Meandered Line Microstrip Filter With Suppression of Harmonic Passband Response

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Abstract —**This paper presents a new technology for implementing parallel-coupled line filters with suppression of passband harmonics. The meandered line design suppresses passband harmonics by using numerous bends and angles to equalize the phase velocities of the odd and even mode field distributions that occur in conventional straight-coupled line filters. A meandered line filter fabricated as part of this study achieved 40% size reduction and 70 dB rejection at the 2nd harmonic without degrading the passband performance.**

I. Introduction

Edge coupled microstrip transmission-line filters are very common for implementing bandpass filters. The design equations are well defined and easily implemented. However, one fundamental limitation of coupled filter design is the evidence of repeating passbands appearing at the harmonic frequencies. The harmonics can affect adjacent systems creating unwanted noise. A common solution to this problem is to cascade a low pass filter with the bandpass filter to attenuate the unwanted responses. An additional filter increases the size and loss of the system and is only effective in eliminating the first unwanted harmonic created from the passband region. The low pass filter also contributes to unwanted harmonics. There is a need for a single bandpass filter that attenuates unwanted harmonics while still providing for a good response throughout its passband.

A recent study [1] has shown that using a uniplanar compact photonic-bandgap structure as a ground plane in a coupled-line microstrip filter introduces a periodic disturbance that rejects passbands. However, modifications to the ground plane create devices that are difficult to realize. The whole structure must be isolated from other ground conductors for the periodic ground plane to be effective. It has also been shown that introducing a periodic meandering to modulate the strip widths of a coupled line microstrip bandpass filter greatly reduces passband harmonics, while keeping the ground plane constant [2].

The previous cited work [2] achieved harmonic rejection at the cost of insertion loss in the passband. Even though over 40 dB of harmonic rejection was measured at the first harmonic the passband insertion loss was in the order 3 dB.

It will be shown in this paper that by using alternative meandered line approaches, such as fractals, combined with complementary design changes it is possible to design a bandpass filter that provides harmonic rejection, overall size reduction, and improved passband performance relative to the filters detailed in the literature.

Research done at Raytheon, St. Petersburg, and externally [3] [4], has shown that fractal concepts can be applied to an antenna element as a means to reduce the element's effective (tip-to-tip) length without a significant reduction in element performance. Furthermore, it has been shown that the resulting reduced size element actually has an increased conductor path length and, in some cases, enhanced bandwidth. The underlying mechanisms that facilitate these changes for antenna elements can apply equally well to a filter, or any other device that utilizes transmission lines and/or exhibits resonant behavior.

Conceptually, the fractal "bending" facilitates a more efficient "packing" of the conductor and gives rise to a distributed reactive loading. Each bend of the fractal structure increases conductor length and represents a discontinuity in the charge-carrying path. Electrically, these discontinuities appear to be either capacitive or inductive, thus creating a distributed reactive loading effect. This loading serves to slow a propagating wave, and thereby reduce the effective wavelength. This allows the size of the structure to be reduced without shifting its frequency response.

II. FILTER DESIGN

The first step in designing a meandered line band pass filter is to determine the best topology for the fractal shape that is being implemented. A modified version of the Koch curve was used for its self-modulating behavior. Modulation introduces a periodic disturbance that rejects the harmonic passbands, and acts as a slow wave structure that reduces the total physical size of the parallel-coupled line microstrip filter. The slow wave effect is stronger in the even mode of the coupled lines and weaker in the odd mode. The difference in even and odd mode phase velocities in coupled line filters creates harmonic passbands that occur at twice the resonant frequency. In the classical straight-coupled line filter the phase velocity of the odd mode is faster than the even mode. [5] Since the odd mode current densities tend to gather around the edge of the coupled side of the resonators it is advantageous to lengthen the coupled sides of the parallel resonators while keeping the outside edges shorter than the coupled segments. To compensate for the phase velocity differential the coupled lines are bent in a fractal shape to allow the electrical length of the even and odd modes to be similar.

The second step is to design a classical parallel straight-coupled line filter with the desired center frequency and bandwidth of interest. In designing the straight-coupled line filter certain considerations had to be addressed. The line widths and spacing of the coupled filter need to be as narrow as possible to accommodate the fractal bending of the parallel coupled lines. It was observed that the narrow line width in the straight-coupled line filter had the advantage of increased bandwidth.

The length, width, and spacing of the quarter wavelength coupled section of the classical coupled filter were used to design the meandered line filter. The new filter should exhibit the same passband at the design frequency as the straight-coupled line filter, with an improved out-of-band behavior (i.e. suppression of passband harmonics).

The design of the meandered line filter entails taking the total length of transmission line required for a 1/4 wavelength version of the straight coupled line filter and dividing it into the number of segments required to form the desired fractal iteration. Figure 1 shows how a standard transmission line is "bent" into a 1st, 2nd, and 3rd iteration fractal pattern, and how many segments make up each iteration. Since the chosen trapezoidal pattern has 5 segments, the successive fractal iterations will have 5^I segments (where I is the iteration number).

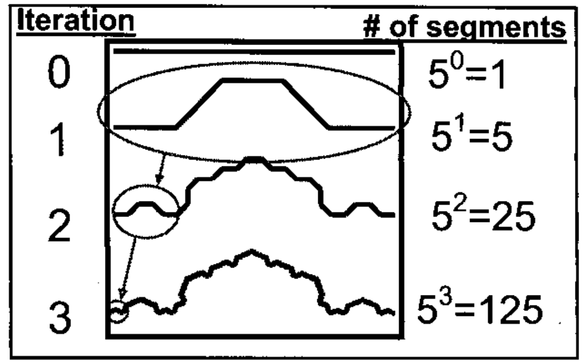

Fig. 1 1st – 3rd iterations of trapezoidal fractal curve.

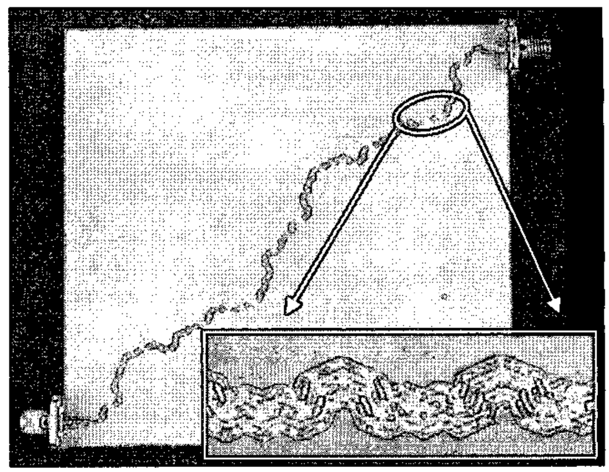

Fig. 2 Third iteration trapezoidal fractal bandpass filter (45-degree modulation angle).

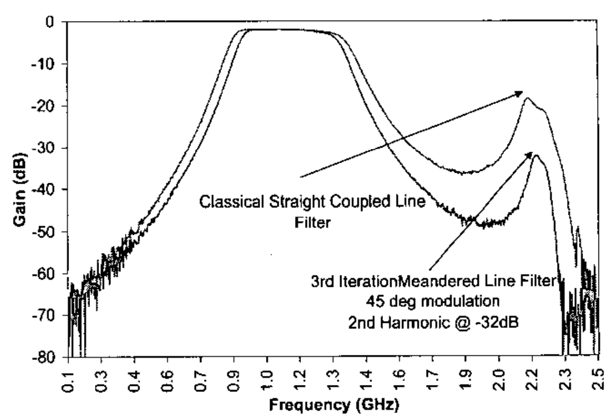

Fig. 3 Insertion loss of third iteration trapezoidal fractal BPF vs. classical coupled line BPF.

III. FILTER FABRICATION & MEASUREMENTS

The filters were fabricated on 30-mil FR-4 substrate using a LPKF milling machine. The measured response of the third iteration trapezoidal fractal bandpass filter (figure 2) indicates a 56% attenuation of the passband at the second harmonic (figure 3). Increasing the angle of modulation from 45 degrees to 60 degrees (figure 4) attenuated the harmonic passband to 70 dB of rejection (figure 5). The result of eliminating the passband harmonic had very little effect on the shape and performance of the filter's bandpass frequencies. It can be shown that as the angle of modulation increased incrementally the second harmonic decreased linearly. There are certain limitations that have to be considered when increasing the angle of modulation. The angle of modulation could not be increased past 70 degrees because it would cause the milling machine to cut back over the filter's coupled lines.

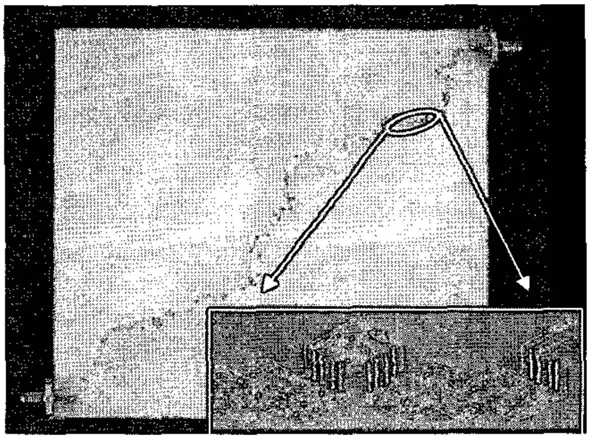

Fig. 4 Third iteration of trapezoidal fractal bandpass filter with 60-degree modulation

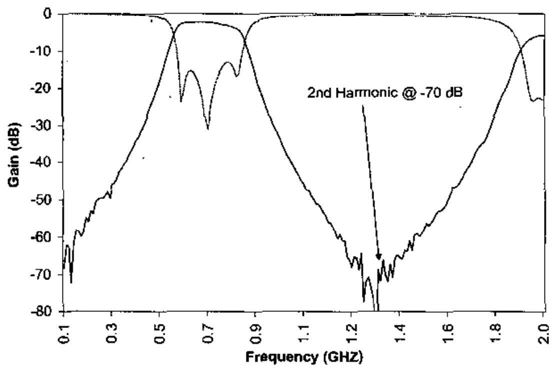

Fig. 5 Insertion Loss of Third iteration trapezoidal fractal BPF with 60-degree modulation

To reduce the insertion loss of the filter the FR-4 substrate (30mil, loss tangent = 4.5, Er = 4.5) was replaced with Rogers 4350 (figure 6) (30mil, loss tangent = .004, Er = 3.45). This reduced the insertion loss from –2.21 dB to -1.2 dB in the middle of the passband (figure 7). The passband at the second harmonic increased from –70 dB to –40 dB. It was observed that the filter designed on the FR-4 had one extra single iteration element in each coupled section. Further investigation is needed to determine if the increased modulation from 45 degrees to 60 degrees and/or the added single iteration element caused the 70 dB of attenuation in the spurious passband rejection. The above observations show a need for optimizing the fractal shape of the filter.

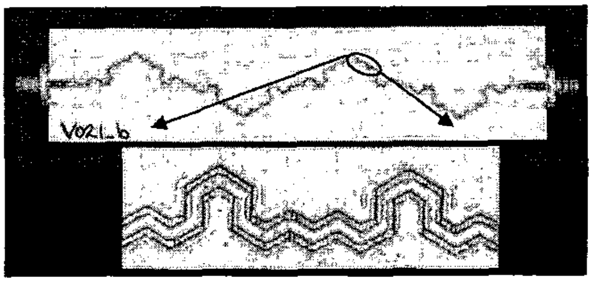

Fig. 6 Third iteration trapezoidal fractal bandpass filter with 60-degree modulation on Rogers 4350

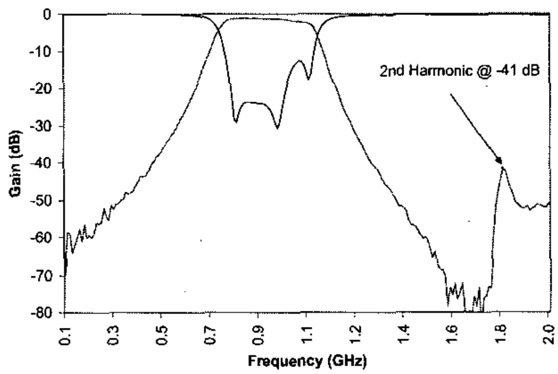

Fig. 7 Insertion Loss of Third iteration trapezoidal fractal BPF with 60-degree modulation on Rogers 4350

III. CONCLUSION

Meandered Line Filters suppress the harmonic passbands that occur at the second harmonic in classical straight-coupled line filters. The added advantage of using a fractal topology is the ability to achieve up to 40% reduction in size depending on the number of iterations and angle of modulation. However, due to limited resolution of fabrication certain fractal topologies will limit the filter size. The advantage of using meandered line technology is the ease of fabrication and the use of conventional coupled straight-line filter design equations. The passband is virtually unaltered while achieving up to 70 dB out of band rejection at the 2nd harmonic.

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