Features

The principal features of this rotary joint design are as follows. The power handling capability is in excess of that of the main waveguide itself. As the power level in each element at the interface is $\frac{1}{16}$ of the input, the joint does not have to be pressurized. The large hole through the center permits two or more rotating antennas to be independently fed from a corresponding number of fixed transmitters which may operate on different frequencies with different or variable power outputs. The joint is free from electrical resonances and from higher order waveguide modes. There are no ripple effects or commutation in input impedance characteristics with rotation. All sliding or other electrical contacts are eliminated. There is no radiation leakage because of the uniform 360° closed field. It is amenable to very broad-band operation. The field pattern is similar to the field pattern associated with the TE_{01} mode in a circular waveguide, but with the advantage that higher order modes cannot propagate in this structure. The system can also be used as a power adder by adding the outputs of several synchronized klystrons. For example, four klystrons could be paralleled by connecting each to the input of the third level splitters.

References

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A Harmonic Rejection Filter Designed by an Exact Method*

BERNARD M. SCHIFFMAN†, MEMBER, IEEE

Summary—**An exact design procedure for band-stop filters is used to design a transmission-line filter with one point of perfect match at a fundamental frequency and one point of infinite attenuation at a harmonic frequency. This design method is based on the mapping of the response of a low-pass prototype into that of a transmission line filter. Here a three-element Chebyshev filter is chosen as the prototype and the otherwise general procedure is adapted for the special case of rejection of the second harmonic.**

Introduction

A HARMONIC REJECTION filter has, ideally, zero attenuation at the fundamental frequency, and infinite attenuation at a harmonic of the fundamental frequency. Although the pass band and stop band of the harmonic rejection filter might be narrow, they are always widely separated. Thus, the band-stop filter design theory that is used must be accurate over very wide bandwidths. Band-stop filters with narrow stop bands have been developed before,[1] and general design formulas of very good accuracy for this case have been given. The band-stop filter design method given here, however, is a special application of an exact design procedure[2] that is not limited theoretically with respect to bandwidth. This exact design procedure applies to a broad class of microwave band-stop filters. The main feature of this method is a table of easy-to-use formulas for one- to five-element (or stub) transmission-line filters. Each such filter is based on a low-pass prototype whose element values are used in the table of formulas.

Second-Harmonic Rejection Filter

A transmission-line filter which has theoretically zero attenuation at a chosen frequency ω_V and infinite attenuation at $2\omega_V$ is shown in Fig. 1 together with the computed attenuation L_A in the stop band, and the computed VSWR and attenuation in the pass band. The filter consists of a symmetrical arrangement of three open-circuited stubs in shunt with the main line. All stub lengths and stub separations are exactly one-quarter wavelength long at the second harmonic frequency. The impedances of the stub and of the connecting lines were found by first choosing a three-element, low-pass, prototype circuit and then applying appropriate exact design formulas,[2] as explained below. The low-pass prototype is of the Chebyshev type with two points of zero attenuation in the pass band and

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† Stanford Research Institute, Menlo Park, Calif.
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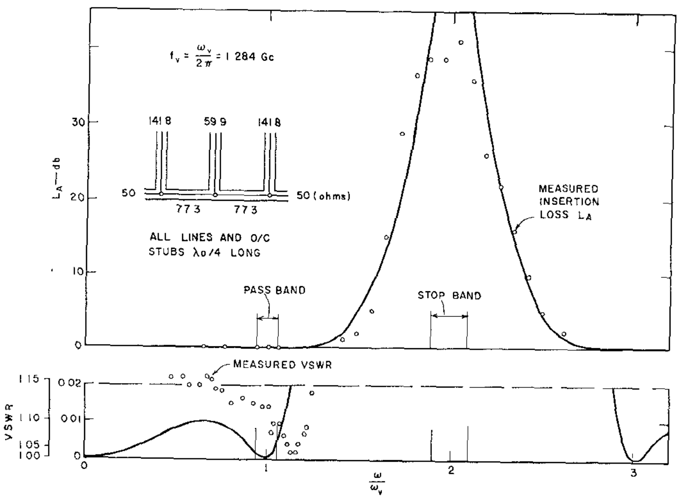

Fig. 1—Measured and theoretical response of filter.

all poles of attenuation at infinity. In applying these design formulas which, in effect, transform the ω' plane of the low-pass prototype into the ω plane of the band-stop filter, one must, for the purpose at hand, know or determine the following two frequencies: 1) the cutoff frequency ω_1' (corresponding to the lower edge of the stop band ω_1 of the band-stop filter), and 2) the first nonzero frequency of zero attenuation ω_V' (the frequency ω_V' corresponds to the center frequency of the pass-band ω_V, of the band-stop filter).

The cutoff frequency ω_1' is always given in the table of element values of the low-pass prototype filter. The points of zero attenuation normalized to the cutoff frequency are easily found from the formula for the positive zeros of the nth order Chebyshev polynomial as follows:

$$\frac{\omega_V'}{\omega_1'} = \cos\frac{(2k+1)\pi}{2n}, \qquad (1)$$

where

$$k = 0, 1, 2, \cdots (n-2)/2 \quad \text{for } n \text{ even}$$

or

$$= 0, 1, 2, \cdots (n-1)/2 \quad \text{for } n \text{ odd,}$$

and where n is the number of filter elements (stubs).

Thus, for $n=3$, $\omega_V'/\omega_1'=0$ and 0.866, the desired solution is $\omega_V'/\omega_1'=0.866$. The formulas that determine the stub impedances Z_1, Z_2, and Z_3 of the transmission-line band-stop filter from the low-pass prototype parameters are[2]

$$Z_1 = Z_3 = Z_0\{1 + 1/(\Lambda g_0 g_1)\} \text{ ohms (end stubs),}$$

$$Z_2 = Z_0 g_0/\Omega g_2 \text{ ohms (center stub),} \qquad (2)$$

and for the connecting line impedances

$$Z_{12} = Z_{23} = Z_0(1 + \Lambda g_0 g_1) \text{ ohms.} \qquad (3)$$

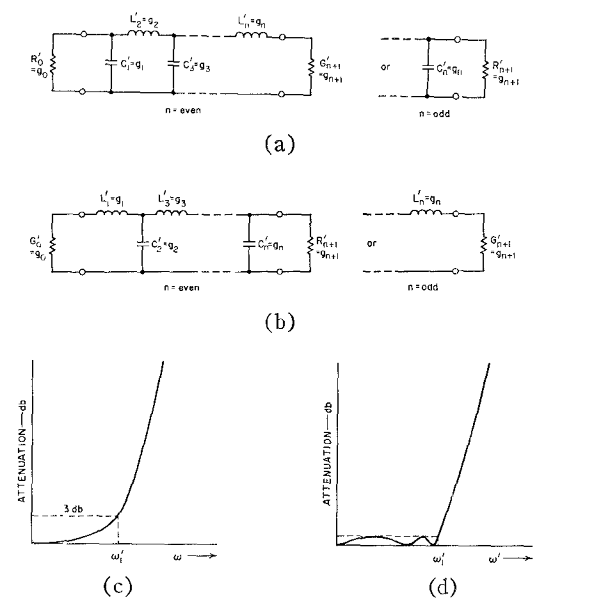

Fig. 2—Low-pass prototype filter. (a) and (b) Four basic circuit types defining the parameters $g_0, g_1, \cdots, g_{n+1}$. (c) and (d) Maximally flat and equi-ripple characteristics, defining the band-edge ω_1'.

In the above formulas, Z_0 is the input and output matching impedance and g_j are the element values in mhos, farads, and henrys [as defined in Fig. 2(b) for n odd] of the prototype circuit which may be obtained from published tables.[3–5] The quantity Λ is defined by the formula[2]

$$\Lambda = a\omega_V' \text{ (radians per second),} \qquad (4)$$

where

$$a = \cot(\pi\omega_V/2\omega_0),$$

$$\omega_0 = \text{frequency to be rejected.}$$

The filter of Fig. 1 was designed from a 0.01-db ripple prototype. The element values were obtained from Matthaei[3] (Table 13-1, p. 202), and are

$$g_0 = g_4 = 1, \quad g_1 = g_3 = 0.6291, \quad \text{and} \quad g_2 = 0.9072.$$

The prototype cutoff frequency ω_1' is 1 radian per second. Now in order to obtain infinite rejection of the second harmonic, we set $\omega_0 = 2\omega_V$, whence $a=1$. With $\omega_V'/\omega_1' = 0.866$ as previously calculated for a three-stub filter, we find $\Lambda = 0.866$. Using this value of Λ, and $Z_0 = 50$ ohms, the set of element values g_j were then inserted into the design formula and the transmission-line circuit illustrated in Fig. 1 was obtained.

A second-harmonic-frequency rejection filter as described above was constructed and tested.

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Description of Filter

A photograph of the second-harmonic-frequency rejection filter with one ground plane removed is shown in Fig. 3. The essential dimensions are given in Fig. 4. All stubs and connecting lines are one-quarter wavelength long at the second-harmonic frequency (2.566 Gc for this design). No allowance was made in the length of the stub for the end capacity of each resonator. However, in general, junction and end effects become negligible as the ratio d/λ approaches zero. Here d is the diameter of the center conductor and λ is the wavelength in the medium. Thus, small rather than large diameters, and high rather than low impedance lines are preferred for more accurate design (although the opposite is true from the standpoint of power-carrying ability). Therefore, in order to reduce these effects where possible, the relatively low-impedance center stub of the test filter was replaced by two stubs in parallel, each twice the design impedance of the center stub as shown in Fig. 4. The diameters of all center conductors were determined from the formula[6]

$$Z_0 = 377\left[\frac{1}{2\pi}\ln\left(\frac{4h}{\pi d}\right) - \frac{0.2153R^2}{1 - 5.682R^2}\right], \qquad (5)$$

where

$$R = (d/2h)^2,$$

$$h = \text{plate separation.}$$

[In (5), the correction term in R^2 is of the order of one per cent of the total for $Z_0 \approx 50$ ohms, and may be neglected for values of $Z_0 \geq 100$ ohms.]

Results of Test

The insertion loss and VSWR of the properly terminated filter was measured and the results are plotted in Fig. 1 together with the theoretical response of the filter. The measured response is seen to be fairly close to the computed response, although it is evident that the frequency of minimum VSWR in the pass band (near ω_V) is somewhat higher than intended. Also, the apparent reduction of stop-band bandwidth may be due to the junction transformer effect which causes each stub to respond as though its impedance were higher than it, in fact, is. A way to compensate for this effect is to make the stub impedances lower by a factor equal to the transformer ratio. Even without such modification, the pass-band VSWR is less than 1.15, which is adequate for most purposes.

Rejection of Other Harmonic Bands

If it is required that, for example, the third harmonic is to be rejected, we set $\omega_0 = 3\omega_V$ and then calculate a new value of Λ in (4), and new values of stub and line impedances by (2) and (3). Also, the stubs and connecting lines are reduced in length accordingly.

[6] R. M. Chisolm, "The characteristic impedance of trough and slab lines," IRE Trans. on Microwave Theory and Techniques, vol. MTT-4, pp. 166–172; July, 1956.

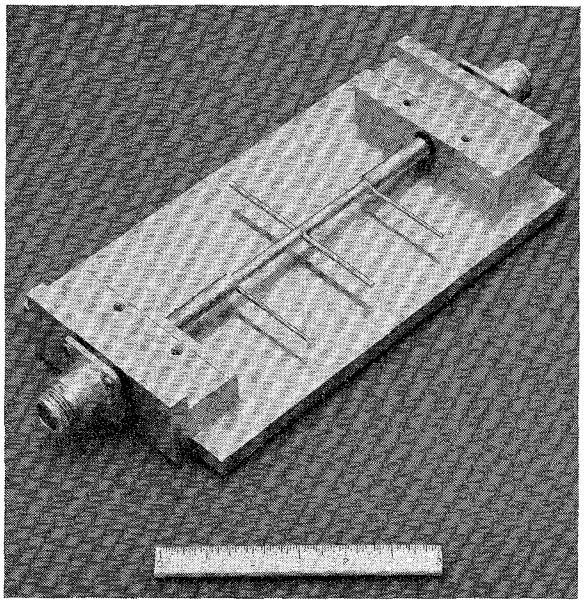

Fig. 3—Photograph of second-harmonic frequency-rejection filter with one ground plane removed.

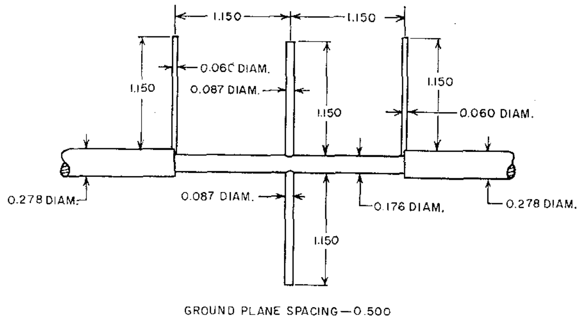

Fig. 4—Sketch of essential filter elements of second-harmonic rejection filter giving dimensions.

Reducing the Reflection in the Stop Band

The harmonic filter attenuates by reflecting the particular (in this case, second harmonic) troublesome frequency. If a high VSWR cannot be tolerated in the stop band, a harmonic pad (such as a short leaky-wave filter[7,8] or 0-db directional coupler[9]) can always be placed in cascade with the harmonic reflecting filter.

Acknowledgment

The author gratefully acknowledges the encouragement and helpful suggestions of Dr. L. Young in this work. P. Reznek ably performed the test measurements.

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