A LOW COST MULTIPLEXER FOR CHANNELIZED RECEIVER FRONT ENDS AT MILLIMETER WAVES

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Summary

Work with millimeter-wave components using printed-circuit techniques has led to the successful development of multiplexers that are compatible with low-cost fabrication and packaging techniques.

This paper will describe a 26 to 42-GHz multiplexer exhibiting 1.2 to 2.8-dB insertion loss over a 4-GHz channel passband and a 45-dB rejection bandwidth of less than 8 GHz. This multiplexer uses a channel-dropping filter technique that splits the band into 4-GHz subbands (channels). Each channel-dropping filter consists of dual band-pass filters separated by a pair of 3-dB directional couplers. Fabrication costs are kept low by using chemically-milled broadwall couplers and E-plane filter resonators.

A series of normalized filter design nomograph's have been generated. Measured multiplexer performance will be presented.

Introduction

Multiplexers to be used in millimeter-wave channelized receivers, covering the 26 to 42-GHz and 42 to 60-GHz waveguide bands, have been developed. The emphasis of the design was to use low-cost fabrication techniques.

The multiplexer is a key component of the channelized receiver. There are several possible ways of frequency multiplexing at millimeter waves; hybrid coupled, circulator coupled, low/high-pass or feed-line multiplexing. The circulator coupled approach is unacceptable because the state of the circulator art is one where low loss per pass can be realized only over a small portion of the described band. Low/high-pass multiplexers and feed-line multiplexers require costly fabrication. The hybrid-coupled multiplexer (shown in Figure 1) is considered to result in low-production costs and performs well over an entire waveguide band. The key building blocks of this multiplexer, the 3-dB coupler and band-pass filter, have been realized by an inexpensive construction technique that yields low loss and predictable performance.

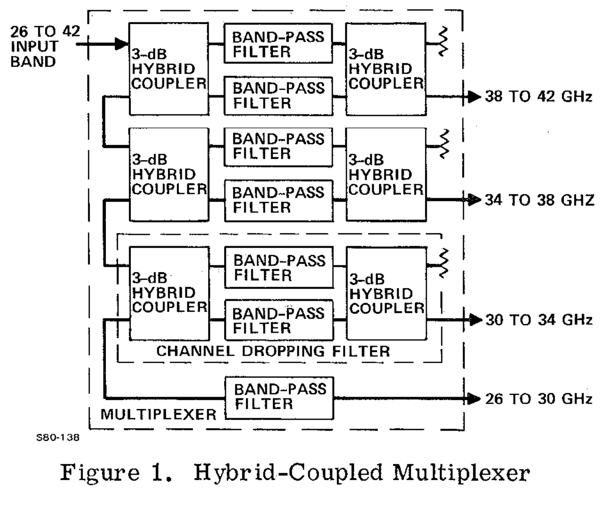

Figure 1. Hybrid-Coupled Multiplexer

Multiplexer

The hybrid-coupled multiplexer is required to split the 26 to 42-GHz threat band into 4-GHz wide contiguous channels. Channelizing is accomplished by use of a channel-dropping filter arrangement shown in Figure 1. The 26 to 42-GHz input is diplexed to first provide a 38 to 42-GHz output channel. The remaining 26 to 38-GHz portion of the input is directed to the next diplexer (channel-dropping filter) in the sequence. This diplexer passes the 34 to 38-GHz channel, and reflects the remaining portion of the input band. The process repeats to the last element in the multiplexer, the band-pass filter for the 26 to 30-GHz channel. Each channel-dropping filter is matched at all four ports. Hence, the connection of several diplexers to form a multiplexer is done with virtually no interaction. Accordingly, the design of a multiplexer is very predictable and repeatable.

Details of the channel-dropping filter are shown in Figure 2. Each diplexer consists of one dual band-pass filter between the two 3-dB quadrature couplers.

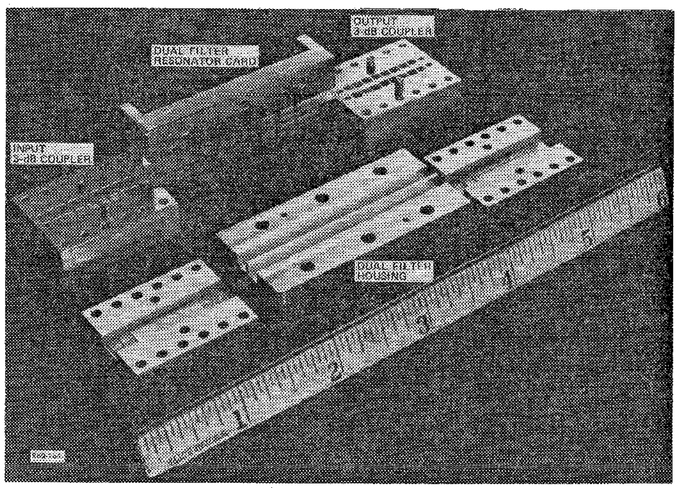

Figure 2. Channel Dropping Filter

Figure 2 depicts the physical makeup of the diplexer-filter resonator and the coupler elements, which are planar and batch-fabricated using printed-circuit techniques. This feature results in low production costs and assures repeatable performance. Since the couplers are H-plane devices and the filter is an E-plane device as indicated, the respective elements are in space quadrature in the composite assembly. It is feasible to replace the broadband H-plane output coupler with a printed E-plane printed-probe coupler covering the 4-GHz passband[1]. The printed-probe coupler uses a housing that is split in the same plane as the filter. This would simplify fabrication and integration.

Filter Design

The dual band-pass filter is a planar resonator card (1-mil copper shim) suspended between two waveguide halfs in the E-plane[2]. This approach offers about 50 percent higher Q over the dielectric-backed type[3].

A series of design nomographs, employing normalized parameters, have been developed to determine the physical dimensions of E-plane waveguide band-pass filters. These curves are presented in Figure 3. Starting with the model in Konishi's work[2], measurements of various test pieces resulted in design nomographs that are empirically adjusted for direct application. These nomographs have been successfully used to realize band-pass filters in the frequency range of 28 to 60-GHz, and can find use in any waveguide application with the proper normalization.

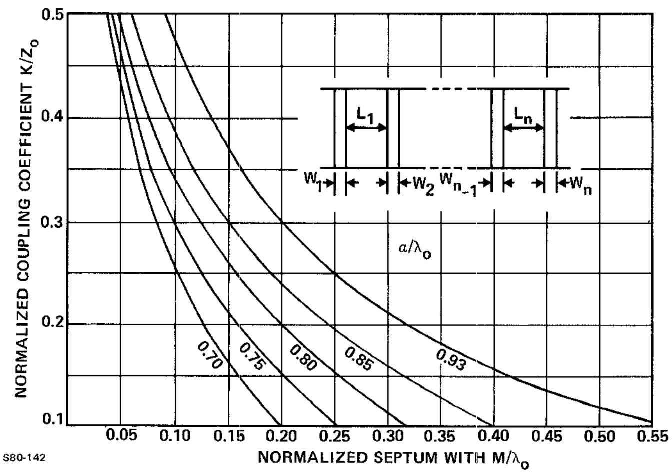

Figure 3. Waveguide Band-Pass Filter Design Nomograph

The millimeter-wave channelizers, operating in the 28 to 42-GHz and 42 to 60-GHz bands, were developed to separate these bands into 4-GHz channels while providing 45 dB rejection to the center of any adjacent channel. A seven-pole 0.1-dB equal-ripple Tchebycheff design was chosen as the optimum filter type. The channel filters have been measured. The measured bandwidths were typically within 0.5 percent (maximum 4 percent) of the desired values and the center frequencies were typically within 1 percent of the design goal. Unloaded Q's, Qu, were within 30 percent of expected values (e.g., at 28 GHz, a minimum passband loss of 0.2 dB was computed, based on an expected Qu of 1700; loss minimum of 0.25 to 0.3-dB were measured.)

The theoretical VSWR for a 0.1-dB Tchebycheff design is 1.5; typical values measured for the filters were 2.0 to 2.5. Further VSWR improvement appears possible with a modification of input/output coupling elements.

Filter Construction

The E-plane resonator, shown in Figure 2, uses photolithographic techniques and chemical milling to produce the resonant elements on 0.001-inch thick beryllium copper, BeCu. Whereas, the BeCu is not an optimal material to minimize RF loss, its mechanical properties are far superior to alternatives. The poor conductivity has been overcome by applying a thin copper cladding after chemical milling.

Nomograph Limits

It has been determined that there are ranges of the normalized filter parameters, a/λ_o, K/Z_o, and W/λ_o over which practical filters may be realized. For very large values of a/λ_o, i.e., frequencies of operation well above the waveguide cutoff, propagation approaches a plane wave. Under this condition, the E-plane septum has little effect, and the rejection above the passband is degraded. Values of $K_o/Z_o > 0.5$ for most values of a/λ_o are not practical since the width of the septum gets exceedingly small and, as was experienced, the lumped-parameter model no longer accurately applies. This was noted for the 28-GHz band-pass filter in which a very poor VSWR (4) was initially measured.

The VSWR of the 28-GHz filter was improved by widening the "a" dimension to obtain a more favorable a/λ_o condition, giving a VSWR of 2.0 with a practical septum width. Conversely, the 40-GHz filter performance might be improved by reducing the "a" dimension. In standard WR-28 waveguide, $a/\lambda_0 = 0.95$ for 40 GHz, resulting in relatively long E-plane stripwidths and a poor upper frequency rejection response. (Since performance was adequate for our present application, the "a" dimension was not modified.)

Filter Design Sequence

Given a desired filter characteristic, physical dimensions are arrived at through the following sequence.

1. Filter design type defines value and number of low-pass prototype element values, g_i.

2. Normalized coupling coefficient, $K_{i,\,i+1}/Z_o$ are computed from:

$$\frac{K_{o1}}{Z_o} = \frac{K_{n,\,n+1}}{Z_o} = \sqrt{\frac{\pi}{2}\,\frac{(W\lambda)}{g_1}}$$

$$\left.\frac{K_{i,\,i+1}}{Z_o}\right|_{i=1}^{i=n-1} = \frac{\pi}{2}\,\frac{(W\lambda)}{\sqrt{g_i\, g_{i+1}}}$$

and

$$(W\lambda) = W\left(\frac{\lambda_{go}}{\lambda_o}\right)^2 = \frac{BW_D/fo}{1 - \left(\frac{\lambda_o}{2_g}\right)^2}$$

where:

n = number of filter poles

BW_D = filter design bandwidth

f_o = filter center frequency

λ_o = free-space wavelength at f_o

a = waveguide width or "a" dimension

3. Using the nomograph of Figure 3, values of K/Z_o are entered, and the corresponding value of W/λ_o is read off using the correct value of a/λ_o. (Extrapolation may be required between plotted curves curves.)

4. The physical spacing between septums, L, is derived from reference 2 under the constraint that each resonator will be one-half waveguide wavelength at f_o, i.e., $\theta_j = 180^o$ (Equation 13 and Figure 5[2]).

Coupler

The coupler is a broadwall multiaperture hybrid which provides more than the required full-waveguide bandwidth[4]. The physical form of the coupler is shown in Figure 2. The housing is split along the H-plane to accommodate a 10-mil, gold-plated, beryllium copper sheet, which forms the common wall between parallel waveguides. A 2 × 10 array of coupling aperture is formed in the sheet by standard photolithographic and chemical etching techniques. These techniques are conducive to minimizing production cost and to repeatable performance. The center section of the waveguides is reduced in height to prevent moding.

The measured performance of this coupler includes high isolation (21 to 42 dB) and flat coupling (3.3 ±0.7 dB) across a 47-percent band (26 to 42 GHz). Measured performance characteristics are shown in Figure 4.

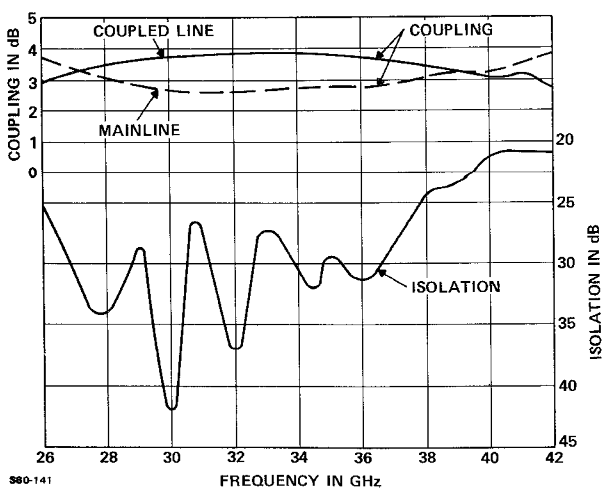

Figure 4. 3-dB Coupler Performance

Multiplexer Performance

The channel-dropping filters were tested as individual diplexers. A photograph of a diplexer is shown in Figure 2. The measured composite multiplexer performance is shown in Figure 5. The passband insertion loss, as shown, is less than 2.8 dB. Crossover losses will be improved by only small changes in band-pass filter bandwidth.

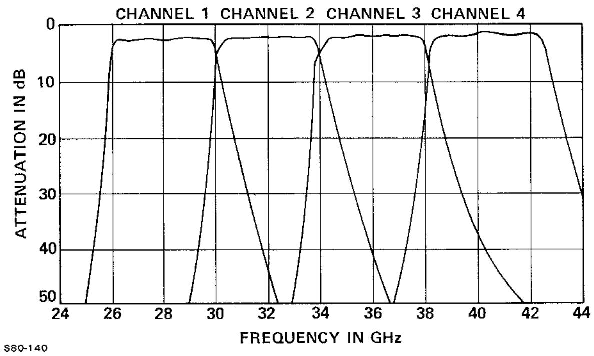

Figure 5. Measured Composite Multiplexer Performance

Conclusion

A hybrid-coupled multiplexer covering a full waveguide bandwidth (26 to 42 GHz) has been developed. The printed-element approach results in low-production costs and repeatable performance, without trimming. The design concept is applicable to higher millimeter-wave frequency bands. A multiplexer covering the 42 to 62-GHz band with five 4-GHz channels has been designed, and performance data will be available shortly.

Acknowledgements

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References

1. P. J. Meier, "Printed-Probe Hybrid Coupler for the 3-mm Band," Proceedings of Ninth European Microwave Conference, p 443-447, September 1979.

2. Y. Konishi and Uenakada, "The Design of a Band-Pass Filter with Inductive Strip--Planar Circuit Mounted in Waveguide," IEEE Trans, Vol MTT-22, p 869-873, Oceober 1974.

3. P. J. Meier, "New Developments with Integrated Fin-Line and Related Printed Millimeter Circuits," Digest of IEEE 1975 MTT-S International Microwave Symposium, p 143-145, May 1975.

4. J. Reindel, "Printed Circuit Waveguide Components," NOSC Technical Note 581, December 1978.