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Compact Wide Stopband Bandpass Filter on Multilayer Organic Substrate

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***Abstract*— We present the design and development of a compact wide stopband bandpass filter using novel quasi-lumped LC resonators on a defected ground structure. The resonators are built on a multilayer organic substrate and are coupled to external circuits by shunt-inductive impedance inverters. Experimental results show that the filter has a center frequency of 960 MHz and a 3-dB fractional bandwidth of 8%. The filter has a wide stopband that has an out-of-band rejection of better than 30 dB up to five times of the center frequency. The size of the filter is 5.4 mm x 27 mm or 0.027λ_g x 0.132λ_g, where λ_g is guided wavelength at 960 MHz.**

***Index Terms*— Band-pass Filter, Wide Stopband, Quasi-lumped, Multilayer.**

I. Introduction

BAND-PASS filters play an important role in many communication circuits. Band-pass filters with wide stopband and high selectivity are desirable to improve system performance. An ideal filter is expected to be free of spurious pass-bands. Conventional filter designs that are based on distributed components usually suffer from unwanted spurious responses. There are many techniques that have been proposed to design bandpass filters that have wide stopband [1 - 5]. In [1], the stopband of a conventional J-inverter filter is widened with the assistance of open transmission line stubs and interdigitated capacitors. In [2], the rejection of multi-spurious pass bands in a parallel-coupled-line microstrip bandpass filter is achieved by using "Wiggly-line" structures. In [3], the suppression of spurious responses in the stopband is realized by choosing the constitutive resonators that has the same fundamental frequency, but staggering higher order resonant frequencies. In [4], wide-stopband microstrip bandpass filter is designed by using quarter-wavelength shorted coupled-lines. In [5], a defected ground structure (DGS) is deployed to realize a wide-stopband coupled-line bandpass filter.

In this letter, we present the development of a compact, wide-stopband bandpass filter using novel quasi-lumped LC resonators. The equivalent circuit of the quasi-lumped LC resonators consists of a capacitor in series with an inductor. The capacitor is formed by a metal-insulator-metal (MIM) structure while the inductance of the series inductor is dependent on the size of the rectangular-shape DGS on the ground plane. The filter is implemented on a thin-film, multilayer Liquid Crystal Polymer (LCP) substrate that has 3 metal layers and 2 dielectric layers. The experimental results show that the measurement is well correlated with the EM simulation. The filter has the smallest size while achieving a comparable stopband performance in comparison with other published wide-stopband bandpass filters. Other reports on compact filters on LCP can be found in [12-14] which show great potential of using LCP in compact RF/microwave passive component designs.

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II. Bandpass Filter Design

A. MIM capacitor on a defected ground structure (DGS)

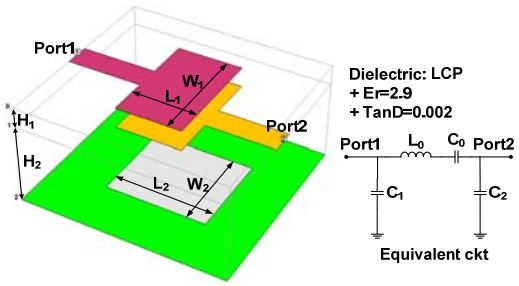


Fig. 1 3-dimensional view and lumped equivalent circuit of a MIM capacitor on a DGS

An MIM capacitor on a rectangular-shape DGS and its lumped equivalent circuit is presented in Fig. 1. The MIM capacitor is realized on a 3-metal layer LCP substrate that has a dielectric constant of 2.9 and a loss tangent of 0.002. The dielectric thicknesses are H_1 = 2 mil and H_2 = 12 mil. The MIM capacitor has dimensions L_1 and W_1 while the dimensions of the rectangular DGS are L_2 and W_2. In the equivalent circuit of the MIM capacitor, C_0 is the main capacitance of the MIM capacitor. C_1 and C_2 are parasitic capacitances which are usually much smaller than C_0 can be negligible at low frequency ranges. The series inductance L_0 is mainly from the DGS [6].

C_0 can be approximated by the equation:

$$C_0 = \varepsilon_r \varepsilon_0 \frac{W_1 L_1}{H_1} \quad (1)$$

where ε_r=2.9 is the dielectric constant of the dielectric layer between the top- and second-layer conductor; ε_0=8.854 x 10-12 is the permittivity of free-space.

In this configuration, C_1 and C_2 are << C_0 and can be negligible. L_0 can be determined by the equation:

$$L_0 = \frac{1}{\varpi_0^2 C_0} \quad (2)$$

where ω_0 is the self-resonant frequency of the MIM capacitor. ω_0 can be determined by looking at the imaginary part of the input impedance at port 1 of the capacitor while port 2 is shorted. ω_0 is the frequency where the imaginary part equal to zero.

High frequency structure simulator (HFSS) [7] is used to model and evaluate the input impedance of the MIM capacitor. From this input impedance, the resonant frequency ω_0 of the MIM capacitor can be determined. Once ω_0 is known, C_0 and L_0 can be calculated from equations (1) and (2). For fixed values of W_1 and L_1, C_0 is almost constant while L_0 is proportional to both W_2 and L_2. Fig. 2 shows the variation of L_0 as W_2 and L_2 change. The data were taken with L_1=105 mil and W_1=175 mil. With these dimensions, the value of C_0 is ~6pF.

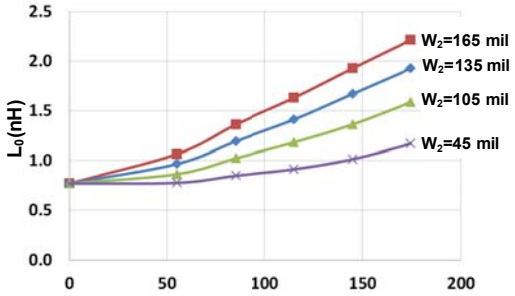


Fig.2. Variation of L_0 as L_2 and W_2 change

B. *Bandpass filter design*

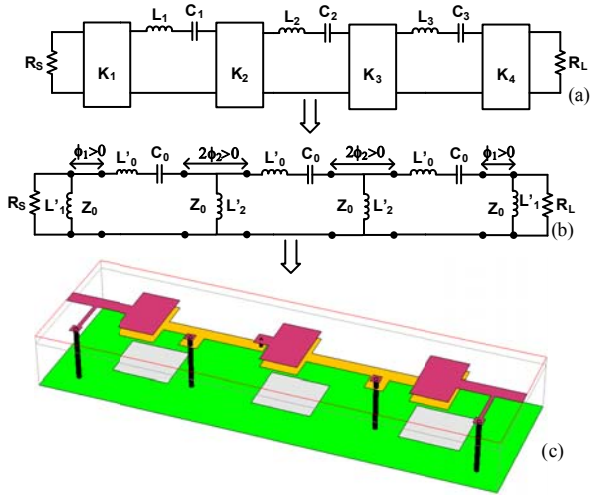


Fig. 3. Circuit schematic and realization of the band-pass filter

Fig.3. shows the circuit schematics and the 3-Dimensional view of the band-pass filter realized on a multilayer dielectric substrate. The filter is based on direct-coupled resonators with impedance inverters and series LC resonators as shown in Fig. 3(a). The values of the characteristic impedance of the inverters Kj (j=1-4) and the series capacitances and inductances Cj and Lj (j=1-4) are determined by using the equations in [8]. The filter is designed to have 3rd-order 0.1-dB-ripple Tchebycheff response, a center frequency of 960 MHz and a 3-dB bandwidth of 5%. Impedance inverter transformations are used to make the series LC resonators become identical. The equations for these transformations can be found in [9]. The impedance inverters are realized by a shunt inductor, series transmission line elements and series negative inductors as shown in Fig. 3(b). The method to realize these impedance inverters can be found in [10]. The series LC resonators are realized by using DGS MIM capacitors on a multilayer dielectric substrate. From the value of C_0, the dimensions W_1 and L_1 can be determined. From analysis of a DGS MIM capacitor, the values of W_2 and L_2 can be chosen to obtain the series inductance L'_0. Fig. 3(c) represents the implementation of the filter. Tables 1 and 2 summarize the values of inductances, capacitances, transmission line electrical lengths and dimensional parameters of the DGS MIM capacitor.

TABLE I
SUMMARY VALUES OF INDUCTANCES, CAPACITANCES AND ELECTRICAL LENGTHS

L_0' (nH)	C_0 (pF)	L_1' (nH)	L_2' (nH)	ϕ1 (degree)	ϕ2 (degree)
1.8	6.2	1.7	0.25	2.9	7.6

TABLE II
SUMMARY OF THE RESONATOR'S DIMENSIONS

W_1 (mm)	L_1 (mm)	W_2(mm)	L_2 (mm)
4.45	2.67	3.68	4.19

The shunt inductors are realized by short-circuited transmission line stubs. The series transmission elements have the same characteristic impedance of 50 ohm. Fabricated prototype of the filter is shown in Fig. 4. Coplanar wave guide pads are added for probe measurement. The total size of the filter without probe pads is 5.4 mm x 27 mm.

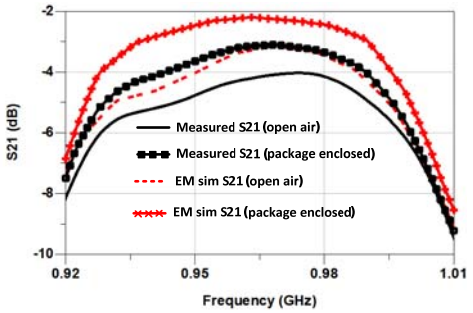
Fig. 4. Filter fabricated prototype

III. EXPERIMENTAL RESULTS

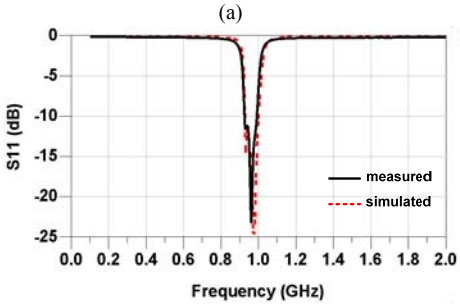
The filter is modeled in high frequency structure simulator (HFSS) [7]. Electrical performance of the filter was measured on a Cascade Microtech RF probe station with an Agilent E8364 2-port network analyzer. The probes were calibrated using standard TRL calibration on a Picoprobe CS-9 substrate [11].

The simulated and measured results of S11 and S21 of the filter are shown in Fig. 5. As can be seen, the measurement is well correlated with the simulation. Based on measured results, the filter has a center frequency at 960 MHz, a 3-dB bandwidth of 8%. The measured insertion loss at the center frequency is 4.0 dB. The loss is mainly from conductor and radiation losses. The radiation loss is caused by the DGS as well as the air exposure of the MIM capacitor metal pads. This loss can be reduced by putting the filter inside an enclosed metal package. As can be seen in Fig. 5a, the in-band insertion can be improved by ~1dB if the filter is enclosed in a metal package. The enclosed metal package is described in Fig. 6.

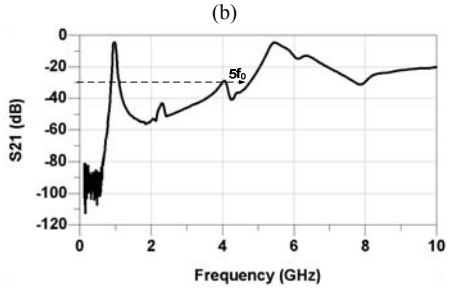
The filter has an out-of-band rejection of better than 30 dB up to five times of the center frequency. Table III shows the comparisons of this filter with other published wide-stopband bandpass filters.



(a)



(b)



(c)

Fig. 5. Measured response of the filter. (a) – In-band insertion loss; (b) – Return loss; (c) – Wideband insertion loss

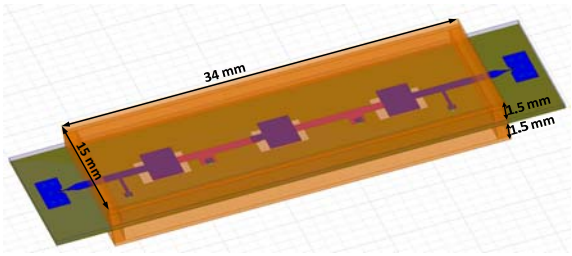


Fig. 6. Enclosed the filter by a metal package.

TABLE III
BANDPASS FILTER COMPARISONS

Filters	f_0/ FBW	Order/ Loss	Size	Stopband
[1]	1 GHz/ 18%	5th/ 0.9dB	$0.17\lambda_g$ x $0.18\lambda_g$	26 dB up to $22f_0$
[2]	2.5 GHz/ 10%	7th/ 2.0 dB	$0.37\lambda_g$ x $2\lambda_g$	30 dB up to $7f_0$
[3]	1.5 GHz/ 5.6%	4th/ 2.7 dB	$0.23\lambda_g$ x $0.97\lambda_g$	30 dB up to $5.4f_0$
[4]	2.35 GHz/ 6.54%	3rd / 2.1 dB	$0.18\lambda_g$ x $0.26\lambda_g$	20 dB up to $4.5f_0$
This work	960 MHz/ 8%	3rd / 4.0 dB	$0.03\lambda_g$ x $0.13\lambda_g$	30 dB up to $5f_0$

IV. Conclusion

We present the development of a compact wide stopband bandpass filter using novel quasi-lumped LC resonators on a defected ground structure. Experimental results show that the filter has a pass band at a center frequency of 960 MHz with a 3-dB fractional bandwidth of 8%. The filter has a wide stopband that has an out-of-band rejection better than 30 dB up to five times of the center frequency. The measurements are well matched with the EM simulations. The size of the filter is 5.4 mm x 27 mm or $0.027\lambda_g$ x $0.132\lambda_g$, where λ_g is guided wavelength at 960 MHz.

ACKNOWLEDGMENT

This work is supported in part by Vietnam Education Foundation and Agilent Technologies.

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