MICROWAVE DIELECTRIC RESONATOR FILTERS UTILIZING $Ba_2Ti_9O_{20}$ CERAMICS

J. K. Plourde and D. F. Linn
Bell Telephone Laboratories, Inc.
555 Union Blvd.
Allentown, Pennsylvania 18103

ABSTRACT

Dielectric resonators utilizing $Ba_2Ti_9O_{20}$ ceramic yield high Q's (Q = 8000-10000) along with excellent temperature stability (τ_f = 0-2 ppm/°C) at 4 GHz. Integrable bandpass and bandreject filters having low losses and excellent temperature stability are obtained in structures containing $Ba_2Ti_9O_{20}$ resonators coupled to either stripline or waveguide.

Introduction

For a decade now, dielectric resonators have held promise for use in high quality integrable microwave filters. The lack of a suitable resonator material, which in the past has limited dielectric resonator applications, has been overcome by recent advances in resonator materials[1,2,3]. At 4 GHz, $Ba_2Ti_9O_{20}$ ceramic resonators yield high Q's (8000-10000) along with excellent temperature stability ($\tau_f \sim 0$ to 2 ppm/°C). The dielectric constant is 40.0.

This work was directed primarily towards developing bandpass and bandreject filters with the following objectives: (1) low cost, integrable designs; (2) minimum degradation of resonator Q; (3) no spurious filter responses in band; (4) strong resonator coupling capability to permit wide filter bandwidths. Although higher order modes or multiple modes may be used, only the $TE_{01\delta}$ cylindrical resonator mode was considered. Cylindrical resonators were used in preference to other geometries because of lower fabrication costs.

Stripline to Resonator Coupling

The resonator mounting scheme shown in Figure 1a has several distinct advantages over the usual approach of mounting the resonator directly on the substrate. The resonator is located at a coupling maxima with respect to its transverse position and therefore is relatively insensitive to variations in this parameter (Figure 1b). The coupling is easily controllable and is a function of the height of the dielectric spacer used to support the resonator. This "over the line" coupling configuration results in a reduced housing width, thereby suppressing spurious housing resonances. It also increases the bottom ground plane to resonator spacing, which reduces the Q degradation due to the proximity of conductors to the resonator. Sufficient clearance between the upper ground plane and each resonator must also be provided. The first spurious resonance for the three filters described in the following sections occurs well out of band at approximately 850 MHz above the filter response.

Bandreject Filter

The following representative bandreject filter design objectives were chosen to demonstrate the design procedure and filter performance:

Center frequency	f_o = 3920 MHz
Number of resonators	n = 3
3 dB bandwidth	Δf = 34 MHz
Response	Butterworth maximally flat

An inter-resonator spacing of 3/4 λo provides suitable isolation between resonators. Following standard design procedures, the resonator couplings can be obtained from the lossless lumped element lowpass prototype values as a function of the above parameters[4] giving $Qex_1 = Qex_3 = 230$ and $Qex_2 = 115$. The resonator positions corresponding to these values are obtained from coupling measurements as presented in Figure 1b. The filter configuration is presented in Figure 2. The stripline pattern shown is required in order to account for both the increased housing dimensions and dielectric loading at each resonator position. This maintains the stripline at 50 Ω and provides a high out-of-band return loss.

Good agreement between the calculated lossless Butterworth response and the measured response is obtained as indicated in Figure 3. The insertion loss and return loss at the band center are 87 dB and 0.31 dB. The return loss corresponds to an effective resonator Q of Q_{eff} = 6300.

Bandpass Filter

A direct-coupled bandpass filter is presented in Figure 4. The coupling to the end resonators uses a configuration similar to the one described with the bandreject filter. The following filter design objectives were chosen:

Center frequency	f_o = 4110 MHz
Number of resonators	N = 3
3 dB bandwidth	Δf = 26 MHz
Response	Butterworth maximally flat

The coupling values corresponding to the above parameters are $Qex_{A,B}$ = 160 for the end resonators, and the interresonator couplings are $k_{12} = k_{23} = .00447$. The resonator positions corresponding to these coupling values are determined from measured inter-resonator and end resonator coupling data similar to that described with the bandreject filter.

The filter performance and the Butterworth function agree well as observed in Figure 5. The insertion loss and return loss at the band center are 0.615 dB and 32 dB. Using S. B. Cohn's Formula[4] with allowance made for the coaxial connector losses, the effective resonator Q which includes all other circuit losses can be obtained from the insertion loss giving $Q_{eff} = 5320$ (down from an intrinsic Q of 9000).

The very low temperature coefficient of the $Ba_2Ti_9O_{20}$ resonator can be made even smaller for the filter by careful positioning of the housing walls. The resonator itself typically yields

$$\tau_f = 1.4 \text{ ppm/°C} + 0.02 \text{ ppm/°C}^2,$$

with a reference temperature of 25°C. The linear term is balanced by the differential expansion between the resonator support (quartz tubing) and the housing, to yield a filter temperature coefficient of approximately 0.02 ppm/°C^2. For a 100°F (56°C) temperature range, this gives a total frequency shift as low as 15 ppm or 60 kHz at 4 GHz. However, the use of conducting screws for resonator frequency tuning also introduces small linear effects and determines the practical limit on this balance.

Bandpass Filter Coupled to Waveguide

A direct coupled six resonator bandpass filter coupled to waveguide is presented in Figure 6. The filter has a non-symmetrical coupling distribution and is synthesized from the appropriate lowpass lumped element prototype values to complement a delay equalizer. Preliminary inter-resonator spacings corresponding to the desired coupling values were determined from measurements on a two resonator housing. The final positions were then determined from measurements on the six resonator housing using Dishal's technique[5]. The filter was tuned with Dishal's single frequency technique[5]. Dishal's swept frequency technique can also be used, where the response of the first resonator is detected with a magnetic field probe entering the housing through a small hole on the side.

The filter was tuned to center the envelope delay distortion at 3990 MHz. The envelope delay distortion displays the desired parabolic shape as shown in Figure 7 where a comparison with the mapped prototype response is also given. Better agreement with the calculated delay would be obtained if the filter bandwidth were narrowed slightly.

The centers of the insertion and return loss responses occur at approximately 3988 MHz (Figure 8). The insertion loss at 3988 MHz is 0.48 dB which corresponds to an effective Q of 5700 (down from 7650). The resonator coupling is a function of frequency which gives a skewed insertion loss response similar to that found with waveguide filters.

Conclusion

Bandreject and bandpass filters using $Ba_2Ti_9O_{20}$ ceramic dielectric resonators compare favorably with copper waveguide filters. They are smaller, integrable and provide much superior temperature stability while yielding losses approaching those of waveguide filters. The six section filter with dielectric resonators is 5.75 inches long versus 18 inches for the waveguide filter for example. The $Ba_2Ti_9O_{20}$ resonators yield temperature stabilities an order of magnitude better than copper filters. At 4 GHz, effective resonator Q's between 5300 and 6300 have been obtained. This compares with effective Q's of 7000 to 9000 for waveguide filters. Spurious filter responses in band are avoided. The first spurious response occurs at approximately 850 MHz above the center frequency and corresponds to the second resonator mode.

Standard synthesis techniques using lumped element lowpass prototype values have been used. Good agreement between theoretical and measured characteristics are obtained.

Acknowledgments

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The waveguide filter data used for comparison and the lumped element lowpass prototype values for the six-resonator filter were provided through the courtesy of R. F. Wessling, Jr. and H. C. Wang.

References

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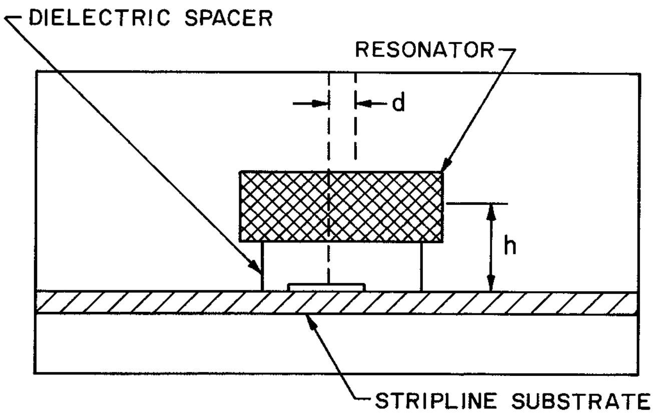

Fig. 1(a)-Cross section showing position of dielectric resonator over a strip-line on suspended substrate.

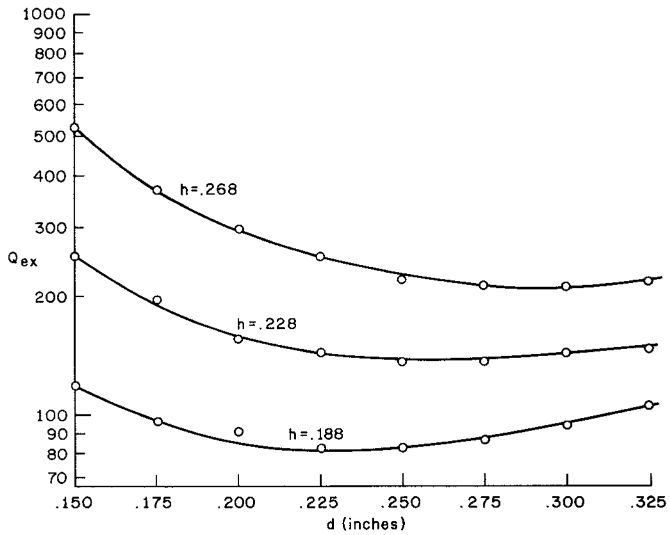

Fig. 1(b)-Measured stripline to resonator coupling.

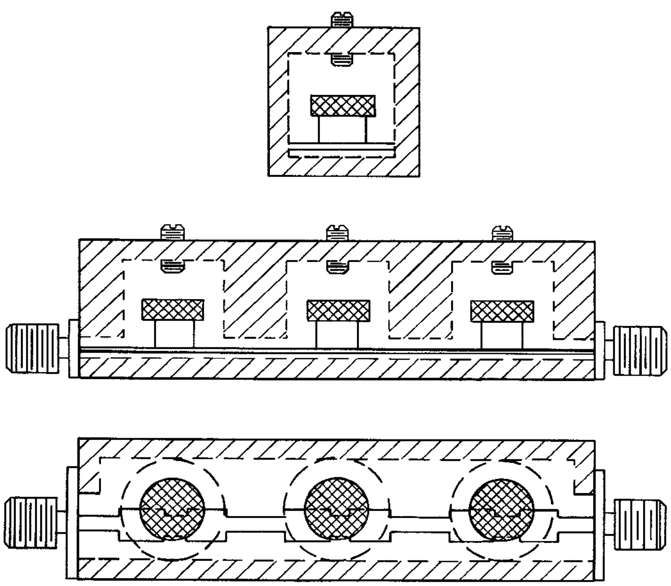

Fig. 2-Three resonator bandreject filter at 4 GHz.

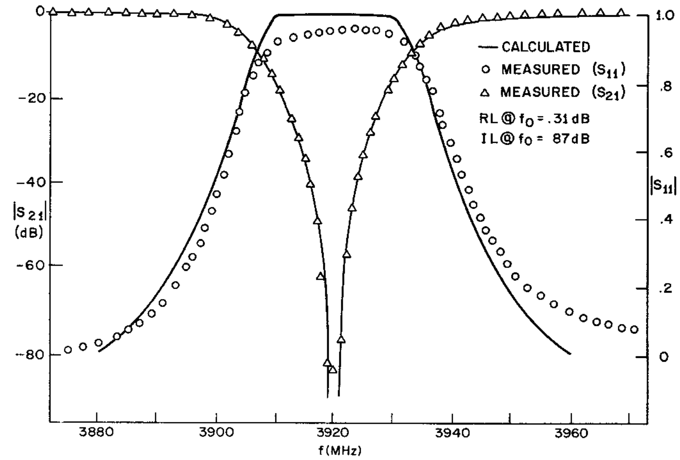

Fig. 3-Response of three resonator bandreject filter.

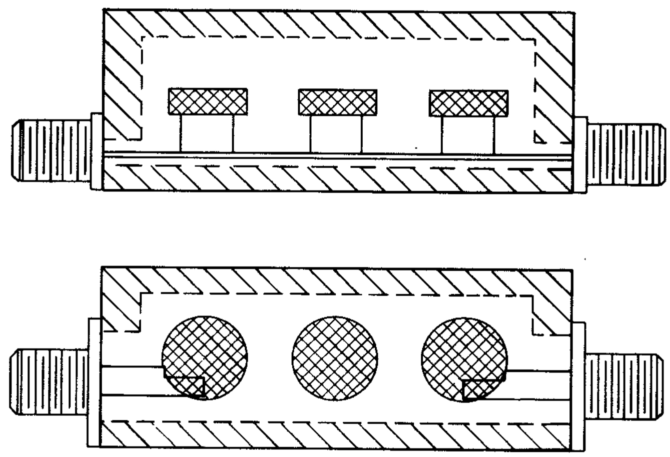

Fig. 4-Three resonator direct coupled bandpass filter at 4 GHz.

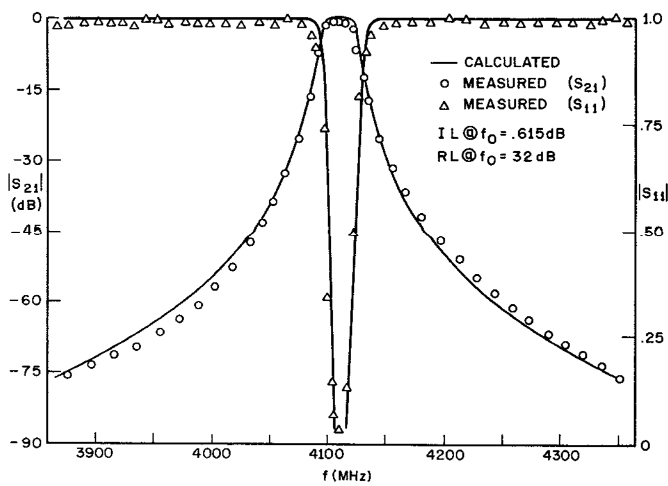

Fig. 5-Response of three resonator bandpass filter.

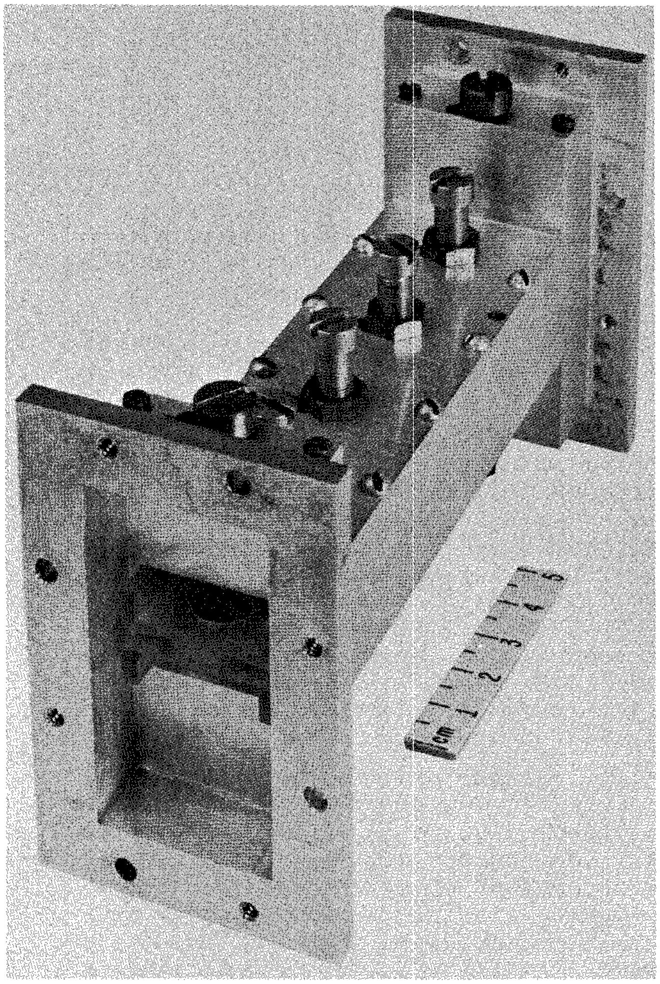

Fig. 6-Six resonator direct coupled 4 GHz bandpass filter with WR-229 waveguide ports.

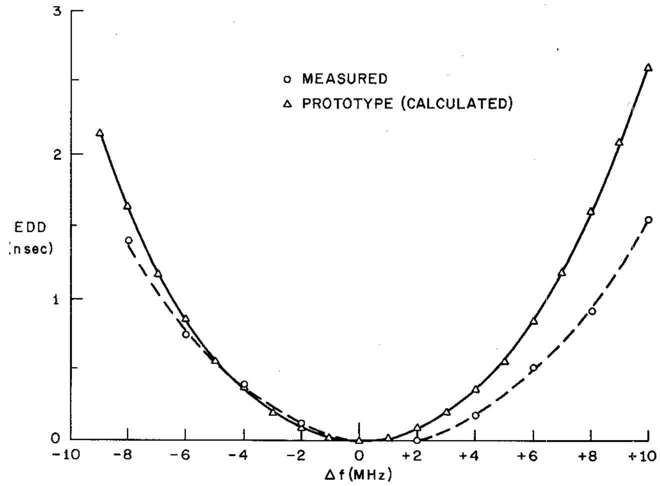

Fig. 7-Envelope delay distortion of six resonator bandpass filter.

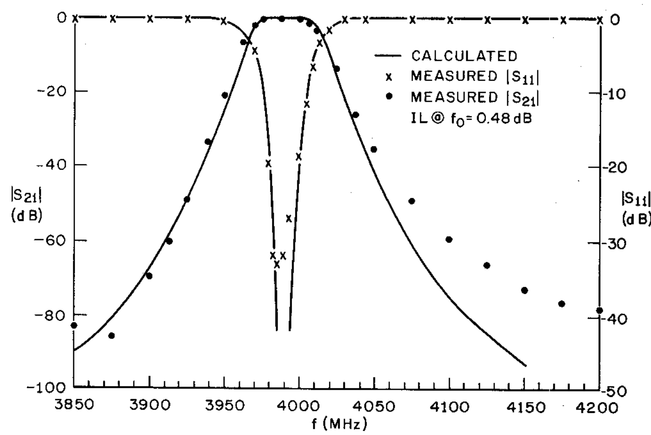

Fig. 8-Response of six resonator bandpass filter.