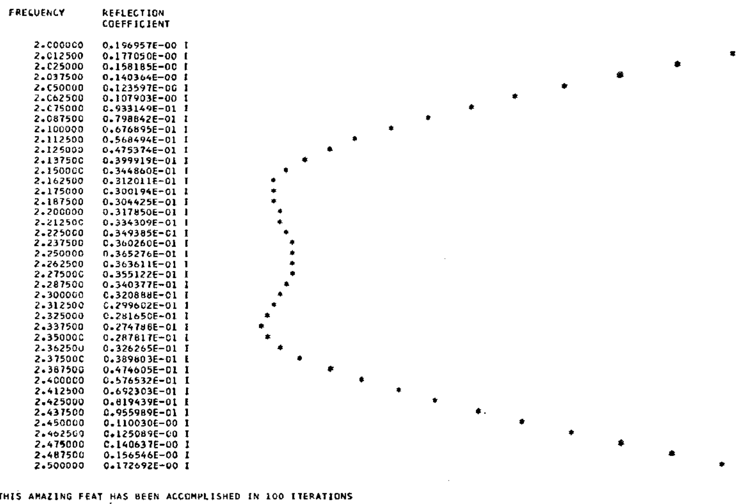
TABLE I
NETWORK MATCHING OUTPUT IMPEDANCE OF AN AMPLIFIER TO A 50 Ω LOAD

Element No.		Initial Value Y_0 (mmhos)	Initial Value $\beta\ell$ at 2.4 GHz (degrees)	Final Value Y_0 (mmhos)	Final Value $\beta\ell$ at 2.4 GHz (degrees)
1	Series	15	45	12	14
2	Open Stub	15	45	20	62
3	Series	15	45	13	18
4	Shorted Stub	15	45	28	20
5	Series	15	45	23	15



FREQUENCY	REFLECTION COEFFICIENT
2.000000	0.196957E-00
2.012500	0.177050E-00
2.025000	0.158185E-00
2.037500	0.140364E-00
2.050000	0.123597E-00
2.062500	0.107903E-00
2.075000	0.933149E-01
2.087500	0.798842E-01
2.100000	0.676895E-01
2.112500	0.568494E-01
2.125000	0.475374E-01
2.137500	0.399919E-01
2.150000	0.344860E-01
2.162500	0.312011E-01
2.175000	0.300194E-01
2.187500	0.304425E-01
2.200000	0.317850E-01
2.212500	0.334309E-01
2.225000	0.349385E-01
2.237500	0.360260E-01
2.250000	0.365276E-01
2.262500	0.363611E-01
2.275000	0.355122E-01
2.287500	0.340377E-01
2.300000	0.320888E-01
2.312500	0.299602E-01
2.325000	0.281650E-01
2.337500	0.274788E-01
2.350000	0.287817E-01
2.362500	0.326265E-01
2.375000	0.389803E-01
2.387500	0.474605E-01
2.400000	0.576532E-01
2.412500	0.692303E-01
2.425000	0.819439E-01
2.437500	0.955989E-01
2.450000	0.110030E-00
2.462500	0.125089E-00
2.475000	0.140637E-00
2.487500	0.156546E-00
2.500000	0.172692E-00

THIS AMAZING FEAT HAS BEEN ACCOMPLISHED IN 100 ITERATIONS

Fig. 5. Reflection coefficient vs. frequency.

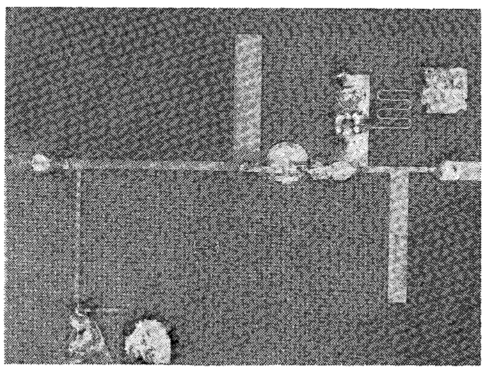


Fig. 6. Peak power amplifier (2.5 watts).

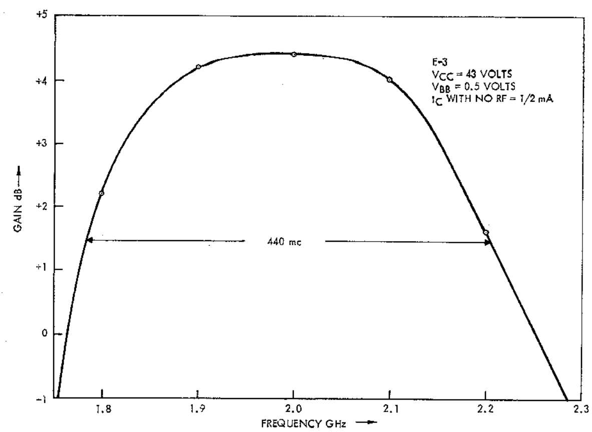


Fig. 7. Frequency performance of amplifier.

ACKNOWLEDGMENT

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Confocal Resonator Band-Pass Filters

Direct-coupled confocal[1] resonators are considered for use as band-pass filters at millimeter wavelengths in this correspondence. In previous work on band-pass filters for millimeter wavelengths [1], two flat reflectors were used to form resonators; these resonators could not produce high unloaded Q values because of the critical tolerances of maintaining parallelism between reflectors [2]. To overcome these difficulties, resonators with curved spherical surfaces have been used at millimeter wavelengths to achieve high Q_u [3]–[5]. Single-resonator Fabry-Perot interferometers and absorption wavemeters were considered (in these references), and the possibility of using them as band-pass filter elements was suggested [5]. One- and two-resonator band-pass filters are described herein together with experimental data. Emphasis is placed on types of coupling structures, reduction of spurious responses, and an extension to filters of arbitrary numbers of resonators.

Figure 1 shows a tunable, single-resonator, band-pass filter constructed of brass and operating in the 40 GHz region. Each reflector is machined into a cylindrically shaped piece which has a concentric thread. One end reflector has a right-hand thread, the other a left-hand thread. Rotation of the cylinder tunes the filter. Two steel guide rods are used to maintain reflector alignment.

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[1] The filters described are confocal and nonfocal; for conciseness, "confocal" will be used to describe either situation.

The radius of curvature a of each spherical reflector is identical, and its value was chosen such that they are in a confocal position (on-axis reflector separation d, equals the radius of curvature) for 40 GHz with an axial mode number of ten and radial and angular mode numbers equal to zero. This is determined from:

$$d = \frac{\lambda}{2}\left[q + \frac{2p + l + 1}{\pi}\cos^{-1}\left(1 - \frac{d}{a}\right)\right]$$

where q, p, and l are the axial, radial, and angular mode numbers, respectively.

The theory predicts an infinite number of modes for this resonator. Each mode has its own characteristic field distribution pattern; however, the diameter of the field pattern increases with increasing mode number. Therefore, a lossy cylindrical insert placed into the resonator will reduce the unloaded Q for each mode, but the $(q, 0, 0)$ mode will be affected least.

The tuning range is such that q at 40 GHz can be varied from 8 to 11 for the $(q, 0, 0)$ mode. Furthermore, circular holes are used to couple the resonator to its input and output single-mode rectangular waveguides. The diameters of these holes were determined experimentally for the various bandwidths chosen.

The two-resonator filter is shown in Fig. 2. A double-sided curved reflector is placed between two end reflectors. In this case two internally threaded pieces are used so that each resonator length can be adjusted independently. Coupling between resonators and to input and output waveguides is by small circular holes. The hole diameters were experimentally set to give the coupling coefficient and resonator decrement consistent with a two-pole maximally-flat response having a 3-dB bandwidth of 25 MHz. This design used different axial mode numbers (stagger tuning) in each resonator ($q=10$ and 11) in order to avoid coincidence of other $(q, 0, 0)$ responses over a 2:1 frequency range. The likelihood of higher order (q, p, l) responses is also reduced.

A single-resonator filter was evaluated and had a 5 MHz 3-dB bandwidth and a 5-dB midband insertion loss at 39.3 GHz. Thus Q_L is about 7850 and Q_u is about 17 700. Other resonances, though, have yielded unloaded Q's of about 25 000. The filter, however, has a number of spurious resonances, due to modes where p and $l \neq 0$, which average about 10 dB down from the main $(q, 0, 0)$ response.

The two-resonator filter was then evaluated. It used two techniques to lower the spurious response level—lossy cylindrical inserts and stagger tuning. Figure 3(a) shows the relative output power vs. frequency curve of the two-resonator filter from 36 to 42 GHz. In this case, no lossy inserts were used, and both resonators had equal lengths (same axial mode numbers). The midband insertion loss of the main response is 1.2 dB, and the 3-dB bandwidth is 25 MHz about a center frequency of 39.9 GHz. Compare this figure with Fig. 3(b). Here, we used conditions similar to that used previously, except that now we placed lossy iron epoxy cylinders into both cavities. In this case the midband loss is 5.6 dB, and the 3-dB bandwidth is 26 MHz centered about a frequency of 39.2 GHz. It is seen that the spurious responses have been reduced considerably. However, the main response is also affected. Nevertheless, the spurious responses are affected to a greater degree as predicted by the theory.

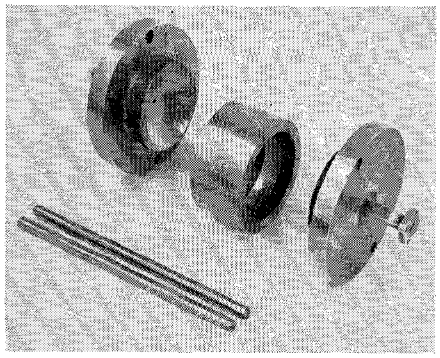


Fig. 1. Single resonator confocal band-pass filter.

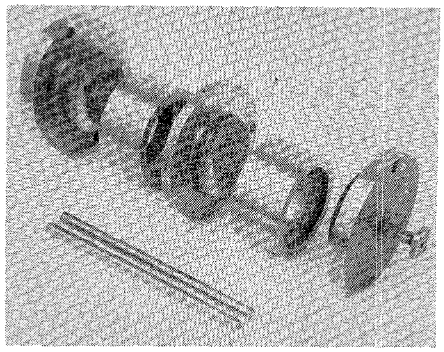
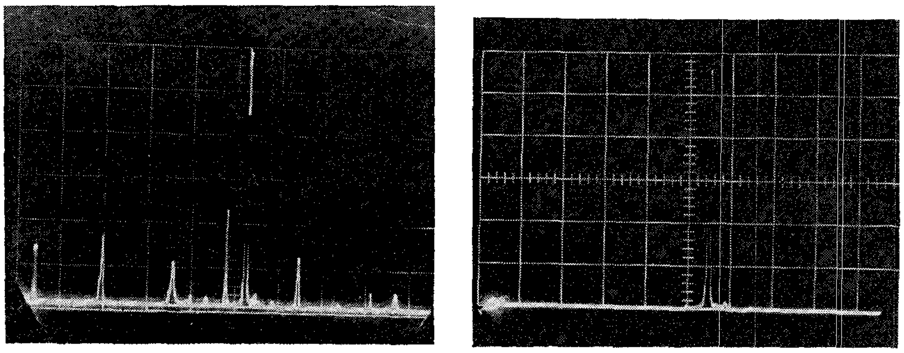
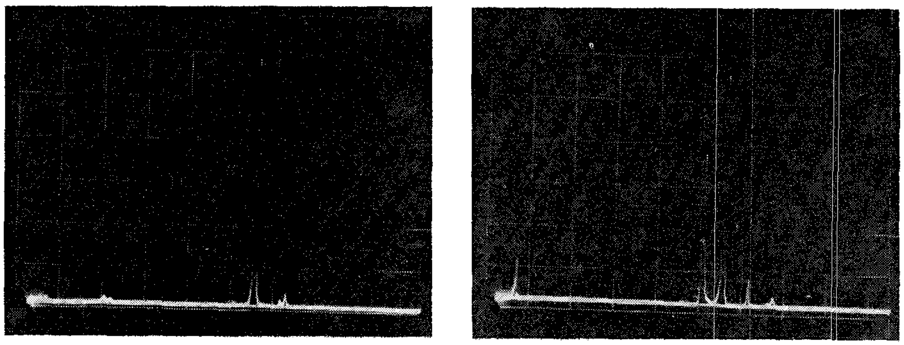


Fig. 2. Two resonator confocal band-pass filter.



(a) (b)

Fig. 3. Relative power output from 36 to 42 GHz of two resonator band-pass filter. (a) No lossy inserts employed. (b) Lossy inserts were used.



(a) (b)

Fig. 4. Relative power output from 36 to 42 GHz of two resonator band-pass filter. (a) Stagger tuning employed. (b) No stagger tuning used.

Figures 4(a) and 4(b) are of identical filters except for one aspect. The filter response recorded in Fig. 4(a) was for a filter that used stagger tuning; one resonator had an axial mode number of 10, and the other resonator had an axial mode number of 11. The filter response recorded in Fig. 4(b) was for a filter in which both resonators had the same axial mode numbers (no stagger tuning). The strongest spurious response level was reduced about 17 dB in the filter that used stagger tuning, whereas the effect on the main response was negligible. This illustrates the effectiveness of stagger tuning as a means of reducing spurious responses.

In conclusion, the use of confocal resonators will yield filters of high selectivity and techniques which are available for reducing spurious responses. Further improvements are possible with three or more resonators using an extension of the two resonator filter described herein.

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