Bandstop Filter Design Using Evanescent Mode Resonators

Richard V. Snyder, Sanghoon Shin, Kevin Keck

RS Microwave Inc.
22 Park Place, Butler, NJ 07405

Abstract – A new bandstop filter design is proposed using evanescent mode cavities consisting of short-circuited lengths of cylindrical waveguide operated below cutoff frequency. The proposed bandstop filter shows a very high Q bandstop response at lower frequencies, unavailable with a lumped element approach and with smaller physical size than can be achieved with coaxial structures.

I. INTRODUCTION

High Q resonant structures are the crucial building blocks in RF and microwave filter designs. Cavity type resonators are widely used for base-stations in both cellular and satellite communication systems due to the high Q and high power capability. High dielectric constant materials are commonly used as dielectric rod resonators and as substrates to miniaturize overall size of circuits at lower frequencies. Coaxial resonators are used for rejection of interference in high power spread spectrum communication systems.

However, cavity type resonators are bulky at lower frequencies. An evanescent mode waveguide approach is commonly used to design compact bandpass filters [1]. In this paper, we introduce a new compact resonator structure characterized by a high dielectric loaded coplanar waveguide (CPW) feed line, with an evanescent mode short-circuited air-filled cylindrical waveguide. The structure is used to obtain high Q bandstop resonance at lower frequencies (1 to 2 GHz). A 6^{th} order bandstop filter is implemented, designed for high power application (the grounded cylindrical waveguide provides a path of low thermal resistance).

II. EVANESCENT CAVITY BANDSTOP FILTER

Fig.1 shows a configuration of an evanescent mode bandstop resonator. The intention is to design a high power notch filter, with volume reduced as compared to the more conventional capacitively coupled, short-circuited coaxial resonator designs ([2], [3]). The designs shown in [2] and [3] find great use for interference suppression in high power spread spectrum communication systems. Smaller designs would result in greater use in the smaller fighter aircraft of the future. In the proposed approach, a coplanar waveguide (CPW) built on barium titanate (BaTiO3, K=80) is used as a feed line to excite the energy into conducting wall cylindrical waveguide. This is an alternative to the use of surface wave line, proposed in [4]. The coplanar ground planes of CPW helps to reduce the radiation which is a problem with surface wave lines. The excited energy is capacitively coupled into the conducting hollow air-filled cylindrical waveguide. The waveguide, below cutoff frequency, behaves as a high Q inductor thus providing an energy storage element. A series shunt resonant circuit, shown in Fig. 2, represents this inductance and the coupling capacitance resulting from the feed line structure [4].

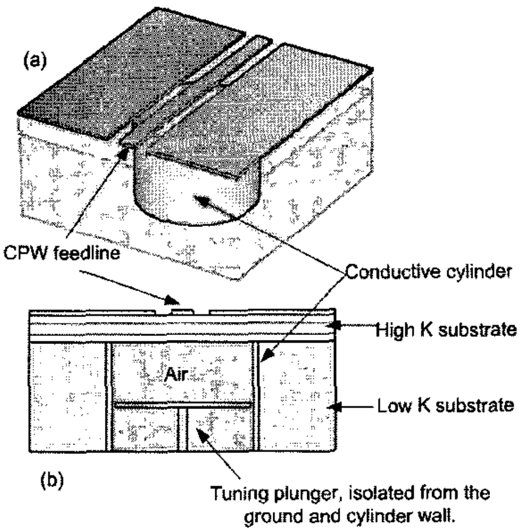

Fig.1 Single evanescent mode bandstop resonator. (a) 3D-view, (b) side view.

The inductance of an evanescent mode inductor displays higher values of than can be obtained with lumped inductors (Fig.3). The theoretical unloaded Q for a round cross section can be calculated using the following formula for below dominant TE_{11} mode of the round cross section [5].

$$Qu = \frac{\pi f \mu d}{R_s}\left[\frac{0.404 + 0.405(1 - f^2/f_c^2)}{1.144 + 0.338(1 - f^2/f_c^2)}\right] \tag{1}$$

$$(fc)_{11}^{TE} = \frac{1.8412}{2\pi a\sqrt{\mu\varepsilon}} \tag{2}$$

$$Rs = \sqrt{\frac{2\pi f c \mu}{2\sigma}} \tag{3}$$

where fc is cutoff frequency, d is diameter of cross section, a is radius, and Rs is ohmic loss.

0-7803-7695-1/03/$17.00 © 2003 IEEE

2003 IEEE MTT-S Digest

The equivalent impedance can be calculated using the following formula [4] and displayed in Fig.4.

$$X_e = Z_0 \tanh\left(\frac{\gamma \ell}{2}\right) + \frac{Z_0^2 \tanh\left(\frac{\gamma \ell}{2}\right)}{Z_0 \tanh\left(\frac{\gamma \ell}{2}\right) + \frac{Z_0}{\sinh(\gamma \ell)}} \quad (4)$$

Z_0 (for round cross section sector with cut-off wave length of λc, ℓ : length of cylinder cavity)

$$Z_0 = \frac{377}{\sqrt{\left(\frac{\lambda_g}{\lambda_c}\right)^2 - 1}} \quad (5)$$

$$\gamma = \left(\frac{6.28}{\lambda_g}\right)\sqrt{\left(\frac{\lambda_g}{\lambda_c}\right)^2 - 1} \quad (6)$$

The resonance effect results from what has been called the ***"Equivalent Frequency"*** principle, by which it is recognized that a below-cutoff section is below cutoff, not to a given frequency, but to the wavelength of energy incident upon it [4]. Eqs. (4)-(6) illustrate that the reactance of the below cutoff section is dependent on the ratio of the ***wavelength of the incident energy*** (λ_g) to the ***cutoff wavelength for the section*** (λ_c). Thus, shortening the incident wavelength through the use of dielectric loading enables the below cutoff section to be effectively closer to cutoff and thus more easily excited, display higher inductive impedance and higher unloaded Q.

This wavelength-shortened energy (shortened during propagation in the high dielectric loaded CPW feed line) is easily coupled to low dielectric constant filled or air filled evanescent cavities.

Fig.5 shows a simulated bandstop response of a single section of the evanescent mode cavity. Due to the high impedance value, available as a result of operation effectively close to the cavity cutoff frequency (the Equivalent Frequency principle results in an operating wavelength close to the air-filled cavity cutoff wavelength), a very narrow deep notch response is achieved. The desired bandstop response is obtained around at 1GHz. The first spurious notch around 0.5 GHz in Fig.5 is generated from the via-hole inductance of the eyelet. This is shown by examining the depth of the two notch responses with perfectly conducting walls and again with finite conductivity (copper). The via hole resonance depth is reduced significantly when the wall conductivity is that of copper, while the depth of the evanescent notch is almost unaffected by this wall conductivity change. This is due to the fact that fields are partially in air and partially in the walls, for the evanescent resonance, but primarily in the walls for the via hole resonance. Simulated and laboratory measurement data are in agreement on this point, and this data will be presented during IMS2003.

When eyelet length is reduced from 0.5" to 0.1", the notch frequency is moved up from 1.0 GHz to 1.25GHz (Fig.6). The shortened physical length of the eyelet decreases the equivalent inductance, and in consequence, the notch frequency is moved up. As seen in Fig.6, the lower notch (from via inductance) moves much more rapidly in frequency than does the higher frequency (evanescent) notch. This is because the via inductance is almost linearly dependent on length, while the evanescent waveguide inductance is essentially insensitive to length once the field has decayed (below about 0.3" in length). Fig.7 shows Poynting vector distribution of the single section eyelet. The coupled energy inside the eyelet gradually decays in the direction of ground. This shows that the evanescent TE_{11} mode is used for the fundamental high-Q filter resonance. An experimental 6-pole bandstop filter is displayed in Fig.8.

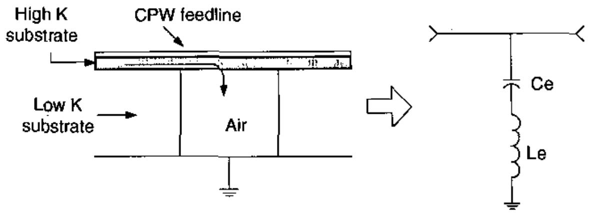

Fig.2 Equivalent circuit of evanescent mode bandstop resonator.

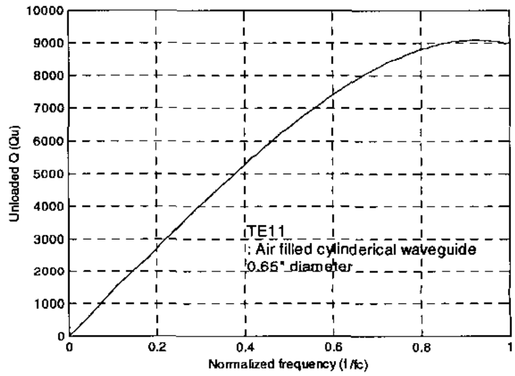

Fig.3 Theoretical unloaded Q (Qu) vs. normalized frequency of the evanescent TE_{11} mode conducting cylindrical waveguide.

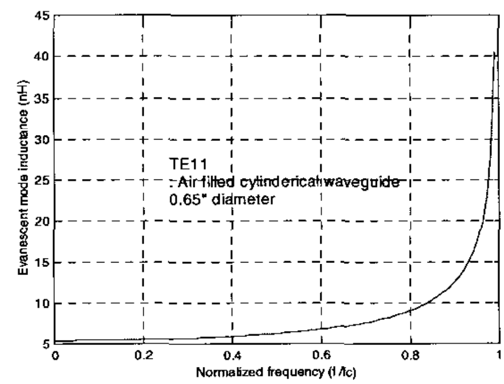

Fig. 4 Equivalent inductance vs. normalized frequency of the evanescent TE_{11} mode conducting cylindrical waveguide.

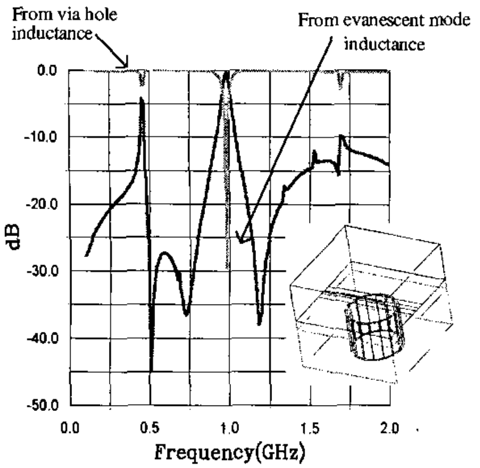

Fig.5 Simulated response of a single evanescent mode bandstop resonator.(Eyelet; diameter=0.65", length=0.5", copper)

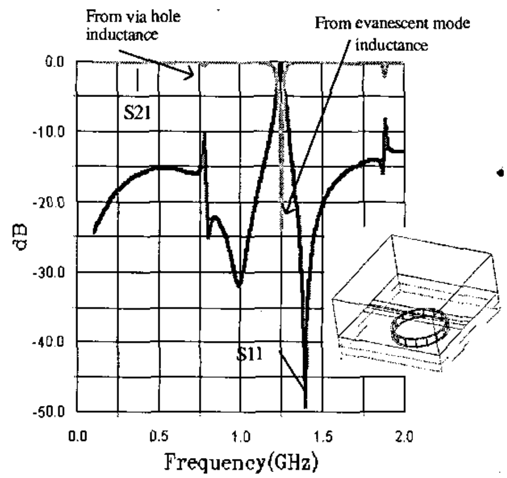

Fig.6 Simulated response of a single evanescent mode bandstop resonator.(Eyelet ; diameter=0.65", length=0.1", copper)

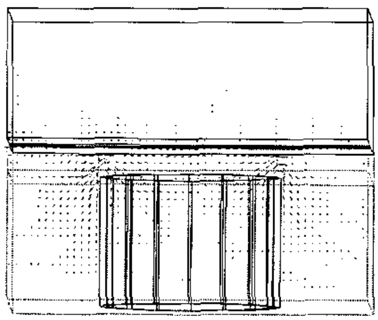

Fig. 7 Side view of Poyting vector at resonance frequency 1GHz. (Eyelet; diameter=0.65", length=0.5").

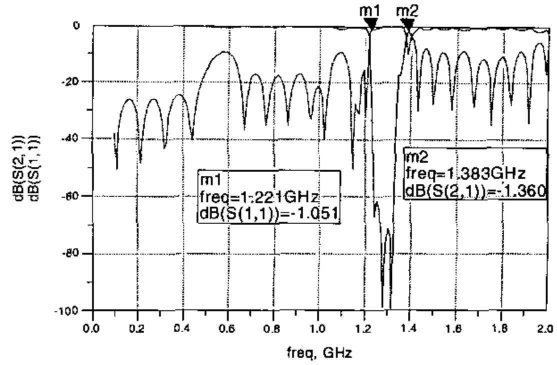

Fig.8 Simulated filter response of a 6-pole bandstop filter. ; Stopband width; 160Mhz, center frequency; 1.29GHz.

III. MEASUREMENTS

A photograph of a single section of an evanescent mode bandstop resonator is shown in Fig. 9. The measured data of a single bandstop resonator is displayed in Fig.10. Although the insertion loss is degraded because of the impedance mismatch of the feed line, measured 23 ohms, to the port networks, a deep notch is obtained at 1.18GHz. It is noted the first notch is came from the via-hole inductance as simulated results in Fig.5. A picture of a 6^{th} pole bandstop filter is displayed in Fig. 11, measured data in fig.12. The notch frequency is obtained at 1.43GHz and via inductance is noticed at 0.743GHz as is observed and computed for a single section resonator. Proper coupling and impedance transforming networks should be considered to get a better VSWR. Certain mechanical shortcomings of the breadboard circuit caused the response at 1.43 GHz rather than 1.25 GHz, and work on the plated substrates continues to alleviate this problem. Final data should be presented at IMS2003.

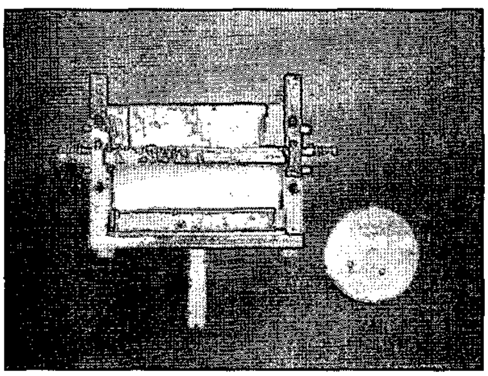

Fig. 9 Photograph of a single section eyelet bandstop resonator.

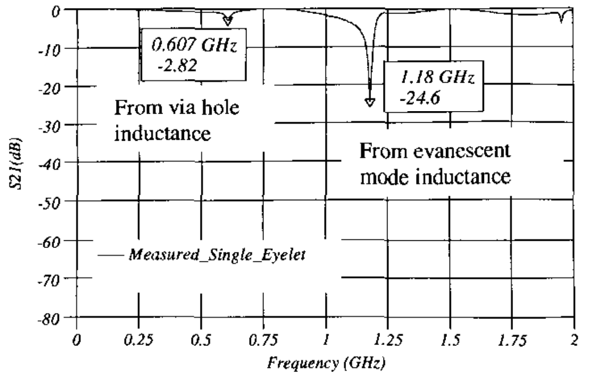

Fig. 10 Measured insertion loss of a single section bandstop resonator.

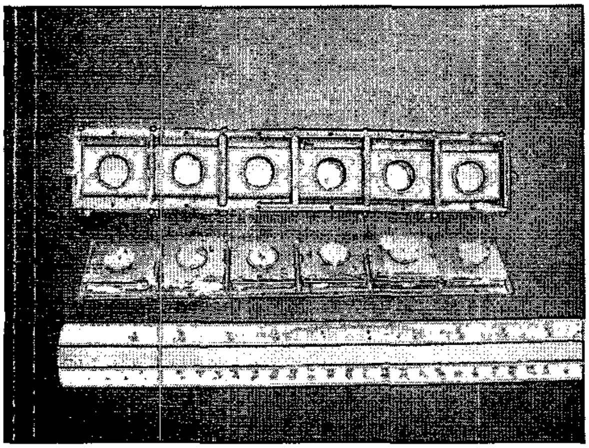

Fig.11 Photograph of a 6-pole bandstop filter.

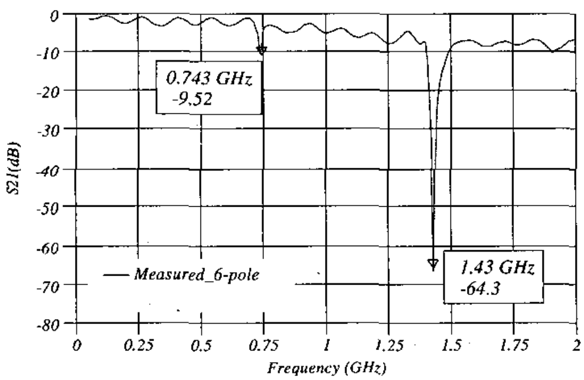

Fig. 12 Measured data of 6-pole bandstop filter.

IV. Conclusion

A new type of bandstop (notch) filter using short–circuited evanescent cylindrical waveguide sections has been presented. The proposed structure is smaller than to conventional cavity resonators, operated above cutoff frequencies, and display higher Q responses than the lumped element circuits used at lower frequencies. The approach is potentially smaller than the conventional coaxial resonator approach, and should not sacrifice performance. A capacitive slot type excitation to the evanescent cavities, typically used in slot waveguide antennas, can be considered as an alternative feed line method. Finally, structures are being investigated in which the feed lines employ low dielectric constant material while the resonators consist of below-cutoff dielectric resonators. A summary of these investigations will also be presented at IMS2003 during paper presentation.

References

[1] Ralph Levy, Richard V. Snyder, George Matthaei, " Design of Microwave Filters", IEEE Trans. Microwave Theory and Tech., Vol. 50, No.3, pp. 783-793, March 2002.

[2] Richard V. Snyder, " A Compact, High Power Notch Filter with Adjustable Fo and Bandwidth", IEEE Trans. Microwave Theory and Tech.,, Vol.42, No.7, pp.1397-1403, July 1994.

[3] Richard V. Snyder, " Quasi-Elliptic Compact high-Power Notch Filters Using a Mixed Lumped and Distributed Circuit", IEEE Trans. Microwave Theory and Tech., Vol. 47, No.4, pp. 518-522, April 1999.

[4] Richard V. Snyder, Edip Niver, Keehong um, Sanghoon Shin, "Suspended resonators for filters- Reduced λg excitation of evanescent cavities using high dielectric constant feedlines", IEEE 2002 MTT-S Int. Microwave Symposium and Transaction, December 2002.

[5] Richard V. Snyder, "New Application of Evanescent Waveguide to Filters", IEEE Trans. Microwave Theory and Tech., Vol. 50, No.3, pp. 1013-1021, Dec. 1977.