Highly Selective Miniaturized Integrated Ceramic Waveguide filters for Cellular Base Station

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Abstract
Design techniques for integrated ceramic waveguide filters with N+1 controllable transmission zeros (TZ) is presented. The integrated dielectric filters offers considerable size reduction as compared to TEM resonators. The selectivity of the filters is increased by introducing N+1 TZ using resonant coupling structures and resonating discontinuities in the external resonators. Simulated results for two asymmetrical generalized Chebyshev designs having N-1 and N+1 TZ in the upper side of the passband are presented.

Index Terms
Dielectric resonators, monolithic integrated filter, Miniaturization, Transmission zeros.

1. Introduction

Microwave filters are the key component in cellular base station transceivers. Conventionally, TEM filters are used in cellular base stations due to their simple fabrication, good out of band performance and high Q factors but these filters are bulky. Future systems require a significantly increased number of highly selective filters and consequently miniaturized solutions without degrading the electrical performance. Usually, highly selective asymmetric filter response is desired in cellular communication bands due to adjacent uplink and downlink frequencies. A monolithic integrated ceramic waveguide filters design has been reported in [1]. It provides considerable size reduction up to 52% as compared to conventional TEM filters. The stop band performance is also improved by employing different techniques like metal posts inside ceramic cavity or employed different width ceramic resonators in monolithic integrated ceramic waveguide filter [2-3]. The same reduced volume can also be achieved by dual mode and triple mode dielectric loaded cavities [4-5]. These multimode filters received a great attention from industry and academia due to an attractive feature of enabling further size reduction while keeping good electrical performance. Both selectivity and insertion loss of the filter are directly proportional to the number of resonator sections. One way to produce highly selective filters with less number of resonators is to introduce transmission zeros at finite frequencies using cross couplings or resonant coupling structures. [6-7]. Two transmission zeros can also be produced and controlled independently without having cross coupling. The shorted stubs and interdigital capacitors can produce transmission zeros with stepped impedance resonators [8]. The dispersive coupling can be used to generate the transmission zeros at higher and lower side of the pass band [9]. The phase cancellation between the two paths in a ring will generate the transmission zeros on either side of the suspended substrate dual mode filter. It obtains the good low pass filter response, good selectivity, better spurious with high Q factor without using any cross couplings [10]. Therefore, it’s obvious that transmission zeros can be produced by employing different techniques without using cross couplings. The generation of transmission zeros by strongly coupled resonators in inline waveguide filters was also discussed in [11]

In this paper, integrated ceramic waveguide filter designs having number of arbitrarily placed TZ in the stopband are presented. Resonating coupling structures and resonating discontinuities are used to generate the TZ in the stopband of the filter. The metal coated blind holes behaving as resonating coupling structures are used to work as impedance inverters and produce TZ at the same time. These TZ improves the overall selectivity of the filter on upper side of the pass band. The hole positions from the side and back wall and their depth inside the filter cavity can be used to control the position of TZ while the height can be used to adjust the bandwidth of a filter.

2. Resonator and Coupling structure

The resonator structures used here are metal coated rectangular ceramic blocks as described in [1] and their resonant frequencies can be computed as [12].

$$f = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{l\pi}{a}\right)^2 + \left(\frac{m\pi}{b}\right)^2 + \left(\frac{n\pi}{d}\right)^2} \qquad (1)$$

Where l, m and n represent half wavelength field variations along width, height and length of the resonator. The field solutions for fundamental TE10 mode in rectangular waveguide with a > b are given as, [15]

$$E_y = -\frac{ja\omega\mu}{\pi} H_0 Sin\left(\frac{\pi x}{a}\right) \qquad (2)$$

$$H_x = -\frac{ja\beta}{\pi} H_0 Sin\left(\frac{\pi x}{a}\right) \qquad (3)$$

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$$H_z = H_0 Cos\left(\frac{\pi x}{a}\right) \quad (4)$$
$$E_x = E_z = H_y = 0 \quad (5)$$

Integrated ceramic filters offer significant volume reduction as compared to conventional TEM resonators with nominal Q-factor values. The unloaded Q-factor for a rectangular waveguide resonator with the aspect ratio of b/a = 0.5 can be calculated as [13]

$$Q_u = \frac{1}{\sqrt{\varepsilon_r}} \frac{\lambda_0}{\delta} \frac{a}{8} \sqrt{\left(\frac{l}{a}\right)^2 + \left(\frac{n}{d}\right)^2} \quad (6)$$

Where $\frac{\lambda_0}{\delta}$ for polished corrosion free silver is $6.76e^{-6}\sqrt{f_{GHz}}$.

Metallized blind holes placed along the width of the ceramic waveguide filter work as resonant coupling structures where coupling bandwidths and the location of TZ can be controlled by hole dimensions and its offset from the sidewall, respectively. The frequency behavior of the coupling hole can be modeled as given in Fig.1

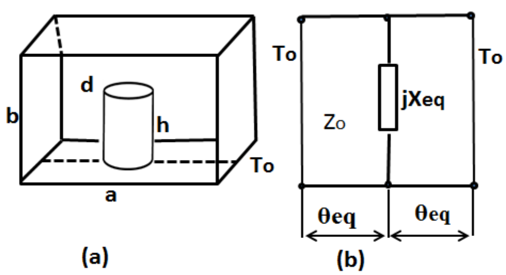

Fig. 1 resonating coupling hole (i) Physical layout (ii) equivalent circuit.

The transfer matrix of the capacitive shunt discontinuity embedded in a uniform length of waveguide with electrical length φ can be written as

$$[T] = \begin{bmatrix} Cos\varphi & jSin\varphi \\ jSin\varphi & Cos\varphi \end{bmatrix} \begin{bmatrix} 1 & 0 \\ jB & 1 \end{bmatrix} \begin{bmatrix} Cos\varphi & jSin\varphi \\ jSin\varphi & Cos\varphi \end{bmatrix} \quad (7)$$

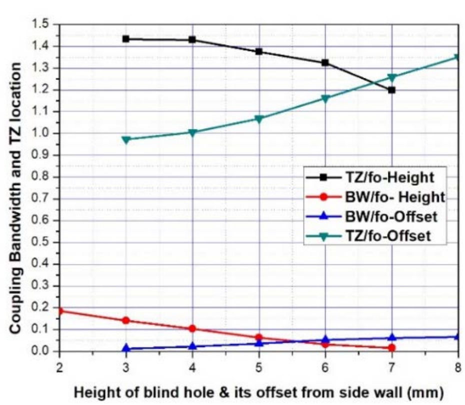

Fig. 2 Coupling bandwidth and Tz location variation with respect to hole height and its distance from side walls.

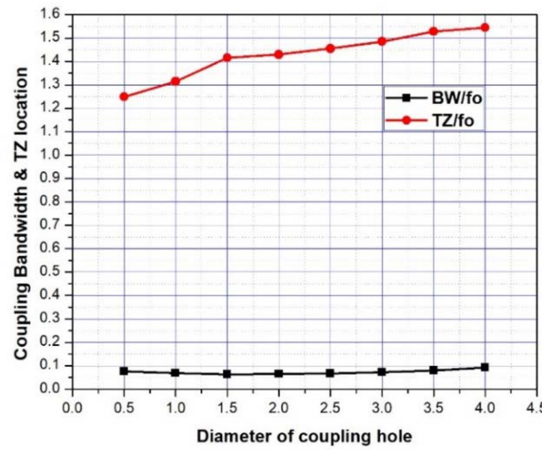

Fig. 3 Coupling bandwidth and Tz location variation with respect to hole diameter

Fig 2 and 3 presents the TZ location as a function of penetration and diameter of the blind hole. The parametric study of the metal coated blind hole dimension and its offset from the side walls has been conducted to visualize their effect on TZ location and coupling bandwidth.

It can be concluded from the graphs that coupling bandwidth would be controlled by adjusting the height of the hole while TZ location is based on hole position and diameter.

3. Discussion

A. design i : integrated ceramic waveguide filter with n-1 transmission zeros

A fourth order ceramic filter with the following specification was designed using λg/2 resonators spaced by metal coated blind holes in ceramic.

Centre frequency	:	1840MHz
Bandwidth	:	80 MHz
Ceramic Permittivity	:	45
No of transmission Zeros	:	3

The inline structure is a rectangular metal plated dielectric bar with blind holes drilled at an interval of half wavelength resonators as shown in Fig.4. The diameter of the metal coated hole and its distance from side wall control the position of the TZ while the desired bandwidth can be achieved by adjusting the height of the hole. The design technique outlined in [13] can be used to design the overall ceramic waveguide filter. Hole position and dimensions i.e. depth and diameter are optimized to satisfy both predefined TZ position and the required inverter susceptances. Input and output coupling is achieved via coaxial probes as mentioned in [1]. The input coaxial probe from the shorted side, diameter and penetration within the wave guide confirm the quantity of coupling achieved, bandwidth and center frequency. The structure is silver plated apart from the input /output coupling probe positions. Figure 5 presents the EM simulated s parameters of the filter-I, where 3 TZ are produced using resonating metal plated holes.

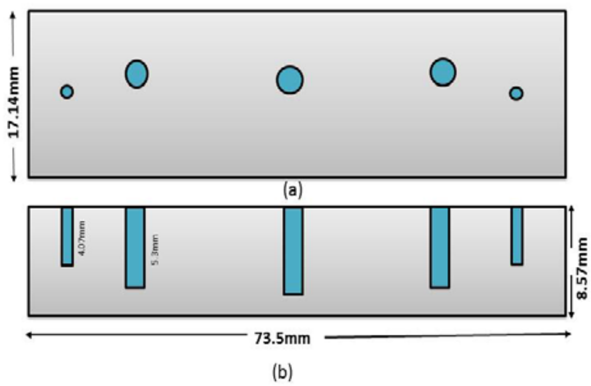

Fig. 4 Physical layout of the Filter-I (a) Top view (b) Side view

EM simulated Filter-I response is presented in Fig.5 shows three TZ on upper side of the passband.

B. Design-ii : Integrated Ceramic Waveguide filter with n+1 tz

Another filter with N+1 transmission zeros is designed with the following specifications.

Centre frequency	:	1840MHz
Bandwidth	:	80MHz
Ceramic Permittivity	:	45
No of transmission Zeros	:	5

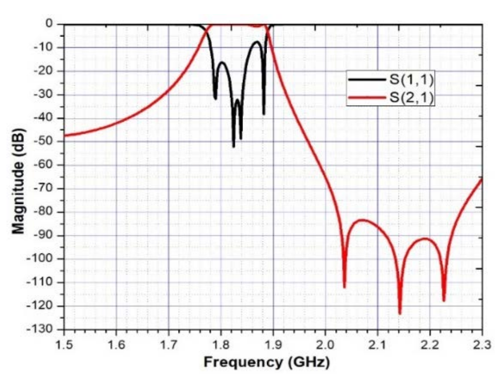

Fig. 5 EM simulated response of the Filter-I

Three TZ are produced from resonating coupling structures as described in section III. Two further TZ are produced by introducing resonating discontinuities (metal plated blind holes) in the external resonators.

4. Results

Two filter designs produce different set of transmission zero on the higher side of the pass band. The first design produces N-1 transmission zero which improves the selectivity of the filter on the higher side, whereas, the second design offer two more TZ in the stopband at the expense of lower Q-factor. The Q-factor of external resonators doesn't contribute much to overall insertion loss variation or selectivity of the filter [14]. The input/output couplings are achieved via coaxial probe placed at the center of the external resonators, where the E-field is maximum.

Fig.6 presents the ultimate layout of the inline miniaturized direct coupled generalized Chebyshev filter with N+1 TZ designed to work at DCS uplink band.

Fig.7 presents the EM simulated response of the fourth order generalized Chebyshev ceramic wave guide filter having N+1 TZ at upside of the passband

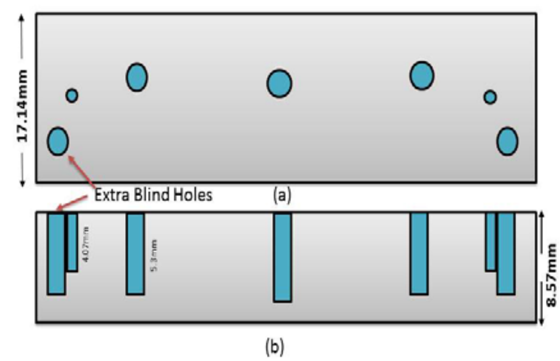

Fig. 6 Physical layout of the Filter-II (a) Top view (b) Side view

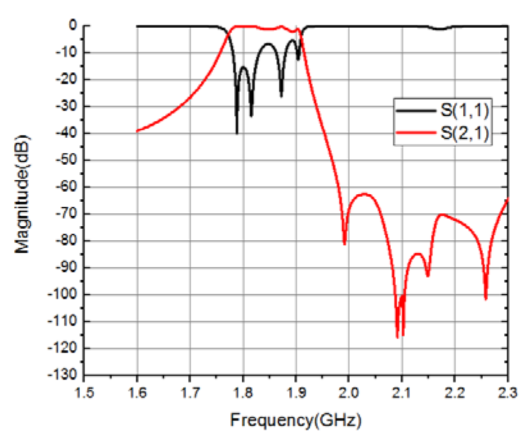

Fig. 7. Ceramic waveguide Filter-II (HFSS Simulation)

5. Conclusion

The design of the miniaturized integrated ceramic waveguide filters with absolute placed N+1 transmission zeros is bestowed during this paper. 2 generalized Chebyshev filters are designed having N-1 & N+1 TZ at top of the passband. This will increase the selectivity of the filter while not increasing the order therefore insertion loss of the filter. This work will be extended further to incorporate fabricated design results, mechanical tolerances, power handling capability etc.

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