedances. Since no closed formula is available for the shielded suspended strip-line, two rigorous analyses are used for study, i.e., the variational method by Smith (7) and the spectral domain technique by Itoh (8). Smith's approach is, in fact, a special case of the spectral domain technique, using a single-term basis function derived from conformal mapping a simplified structure. It is found that Smith's analysis produces results very close to that obtained by the spectral domain technique using three basis functions.

In the physical realization of the broadband filters, it is important to have equal even- and odd-mode electrical lengths for the coupled section. The electrical length is equal to the product of the phase velocity and the effective length of the coupled section. A recent study (9) on the open-end fringing of the coupled line indicates that the effective lengths of the even- and odd-modes are different. Therefore, a structure should be selected such that the difference in the phase velocity will compensate for it. At K- and Ka-band frequencies, we can approximately meet this require-

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ment by choosing a 10-mil Duroid substrate with 25-mil spacing between the substrate and upper and lower ground planes.

To aide in the design of filters at K- and Ka-band frequencies, we have produced two graphs for the chosen structure using the spectral domain technique. Figure 2 presents the design charts for obtaining line width, spacing, even- and odd-mode effective dielectric constants from a given Zoe and Zoo.

The physical length of each section was determined by Del Imagine formula (10). From measurements, the center frequency is shifted downward. Emperically we have corrected the problem by shortening the length by a factor: $\Delta l = .675\ (.4407\ B/2)$ where B is the total ground plane spacing.

Measurement

Figure 3 shows a photograph of the resulting filter. We have designed and fabricated the circuit on a 10 mil RT-5880 Duroid substrate with 1/2 oz. roll copper. The dielectric constant is 2.2. The rubylith layout is prepared using a computer-controlled cutter for high precision. Photo-lithographic and chemical etching techniques are then used to fabricated the circuits. The processes are carefully controlled to achieve a resolution tolerance of .5 mil.

At millimeter-wave frequencies, rectangular waveguides are commonly required as the input and output transmission media. Therefore, to integrate the parallel coupled line filter, transitions from waveguide to suspended-stripline are necessary. An E-field probe transition has been designed and tested similar to that described in (11) from 18-40 GHz. The measured results are shown in Figure 4. The insertion loss is about .5 dB and return loss is about 15 dB from 18 to 32 GHz.

The complete filter including the probe transitions has been tested and the results are shown in Figure 5. The insertion loss is approximately 1 dB and return loss is more than 12 dB in the passband. The measurement in Figure 4 shows that this filter provide more than 40 dB rejection up to at least 2 fo.

Conclusion

Parallel-coupled harmonic reject filters have been demonstrated for wide-band applications at millimeter-wave frequencies. The measured insertion loss is about 1 dB from 18 to 30 GHz and the rejection is more than 40 dB up to at least 2 fo. The combination of printed circuit and simple split-block construction makes these filters highly reproducible at low cost.

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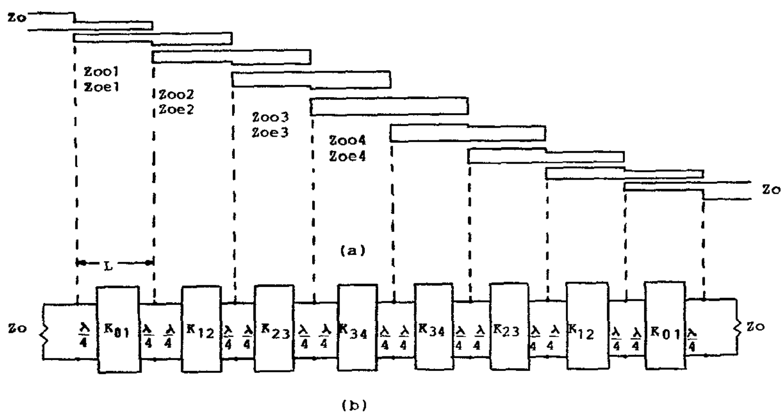


Fig. 1 Parrallel-coupled transmission-line resonator filter, (a) layout (b) equivalent circuit.

FIG. 2a Zoe VS Zoo AS A FUNCTION OF WIDTH AND SPACING

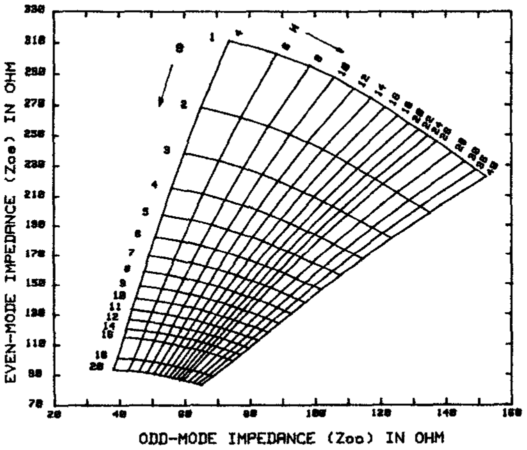
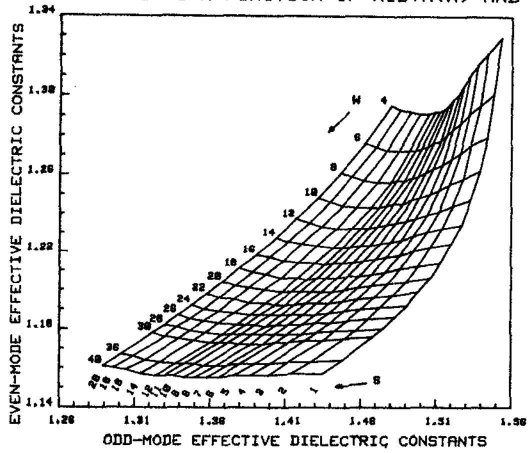


FIG. 2b EVEN- AND ODD-MODE EFFECTIVE DIELECTRIC CONSTANTS AS A FUNCTION OF WIDTH(W) AND SPACING(S)



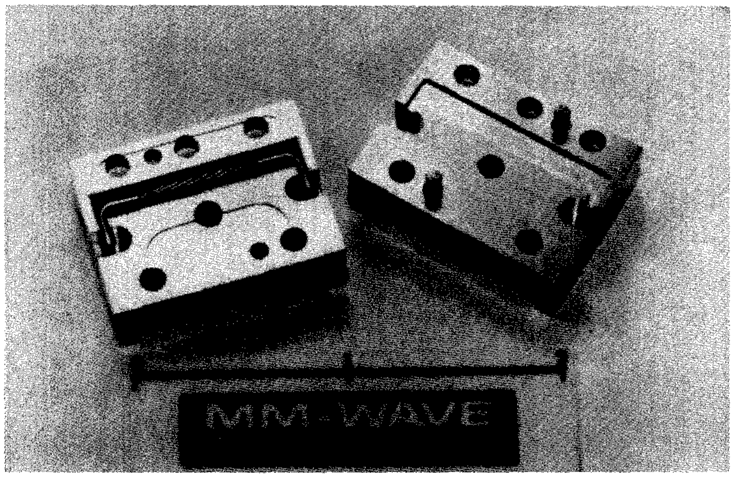


Fig. 3 Photograph of 18-30 GHz Filter.

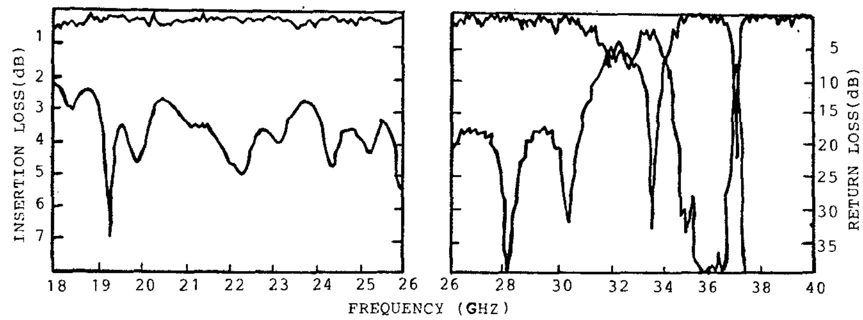


Fig. 4 Measured performance of probe transition.

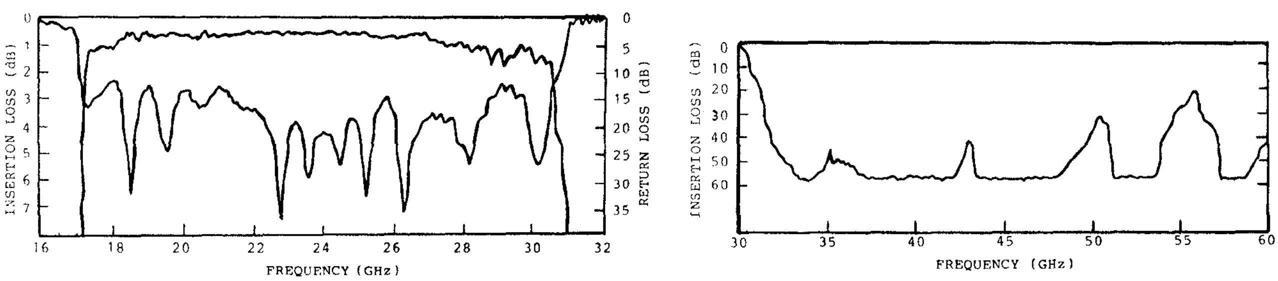


Fig. 5 Measured performance of a 18-30 GHz Filter.