A Compact Semi-Lumped Low-Pass Filter for Harmonics and Spurious Suppression

Jyh-Wen Sheen

***Abstract*—A semi-lumped parallel resonance circuit was employed to design a very compact low-pass filter. The semi-lumped shunt arm consists of a capacitor and a transmission line section. In such an arrangement, two finite attenuation poles can be generated near the passband edge. As a result, the proposed filter enjoys sharper cutoff and fewer filter orders than those of the conventional low-pass filters. In addition, these two attenuation poles can be properly designed to suppress the second and third harmonics generated from power amplifier and frequency source. A low-temperature cofired-ceramic (LTCC) multilayer-ceramic (MLC) low-pass filter and a PCB low-pass filter with a 0402 chip capacitor were designed and tested. Experimental results demonstrate the capability of our filter in harmonics and spurious suppression.**

***Index Terms*—Finite attenuation pole, LTCC, MLC, parallel resonance, semi-lumped low-pass filter.**

I. Introduction

USING a low-pass filter to suppress harmonics and spurious is a common technique in designing a power amplifier, mixer, and voltage-controlled oscillator. Various types of low-pass filters such as open-stub low-pass filter, stepped-impedance low-pass filter [1], [2], and snake-type low-pass filter [3] were proposed. However, due to different drawbacks, these filters cannot meet the requirement for new communication systems like satellite, mobile, and cellular communications. For the open-stub low-pass filter, its distributed-circuit nature causes large size and narrow stopband. For sharper cutoff, the order of the stepped-impedance low-pass filter must be very high. This results in large circuit size and large insertion loss. The snake-type low-pass filter can have attenuation poles at finite frequencies. However, the attenuation poles cannot be located at the neighboring region of the passband since the side-coupled capacitor in the shunt capacitor and inductor pair is too small. Therefore, the capacity to reduce the filter order is limited.

In this paper, we propose a low-pass filter unit, which has two finite attenuation poles at stopband to improve the drawbacks of the conventional low-pass filter. This proposed low-pass filter is semi-lumped type. It consists of a lumped capacitor and a section of transmission line. The lumped capacitor can be a chip ceramic capacitor or the multilayer-ceramic (MLC) metal–insulation–metal (MIM) capacitor with a smaller size and larger value than those of the side-coupled capacitor. The transmission line section can be the microstrip line or the strip line in zigzag, meandered, spiral, or multilayered configuration for further miniaturization. Due to the large value of the lumped capacitor allowed, the finite attenuation poles of the proposed low-pass filter can be very close to the passband edge. Thus, the design reduces filter order as well as size.

Manuscript received December 17, 1999; revised February 3, 2000.

The author is with the Computer and Communication Research Laboratories, Industrial Technology Research Institute, Hsinchu, Taiwan, R.O.C.

Publisher Item Identifier S 1051-8207(00)03343-2.

II. Theory

Fig. 1(a) shows the equivalent circuit of the proposed low-pass filter unit. The $[S]$ matrix can be derived by using the ABCD matrices of the transmission line section and the lumped capacitor shown in Fig. 1(a). First, the two ABCD matrices must be transferred into two $[Y]$ matrices. Second, these two $[Y]$ matrices are summed into one single $[Y]$ matrix. Then, the $[Y]$ is transferred to the final $[S]$ matrix

$$S_{11},\, S_{22} = \frac{Y_0^2 - Y_c^2 + \omega C Y_c(\csc(\beta l) - \cot(\beta l))}{\Delta Y} \tag{1}$$

$$S_{21},\, S_{12} = \frac{2jY_0(\omega C - Y_c \csc(\beta l))}{\Delta Y} \tag{2}$$

$$\Delta Y = Y_0^2 + Y_c^2 + 2jY_0(\omega C - Y_c\ \cot(\beta l)) + \omega C Y_c(\cot(\beta l) - \csc(\beta l))$$

where

- Y_0 characteristic admittance of the input port and the output port;
- Y_c characteristic admittance of the transmission line section;
- C value of the lumped capacitor;
- β propagation constant of the transmission line section;
- l length of the transmission line section.

The finite attenuation poles of the proposed low-pass filter are determined by the zeros of (2). The pictorial description of the numerator in (2) is shown as Fig. 2. The intersection points show the locations of the finite attenuation poles. In Fig. 2, it is observed that two attenuation poles can be located below the frequency point ω_1 by the proper choice of the lumped capacitor. ω_1 represents the frequency point where the length of the transmission line section equal to a half wavelength. It can be observed from Fig. 2 that the length of the employed transmission line section can be smaller than a quarter wavelength at the frequency point near the passband edge.

III. Design Example

Fig. 1(c) shows the PCB-version low-pass filter. This filter is designed to suppress the second and third harmonics for a 560-MHz VCO. A 0402 chip capacitor and a microstrip line are employed. The design procedures are as the followings. First,

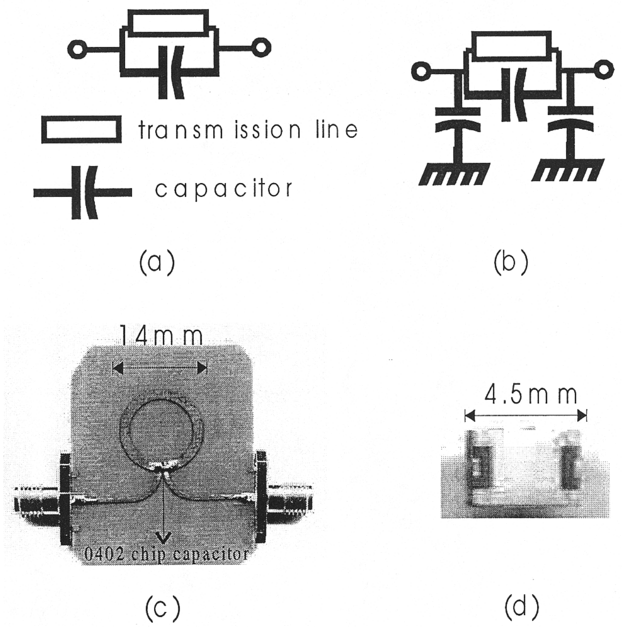

Fig. 1. (a) Equivalent circuit of the proposed low-pass filter unit, (b) equivalent circuit of the proposed low-pass filter unit for MLC application, (c) PCB low-pass filter for 560-MHz VCO, and (d) MLC low-pass filter for 1.5-GHz PA.

the chip capacitor is modeled as an ideal capacitor. Second, we use the optimizer in Libra (circuit simulator) to obtain an initial design. Then, we choose the proper chip capacitor and model this capacitor as an R, L, C series arm [4]. Finally, we simulate the model and reoptimize the parameters of the transmission line section. The measured results of the PCB low-pass filter are shown in Fig. 3. The suppression at the second and third harmonics is better than 40 dB.

Fig. 1(d) show the LTCC MLC low-pass filter. This filter is designed to suppress harmonics for a 1.5-GHz PA. It equivalent circuit is shown as Fig. 1(b). Two grounded capacitors are added into the proposed filter unit shown in Fig. 1 (a). This is due to that the LTCC MLC low-pass filter is buried into the ceramic body between the top and bottom ground planes. These two ground planes and the multilayer MIM capacitor result in two parasitic grounded capacitors. These two capacitors can be employed to tune the return loss in passband, enhance the rejection rate at stopband, and widen the suppression bandwidth. Since there is no model of the MLC MIM capacitor in the circuit simulator, this design must use the EM simulator em from Sonnet to construct the π-type capacitor model of the MLC MIM capacitor. Other design procedures are the same as the previous design example. The measured results are shown in Fig. 4. It is shown that 30-dB suppression can extend over 10 GHz.

IV. Conclusions

In this paper, we propose a very compact low-pass filter unit. The $[S]$ matrix is derived to explain the performance of the filter unit. A PCB low-pass filter and an LTCC MLC low-pass filter are demonstrated. Their performances are proven to be good enough for harmonics and spurious suppression. The proposed filter unit can be used as the unit element in higher order design.

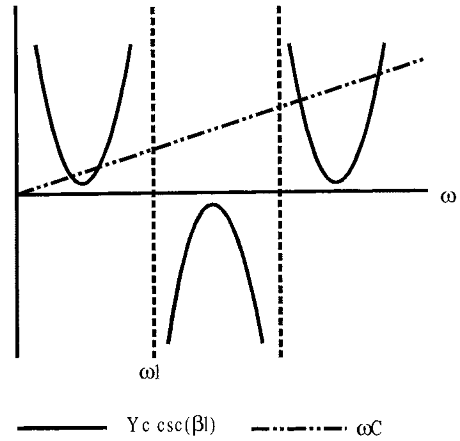

Fig. 2. Pictorial description of the numerator in (2).

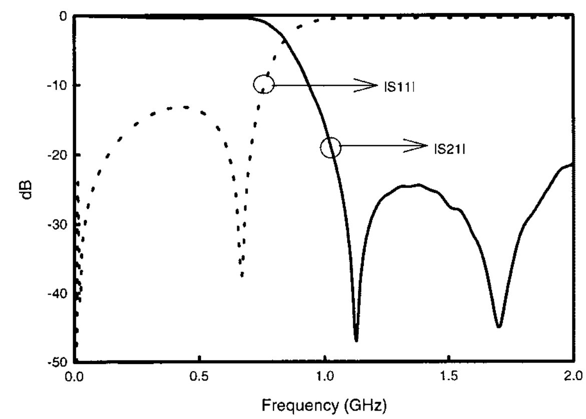

Fig. 3. Performance of the PCB low-pass filter for 560-MHz VCO (PCB: $\varepsilon r = 4.6$, thickness $= 15.7$ mils).

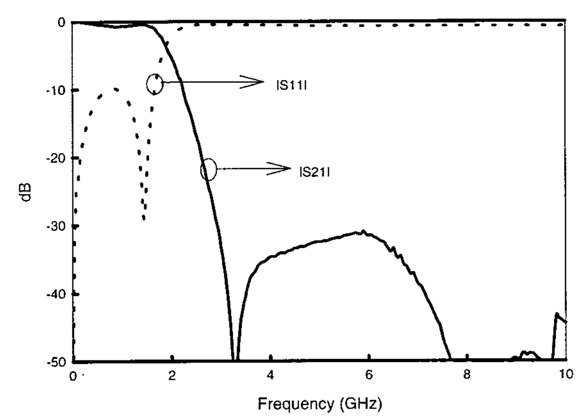

Fig. 4. Performance of the LTCC MLC low-pass filter for 1.5-GHz PA (LTCC: $\varepsilon r = 7.8$, thickness $= 51$ mils).

References

[1] D. M. Pozar, *Microwave Engineering*. Reading, MA: Addison-Wesley, 1990, pp. 498–500.

[2] G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance Matching Networks and Coupling Structures*. New York: McGraw-Hill, 1980, pp. 355–410.

[3] M. Miyazaky, H. Asas, and O. Ishida, “A broad band dielectric diplexer using a snake strip-line,” in *1991 IEEE MTT-S Dig.*, 1991, pp. 551–554.

[4] R. S. Carson, *High Frequency Amplifiers*. New York: Wiley, 1975, pp. 152–155.