A Dual-Mode Frequency Reconfigurable Waveguide Filter with a Constant Frequency Spacing between Transmission Zeros

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Abstract—This paper presents a novel frequency reconfigurable dual-mode waveguide filter with elliptic response. The proposed filter maintains a constant absolute bandwidth and a constant rejection bandwidth (frequency spacing between transmission zeros) over the tuning range. Furthermore, the filter can be tuned using a single tuning mechanism. A 4th order prototype filter at 11.5 GHz with 50 MHz bandwidth and 2 symmetric transmission zeros (±45 MHz) is fabricated and measured. The measured tuning range of the filter is 390 MHz within which the absolute bandwidth variation is within ±1 MHz. In addition, the measured frequency spacing between the transmission zeros varies well within ±2 MHz over the entire tuning range. The proposed filter promises to be useful for flexible payloads in aerospace applications.

Keywords—Elliptic filters, tunable filters, frequency reconfigurable filters, transmission zeros, waveguide filter.

I. INTRODUCTION

The constant thirst for higher data rate fuelled by the revolution in multi-media technology and applications is one of the key driving factors for researchers to explore new communication system architectures. A flexible satellite payload incorporating re-configurability in both radiation coverage as well as frequency allocation, is one such emerging radio architecture in aerospace applications [1] – [4]. A high Q (Quality factor) frequency reconfigurable band-pass filter constitutes an essential part of such a flexible payload.

To enhance the reliability and to significantly ease the complexity of control system (in an eventually closed loop reconfigurable architecture) it is highly desirable to minimise the number of tuning elements in such reconfigurable filters. In this regard, frequency reconfigurable high Q filters have been proposed in recent years in both, coaxial and waveguide technologies, which utilize only one tuning element and yet maintain a constant absolute bandwidth over the tuning range [5] – [8]. However, all these reported frequency reconfigurable filters ([5] – [8]) with single tuning element are all-pole filters operating in a single-mode without transmission zeros.

In this paper, we present a frequency reconfigurable dual-mode waveguide filter with elliptic response. The proposed filter maintains a constant absolute bandwidth and a constant rejection bandwidth (i.e. constant frequency spacing between transmission zeros) over the tuning range. Furthermore, the filter can be tuned using a single tuning mechanism. A 4th order prototype filter at 11.5 GHz with 50 MHz bandwidth and 2 symmetric transmission zeros (±45 MHz) is fabricated and measured. Section II presents the design methodology adopted to realize the proposed filter. Measured results and key observations are expounded in Section III, followed by concluding remarks in Section IV.

Fig. 1. Schematic: Proposed frequency reconfigurable waveguide filter with elliptic response

Fig. 2. Schematic: Internal dimensions and coupling configuration

II. DESIGN METHODOLOGY

A dual-mode rectangular waveguide cavity is adopted to design the proposed frequency reconfigurable filter with transmission zeros. Such a dual-mode cavity resonator has inherent benefits of realizing transmission zeros using virtual negative coupling through iris coupling structures [9].
depicts the schematic of the proposed 4th order frequency reconfigurable filter with 2 dual-mode cavities, while Fig. 2 depicts the internal dimensions and coupling configuration of the filter. The filter is tuned using a common single tuning mechanism (not shown), which linearly displaces the position of metallic tuning element in each cavity, hence effectively tuning the cavity dimension ‘c’ as shown in Fig. 1 and Fig. 2.

The input-output (IO) couplings MS1 and M4L are realized using SMA probes. Two degrees of freedom (pin length and probe position along ‘c’ dimension) enable to realize a constant peak reflection group delay over the tuning range which is essential for maintaining a constant absolute bandwidth [9]. Inter-resonator (IR) couplings M12 and M34 are realized using M1.6 mm screws at 45 degrees as shown in Fig. 1 and Fig. 2. The screw depth controls the coupling strength, while its position (along ‘c’ dimension) determines the flatness of normalized coupling co-efficient, which is essential for maintaining a constant absolute bandwidth [9]. Rectangular slot between the cavities provides the IR coupling M23. The slot position (along ‘c’ dimension) determines the coupling flatness. Finally, the circular slot between the cavities provides the IR coupling M14 essential for realizing transmission zeros. It is strategically located to allow for coupling flatness in order to maintain a constant frequency spacing between the transmission zeros over the tuning range.

To tune the filter, the tuning element in each cavity is linearly displaced using a common single tuning mechanism. To enable for friction free movement between the tuning element and the cavity walls, an air gap of 0.5 mm is provided (Fig. 2). However, such an air gap results in undesired spurious resonance modes within the desired frequency range. Hence, the tuning element is shaped to push the spurious resonance modes outside the frequency band of operation. Dielectric screw (Nylon or PTFE) is used to support the tuning element and connects it to the tuning mechanism.

Fig. 3 and Fig. 4 depict the simulated transmission co-efficient (S21) and reflection co-efficient (S11) of the filter as the tuning element is linearly displaced, respectively. The simulated tuning range of the filter is 600 MHz from 11.4 GHz to 12 GHz. Fig. 5 plots the absolute bandwidth (S11 < -15 dB) over the tuning range, and the variation is within ±1 MHz (between 42 MHz and 44 MHz) over the entire 600 MHz tuning range. Rejection bandwidth is also depicted in Fig. 5. It is worth mentioning here that the key feature of the proposed frequency reconfigurable filter is that the rejection bandwidth is nearly constant. As observed in Fig. 5, the variation of frequency spacing between the transmission zeros is well within ±2 MHz (between 81.6 MHz and 84.6 MHz) over the entire tuning range. Insertion loss variation is within ±0.05 dB (between 0.79 dB to 0.85 dB) over the tuning range. The simulated Q of the resonator is better than 6000 using aluminum cavity. ANSYS HFSS is used for 3D Electro-Magnetic (EM) simulation [10].

III. MEASUREMENT AND OBSERVATIONS

Fig. 6 shows the photograph of the filter parts fabricated using aluminum and the assembled filter. M2.5 screws are used to assemble the filter parts. Silver plated M1.6 screws are used for M12 and M34 coupling screws. Fig. 7 and Fig. 8 depict the measured S21 and S11 of the prototype filter, respectively. The measured tuning range of the filter is 390 MHz from 11.285 GHz to 11.675 GHz. Fig. 9 plots the measured absolute bandwidth (S11 < -15 dB) over the tuning range, and the variation is within ±1 MHz (between 48 MHz and 50 MHz) over the entire 390 MHz tuning range. The rejection bandwidth is also depicted in Fig. 9. The variation of frequency spacing between the transmission zeros is well within ±2 MHz (between 88 MHz and 92 MHz) over the entire tuning range. Insertion loss variation is within ±0.2 dB (between 1.4 dB and 1.8 dB) over the tuning range. Fig. 10 shows the measured response over a wide frequency range depicting the spurious separation better than 2 GHz.
The prototype filter unit is constructed from aluminium cavities and is designed with a bandwidth of 50 MHz, i.e. a fractional bandwidth of 0.43%. With a Q of 6000 the insertion loss of such narrow band filter should not exceed 2 dB over the 50 MHz bandwidth. The higher loss observed in this prototype unit is attributed predominantly to the unintended surface roughness of the middle filter part which incorporates the rectangular and circular slots. In addition, the usage of Kapton tape to ensure the 0.5 mm air gap between the tuning element and the cavity walls, has also contributed to the increased loss. Certainly, silver plating the filter will help in improving the loss. In addition, an exact assembly workmanship of a tuning mechanism integrated to filter housing will improve insertion loss and minimize deviations from theoretical simulations.

IV. CONCLUSION

This paper has presented a novel configuration for a high-Q dual-mode frequency reconfigurable waveguide filter with elliptic response. The filter maintains a constant absolute bandwidth and a constant rejection bandwidth (frequency spacing between transmission zeros) over the tuning range. The key additional feature of this filter is that it is tuned by a single tuning mechanism, which linearly displaces the tuning element. In addition, the proposed design methodology can be scaled to realize higher order filters with additional transmission zeros (e.g. an 8th order filter with 4 transmission zeros). The proposed filter promises to be useful in a wide range of telecommunication applications including flexible payload in aerospace applications.
REFERENCES


