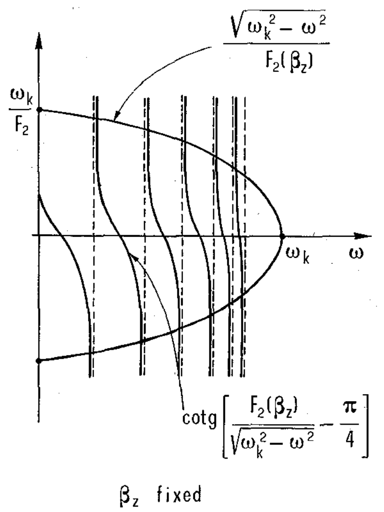

Fig. 2. Graphical solution of dispersion relation for cyclotron modes in vicinity of $\omega=\omega_k$. The value of β_z is fixed.

Furthermore, in the vicinity of $\omega=\omega_k$, (8) can be cast in the following form:

$$\frac{J_1(\tau_2 a)}{J_0(\tau_2 a)}\frac{\omega_c\omega_p}{\omega_k^3}\frac{\omega_k^2+\beta_z^2c^2}{[\omega_c^2\omega_k^2/c^4\beta_z^4-1]^{1/2}}=\sqrt{\omega^2-\omega_k^2} \tag{12}$$

where τ_2 is given by (5). Note that the left member of (12) is a function of β_z alone, say $F_1(\beta_z)$, when the geometry of the guide and the filling material are prescribed. Therefore we have

$$\frac{\omega}{\sqrt{\omega^2-\omega_k^2}}\frac{d\omega}{d\beta_z}=\frac{dF_1(\beta_z)}{d\beta_z}. \tag{13}$$

Hence,

$$\left.\frac{d\omega}{d\beta_z}\right|_{\omega=\omega_k}=0 \tag{14}$$

since $dF_1/d\beta_z$ is finite. It follows that the group velocity at cutoff points is zero.

From (11) and (14) it is then recognized that the correct Brillouin diagram in the vicinity of $\omega=\omega_k$ is the one shown in Fig. 1.

2) For $\omega\simeq\omega_k$, and $\omega<\omega_k$, one obtains from (9)

$$\cot\left[\frac{F_2(\beta_z)}{\sqrt{\omega_k^2-\omega^2}}-\frac{\pi}{4}\right]=\frac{\sqrt{\omega_k^2-\omega^2}}{F_2(\beta_z)} \tag{15}$$

where

$$F_2(\beta_z)=\frac{a\omega_c\omega_p}{c\omega_k}\sqrt{\omega_k^2+\beta_z^2c^2}.$$

The existence of an infinite number of cyclotron modes which cluster at $\omega=\omega_k$ comes out in a natural way from the graphical solution of (15), as shown in Fig. 2.

From (15), for $\omega\simeq\omega_k$ and $\beta_z=0$ the cutoff points for the higher order cyclotron modes are easily obtained:

$$\omega_m=\omega_k-\frac{\omega_c^2\omega_p^2}{2c^2\omega_k(\pi^2/a^2)(m+3/4)^2},\qquad \beta_z=0 \tag{16}$$

where m is a large integer.

References

[1] H. Suhl and L. R. Walker, "Topics in guided wave propagation through gyromagnetic media, pt. I," *Bell Syst. Tech. J.*, vol. 33, pp. 579–659, May 1954.

[2] V. Bevc and T. E. Everhart, "Fast wave propagation in plasma filled waveguides," *J. Electron. Contr.*, vol. 13, pp. 185–212, Sept. 1962.

[3] M. Camus and J. Le Mezec, "Propagation des ondes dans une guide rempli de plasma en présence d'un champ magnétique," in *Proc. Symp. Electromagnetic Theory and Antennas*. New York: Macmillan, 1963, pt. I, pp. 323–347.

[4] G. H. B. Thompson, "Backward waves in londitudinally magnetized ferrite filled guides," in *Proc. Symp. Electromagnetic Theory and Antennas*. New York: Macmillan, 1963, pt. I, pp. 603–613.

[5] R. Likuski, "Free and driven modes in anisotropic plasma guides and resonators," Elec. Eng. Research Lab., Univ. of Illinois, Urbana, Rep. ALTDR-64-157, AF(657)-10224, July 1964.

[6] R. W. Damon and J. R. Eshbach, "Magnetostatic modes of a ferromagnetic slab," *J. Appl. Phys.* (Suppl.), vol. 31, pp. 104S–105S, May 1960.

Tunable Frequency Range and Mismatch Adjustment for Comb-Line Bandpass Filters

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***Abstract*—*S*-band comb-line filters can be tuned over a frequency range of approximately 200 percent of the design frequency. A simple technique is also described that compensates for impedance match and coupling deficiencies associated with the filter.**

I. Introduction

Many communication systems require narrow-band filters with center frequencies that are within an octave of one another. Therefore, it would be economical to utilize one filter design that could be tuned over the desired range of center frequencies rather than design individual filters for each center frequency.

Comb-line filters [1], [2] possess the ability to be tuned over a wide range of frequencies without suffering significant degradation in performance. The filter's frequency range is a function of the amount of capacitance adjustment between each resonator post and tuning screw.

II. Filter Bandwidth Variations Over Tuning Range

Jones [3] describes a method of designing comb-line filters which exhibit no appreciable change in bandwidth while being tuned over a 2:1 frequency range. In his paper Jones states, "For minimum variation in passband width as the filter is tuned, the electrical length of the lines (filter resonator posts) should be 58° at the center of the tuning range." Jones states further, "A bandwidth variation of 14 percent over a 2:1 tuning range can be expected."

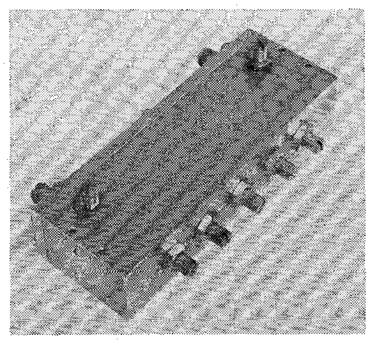

Fig. 1. Five-pole *S*-band comb-line filter (with transformer post tuning elements).

III. Compensation for Mismatch and Over-Coupling

Although the comb-line filter center frequency is variable, it is often impossible to eliminate excess ripple by resonator post tuning alone. Much of the excess ripple can be attributed to overcoupling

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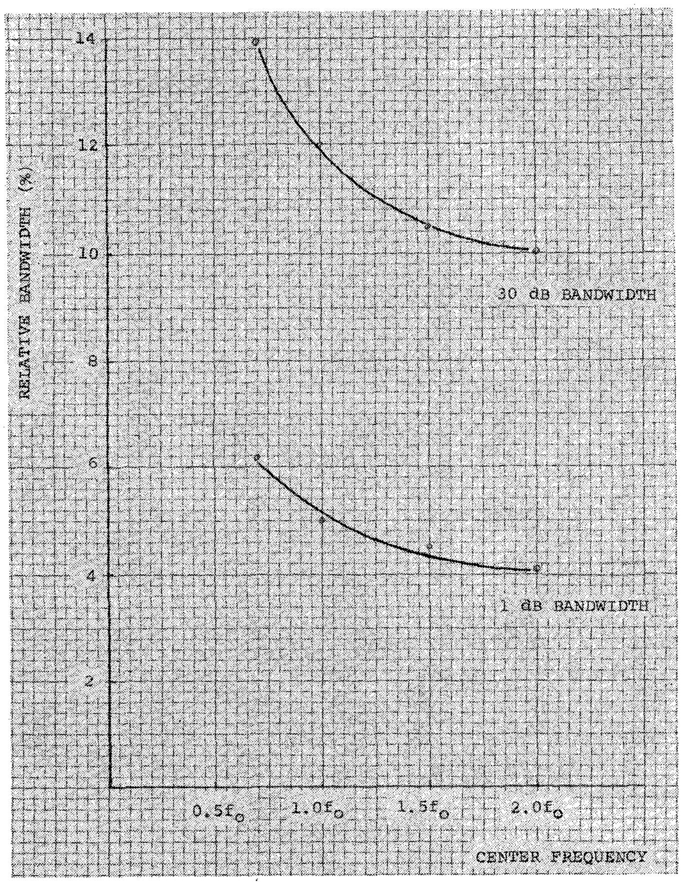

Fig. 2. Variation of 1-dB and 30-dB bandwidth versus frequency for a five-pole comb-line filter with resonator posts cut for f_0.

and/or mismatch. Experience with comb-line filters at S and C bands indicates that the excess ripple can be significantly reduced by introducing a tuning element at a position along a certain length directly over each transformer post. The two tuning elements are shown at each end of the comb-line filter in Fig. 1.

If mismatch and overcoupling are not a problem, the tuning elements and the input/output transformer posts can be eliminated resulting in a considerable filter size reduction.

IV. Experimental Results

The five-pole comb-line filter shown in Fig. 1 was designed for a center frequency of 1.6 GHz, a 5-percent 1-dB bandwidth, and a 12-percent 30-dB bandwidth (Fig. 2).

The data shown in Fig. 2 indicate that S-band comb-line filters, with resonator posts designed for a frequency f_0, can be tuned to frequencies of 0.70 f_0 to 2 f_0 with no serious degradation in either bandwidth or skirt selectivity.

Fig. 2 shows the variation in 1-dB and 30-dB bandwidths for a five-pole comb-line filter tuned over a wide frequency range. The insertion loss increase (as the comb-line filter is tuned from 0.7 f_0 to 2 f_0) also appears to be less than 0.3 dB at S band. The 1-dB bandwidth variations over a 2:1 range of frequency are approximately 30 percent for resonator post electrical lengths of 45° and 20 percent for resonator post electrical lengths of 53°. This agrees closely with the data presented in Jones [3].

In addition, by adjusting the transformer post tuning elements the ripple due to nonideal coupling or mismatch conditions at the filter-load interface can be reduced significantly. A voltage standing-wave ratio of 3:1 at S band was reduced to 1.4:1 by this method.

Although the optimum position for the transformer post tuning element was not determined, excellent results were obtained by placing the element from 0.06 to 0.09 λ up from the base of the transformer post.

V. Conclusions

The wide range of frequency adjustment inherent with comb-line filters is described along with a simple technique to reduce the effects of mismatch or coupling deficiencies. The ease of obtaining good matching, bandwidth control, and tunability indicates that one comb-line filter design can satisfy the performance requirements of a wide range of frequencies.

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References

[1] G. L. Matthaei, L. Young, and E. M. Jones, *Microwave Filters, Impedance-Matching Networks and Coupling Structures.* New York: McGraw-Hill, 1964.
[2] R. M. Kurzrok, "Design of comb-line band-pass filters," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-14, pp. 351–353, July 1966.
[3] W. L. Jones, "Design of tunable comb-line filters of near constant bandwidth," *Electron. Lett.*, vol. 1, pp. 156–158, Aug. 1965.