Reconfigurable Bandpass Filter with Variable Bandwidth at 5.8 GHz Using a Capacitive Gap Variation Technique

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Abstract- A reconfigurable bandpass filter that consists of capacitive coupled resonators has been designed with the capability to switch between two distinct bandwidths while keeping a fixed center frequency of 5.8 GHz. This filter can be adapted between a narrowband state with a 4% bandwidth and a wideband state with a 10% bandwidth. This filter achieves a passband reconfiguration ratio greater than 2:1 using only 2 resonators. The design presented here introduces a capacitive gap variation technique for tunable bandpass filters offering great adaptability and full control over parameters such as overall quality factor, center frequency, passband ripple, and bandwidth. Measurements are included demonstrating this technique and verifying the implementation of the filter.

I. Introduction

The creation of microwave bandpass filters whose center frequency can be varied is a relatively new technology. Several microstrip structures such as capacitive edge coupled, inter-digital, comb-line, and hairpin filters, among others, have been successfully modified to allow filtering at a range of frequencies [1], [2]. The most widely used tunable techniques involve variable reactance elements to produce continuous tuning and coupling variation by means of varactor diodes. Current efforts to produce wider reconfigurable frequency ranges involve the use of MEMS or pin diodes to achieve discrete tuning. However, filters with variable bandwidth are difficult to achieve at a fixed center frequency. The reconfigurable filter presented in [3] is one of the few filters to achieve a switchable bandwidth by means of pin diodes and inter-digital coupled resonators. The filter design presented in this paper makes use of a capacitive gap variation technique and gives an alternative solution to the new trend of discrete tunable filters. In addition, it can be easily adapted for use with MEMS switches [4], [5] or pin diodes. One of the most attractive characteristics of this topology is the reduced amount of circuit complexity. The reconfigurable property of the filter is accomplished by a technique that allows the modification of the effective gap width between resonators to produce variable capacitive coupling. The technique introduced in this paper is a new approach for the design of reconfigurable bandpass filters. The current circuit uses ideal open and short connections in strategic sections to demonstrate the two discrete states. The filter was fabricated on Duroid, an organic substrate with ε_r = 6.15, thickness of 50 mils and 0.5 oz. of copper metallization. The theoretical and measured results presented here demonstrate the application of this technique for the first time.

II. Theory and Measurements

A. Gap Manipulation Technique

A gap in a microstrip transmission line is a discontinuity that can be modeled as a series capacitor C_g between transmission line sections and a shunt capacitor C_p between the transmission line and ground plane as shown in figure 1.

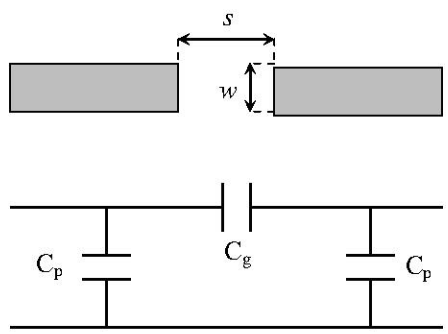

Fig.1. Gap in a Microstrip [6]

One of the difficulties of using capacitive coupled resonators is that the series coupling capacitance C_g may be of such large value that it may be difficult to implement. In this situation, the gap separation *s* becomes very small presenting a potential problem for fabrication. In many instances, a very precise capacitance value is needed for a desired filter response. Lateral extensions give a practical solution to this problem as they have the capability to increase the capacitance C_g avoiding the need of unrealistic gap separation s. In order to find the approximate values for a given gap separation, each of the transmission line sections of the filter that is separated by a gap was simulated and compared to a similar structure consisting of the same two transmission line sections coupled by an ideal capacitor Cg. The gap between each section is then optimized to match the S-parameters produced by the structure consisting of the resonators coupled by the ideal capacitor. This procedure yields the approximate dimension for the gap separation s. Once the initial values of all gap separations are determined, and all the sections are put together, optimization of the complete structure is needed to obtain the final results. An in-depth analysis of transmission line filters using capacitive loaded coupled lines was first introduced in [7] where the coupling lengths are usually a quarter-wavelength long.

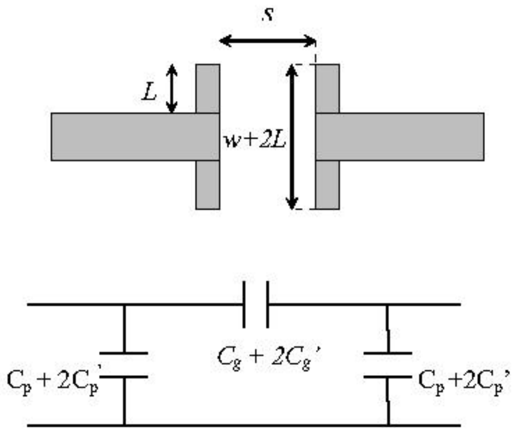

Fig. 2. Extended Gap

Figure 2 shows a microstrip gap whose capacitive coupling has been increased by adding lateral open stubs with length L. Each side of the extended gap produces a series coupling capacitance Cg' resulting in a total series capacitance Cg + 2Cg'. In addition, the new coupling present between the extended sections and the ground plane causes the shunt capacitance to increase to an overall value of Cp + 2Cp'. Although the extra shunt capacitance Cp' seems to have very little impact in the bandwidth, the resonator effective lengths are increased with increasing the lateral extension L, producing a shift in the center frequency. Approximate relationships between the dimensions of the geometry of the filter and the frequency response are established in the following section. A systematic approach may be followed when optimizing for a specific design based on the approximate relation between the geometry and design specifications such as bandwidth, Q factor, center frequency and passband ripple.

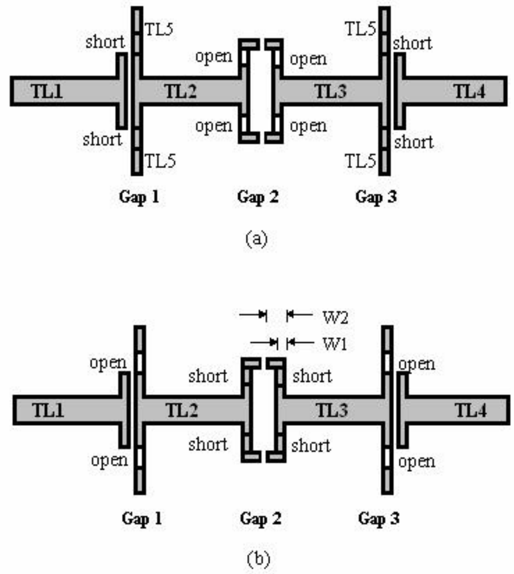

Fig.3. Reconfigurable Structure (a) Narrowband Configuration (b) Wideband Configuration

B. Analysis of Reconfigurable Parameters

A Chebyshev bandpass filter was fabricated and measured to demonstrate the gap coupling variation technique and is shown in Figure 3. The design consisted of two capacitive coupled resonators, labeled above as TL2 and TL3. It was designed to have a center frequency around 5.8 GHz and bandwidths of 4% and 10%. The filter structure consists of two outer gaps with identical separation of 5 mils. These gaps play a direct role in the external quality factor, Q_e of the filter. The distance should be such as to allow both narrow and wide configurations a range of acceptable tunability. A higher capacitance value at these two gaps will lower the Q_e of the filter. Inner gap 2 is the coupling between resonators and is responsible for the frequency separation of the resonant poles. The capacitance in this gap is increased when short connections are placed as shown in figure 3b. The individual resonant frequencies will be located at a greater distance between each other moving away from the center frequency creating a wideband configuration. Consequently, a narrowband configuration is created when open connections are present between the lateral stubs and the gap as shown in figure 3a. In the present design, the upper lateral extensions of gap 2 were increased in width from W1–30 mils to W2–50 mils to allow a further reduction in the overall effective gap separation s and to produce broader bandwidth. The gap separation is 50 mils for narrow band and 10 mils in the upper area for the wideband state. Changing from narrow to wideband states also results in the change of effective resonator lengths and therefore a shift of the center frequency. In order to avoid this shift, the effective length of the resonators needs to remain the same. This is accomplished by the lateral extensions TL5. When placing short connections extends inner gap 2, outer gaps 1 and 3 are open circuited, forcing the effective resonator lengths to remain constant. In the narrow band configuration, inner gap 2 is open circuited and gaps 1 and 3 are shorted. This interchange between inner and outer gaps must exist to obtain a fixed center frequency. The current circuit topology minimizes the number of electronic switching elements.

C. Fabrication and Measurement Results

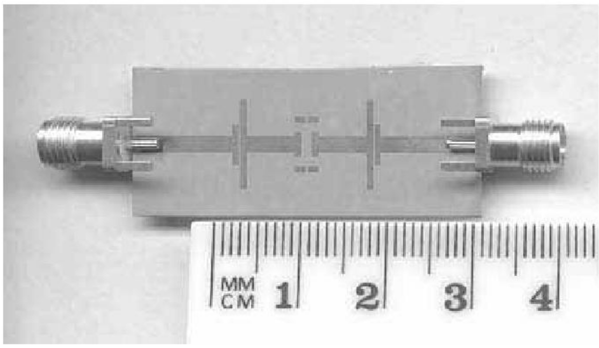

Fig.4. Narrowband filter.

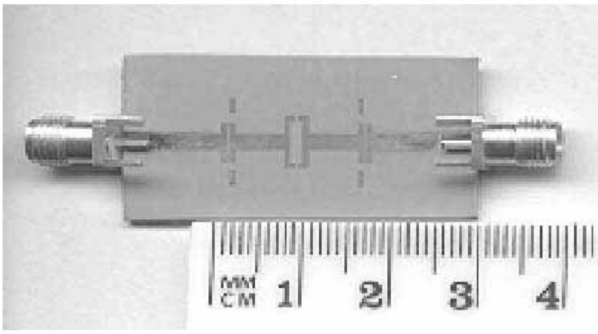

Fig.5. Wideband filter

The filter prototypes were fabricated on Duroid using standard photolithographic techniques. Figures 4 and 5 show the fabricated circuits at their narrow-band and wide-band state respectively. The working topology is demonstrated by using ideal open and closed sections of transmission line as switching elements. Both filter configurations had a center frequency of 5.71 GHz. Figure 6 shows the measured results of the narrowband configuration. The insertion loss at the center frequency was 1.821 dB and the 3-dB bandwidth was 4.46 %. The wideband configuration yields an insertion loss of 1.564 dB and a bandwidth of 11.14 % as shown in figure 7, which results in a 2.5:1 reconfigurable passband.

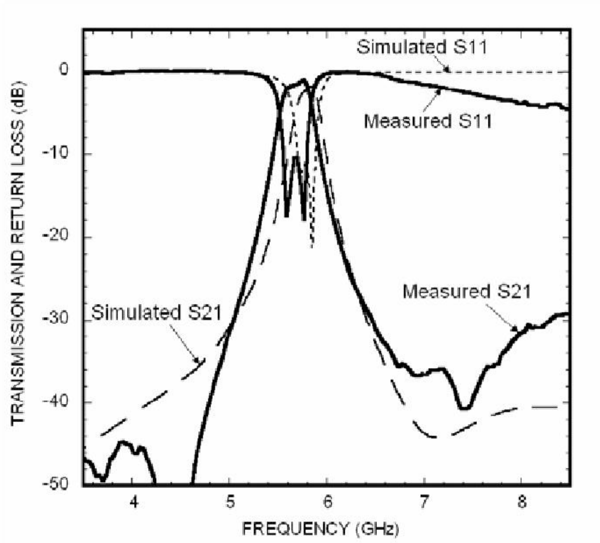

Fig.6. Measured vs. simulated transmission and return loss of the filter in the narrowband state.

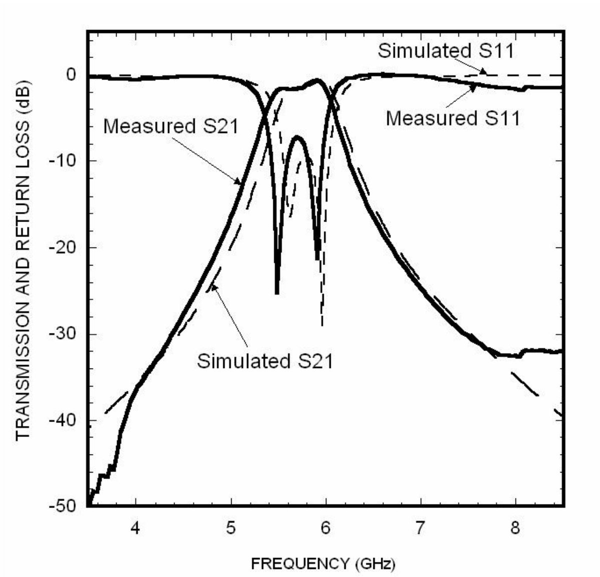

Fig.7. Measured vs. simulated transmission and return loss of the filter in the wideband state.

III. Conclusion

This paper introduces a technique that consists of varying the series capacitance value by changing the effective width of the gap. When lateral open stubs are added to the sides of the gaps, an increase in the coupling strength is observed. This avoids the need of unrealistic gap separations and adds tunable properties to the filter. The current trend of switching devices such as MEMS and pin diodes presents the possibility of switching between discrete values of effective gap widths. To the best of our knowledge the filter structure presented here is the first reconfigurable bandpass filter design with variable bandwidth that uses the capacitive coupled gap manipulation technique. Future work will involve the use of MEMS switches as primary switching elements in conjunction with the variable coupled gap procedure to produce tunability in bandwidth as well as center frequency.

IV. Acknowledgements

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V. References

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