Shunt Capacitor Approximation for HTS Microstrip Circuit Design

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Abstract — **This paper presents a novel technique of using loop transmission lines to approximate shunt capacitors for microstrip type circuit design. The size of the surface area may be effectively reduced and greater layout flexibility can be achieved. This is particularly useful in HTS thin film microstrip circuit design because of its extreme low loss and limited substrate sizes. A 5-pole AMPS 1 MHz bandstop filter is shown as an example.**

I. Introduction

Shunt capacitors are one of the basic components in microstrip circuit design. They are typically realized by large metal conductor patches. Such patch capacitors can be found, for example, in bias networks of amplifiers, microstrip filters, etc. Examples of microstrip patch capacitors are shown in Figure 1.

Similar to parallel plate capacitor, capacitance realized from conductor patches on a microstrip circuit is in direct proportion to the area of the metal and the dielectric constant of the substrate. These patch capacitors can take a significant amount of surface area depending on the amount of capacitance required.

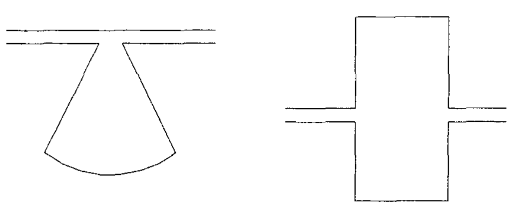

Figure 1. Examples of microstrip shunt patch capacitors.

This paper introduces an alternative way to approximate shunt patch capacitors on microstrip type circuits in the frequency range of interest, in particular for large capacitors at relatively lower frequencies. It uses two transmission lines in parallel, as shown in Figure 2. One of transmission lines has close-to-zero (but not equal to zero) electrical length, while the other can have different width and length depending on the desired capacitance value.

It will be shown that besides providing layout flexibility, the size of the capacitor can be effectively reduced compared with typical shunt patch capacitor with similar capacitance. This is particularly useful when using HTS thin film technology because of its limited substrate size and extremely low loss on long narrow transmission lines.

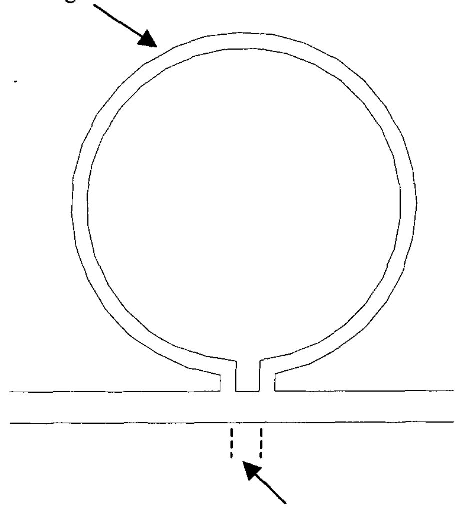

Figure 2. Schematic illustration of a pair of parallel transmission lines approximating shunt capacitor, where one line has very short electrical length and the other has length according to the capacitance to approximate.

II. Description

An ideal shunt capacitor is shown in Figure 3. Figure 4 provides an equivalent circuit model of the loop transmission line shown in Figure 2.

From Figure 3, V is the voltage across capacitor C and I_3 is the current following through C from node 1 to ground. The output current I_2 is the difference between input current I_1 and I_3 of capacitor C, i.e.,

$$I_2 = I_1 - I_3 \qquad (1)$$

In Figure 4, V_1 and V_2 are the voltages from node 1 and node 2 to the ground, respectively. However, since the

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electrical length of the short transmission line is close to zero, $V_1 \approx V_2$ and $I_{S1} \approx I_{S2}$. The output current

$$I_2 \approx I_1 - (I_{L1} - I_{L2}) \tag{2}$$

Comparing Equations (1) and (2), we may select appropriate length and impedance of the long transmission line, such that

$$(I_{L1} - I_{L2}) \approx I_3 \tag{3}$$

at a given frequency or frequency range of interest.

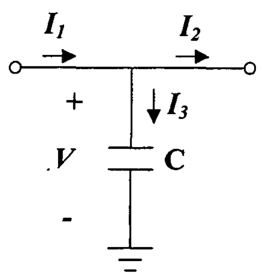

Figure 3. An idea lumped element shunt capacitor equivalent circuit.

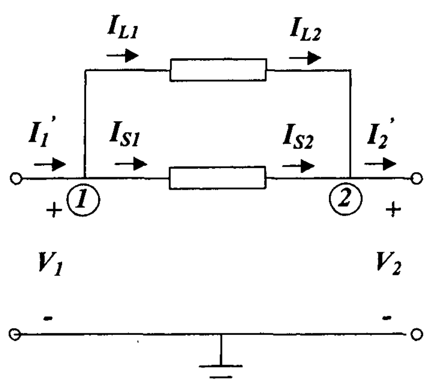

Figure 4. The equivalent circuit of the loop transmission line shown in Figure 2.

III. EXAMPLE 1

A single microstrip resonator circuit is shown in Figure 5. It is assumed that the substrate size is 512 x 256 mils and thickness is 20 mils with dielectric constant 10. The resonator shown in Figure 5 consists of two large patch capacitors and an inductor approximated by a high impedance transmission line. Figure 6 shows a modification of the resonator in Figure 5, where a loop transmission line replaces one shunt capacitor. Figure 7 provides EM simulation [1] results of Figures 5 and 6. The responses from the two simulations are almost identical. However, the layout size of the loop transmission line in Figure 6 is about 13% smaller than the corresponding patch in Figure 5.

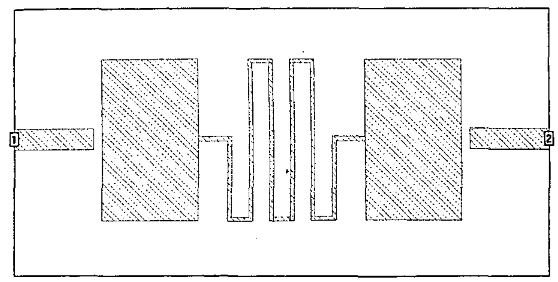

Figure 5. A single microstrip resonator circuit.

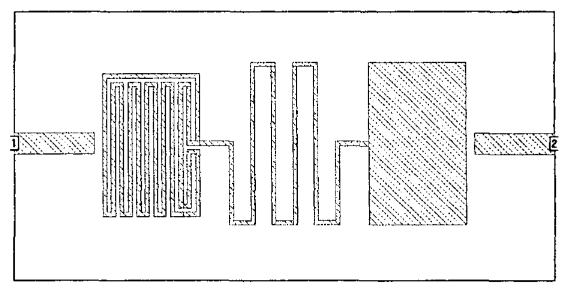

Figure 6. A single microstrip resonator the same as the one in Figure 3 except that the left shunt capacitor is replaced by a loop transmission line.

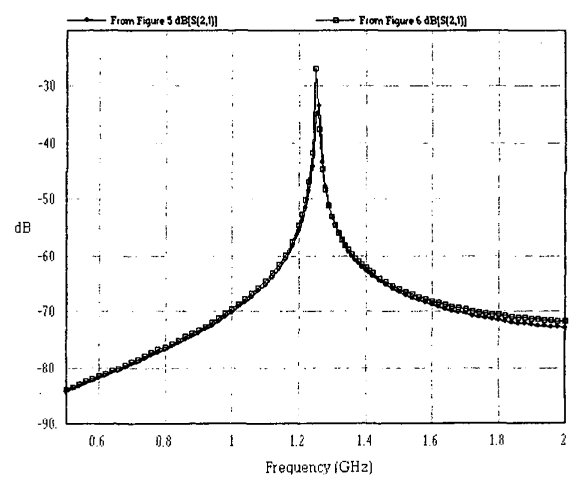

Figure 7. Simulation results of the microstrip resonator shown in Figures 5 and 6.

IV. Example 2

The second example is an actual design of a 5-pole band-stop filter built on 20-mil thick MGO substrate with YBCO thin film high temperature superconductor. The configuration of the filter is a transmission line coupled with grounded resonators [2][3]. The equivalent circuit simulation indicates that besides the conventional delay line between the resonators, the design requires large shunt capacitors at each of the input ends of the resonators. Figure 8 shows the filter layout, where a loop-transmission line approximation to the third shunt capacitor is illustrated in detail. Substrate area saving for the third shunt capacitor is about 37% and over 55% for the fourth shunt capacitor. A very compact design was achieve by using loop transmission line to replace those large shunt capacitors. Otherwise, the design would be difficult fit into half of a 2-inch diameter wafer with proper isolation from non-adjacent parts of the filter. The measured response of the 5-pole band-stop filter is provided in Figure 9, where the filter center frequency is at 845.75 MHz and bandwidth 1.0 MHz.

IV. Conclusion

In addition to the advantage of layout flexibility, using loop-transmission line to replace patch shunt capacitor may effectively reduce surface area, especially for lower frequency applications. This is particularly useful in HTS thin film microstrip circuit design because of its extreme low loss and limited substrate sizes. In addition, using loop transmission line to approximate large shunt capacitors may improve the performance of other microwave circuits, such as low-pass filters.

Acknowledgement

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References

[1] Sonnet 6.0b-Lite, Sonnet Software, Inc., Liverpool, NY.

[2] G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance Matching Networks, and Coupling Structures*. New York: McGraw-Hill, 1964.

[3] H. C. Bell, "L-Resonator Bandstop Filters," *IEEE Trans. Microwave Theory Tech.*, vol. 44, pp. 2669-2672, 1996.

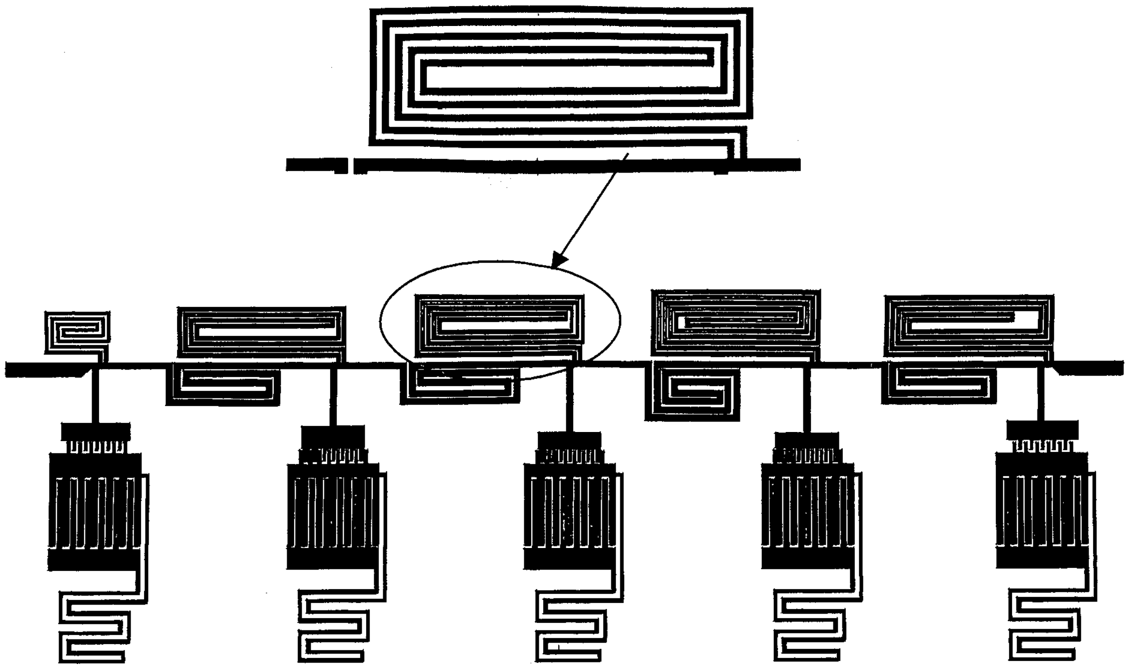

Figure 8, Layout of a 5-pole band stop filter. The filter fits half of 2-inch MGO wafer with 20-mil thickness.

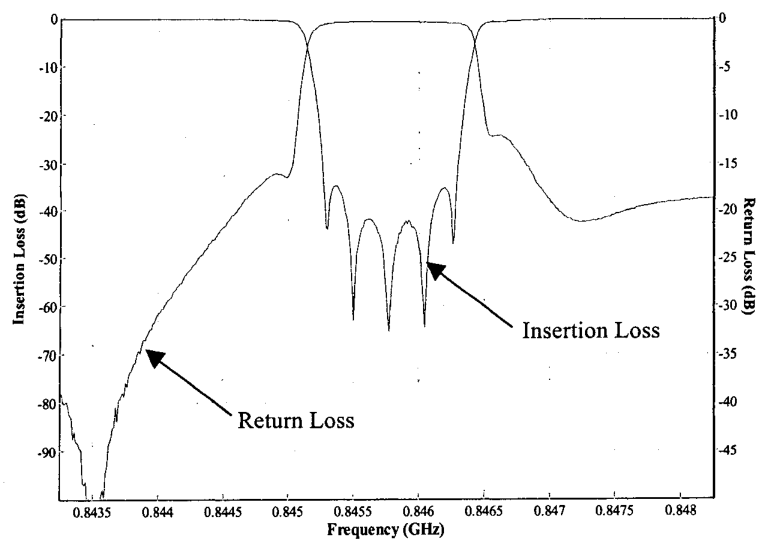

Figure 9. Measured response of a 5 pole HTS band-stop filter using loop transmission lines for shunt capacitors.