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Ultra-compact capacitively loaded evanescent half-mode SIW filters for LTE applications

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This paper presents a novel miniaturized substrate integrated waveguide filter by combining both half-mode resonators and capacitive loading on a conventional two-layer printed circuit board (PCB) process. The resulting synthesis is successfully demonstrated in an long-term evolution application by means of a third-order filter of <225 mm² in size while featuring 2.3 dB insertion loss over a 5.5% fractional bandwidth at 3.7 GHz. Good first-iteration agreement between simulated and measured results, both in center frequency and bandwidth, are achieved.

Keywords: Applications and standards (Mobile, Wireless, networks), Filters

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I. INTRODUCTION

With the large-scale commercial adoption of the long-term evolution (LTE) and IEEE 802.11y standards, there is a renewed drive to find compact, low-loss, and low-cost implementations of S- and C-band microwave filters on conventional soft substrates. Substrate integrated waveguide (SIW) [1] filters have the advantage of high resonator Q-factor whilst requiring only a conventional two-layer RF PCB process to manufacture. The technology does, however, occupy more board space than equivalent planar resonators [2] or off-board manufactured filters such as low-temperature co-fired ceramics (LTCC) [3]. Apart from using multiple metalized layer geometries [4] or alternative cavity geometries [5], SIW resonators have been miniaturized successfully by loading of the SIW cavities to create evanescent mode cavity (EMC) resonators (the operating theory of which is described in [6]). This loading has been accomplished with dielectric posts [7], defected ground structures [8], complementary split-ring resonators (CSRRs) [9], and capacitive posts [10]. This capacitive loading may be increased to the point where the area of the capacitive plate, and not the surrounding fencing, defines the resonator, as was shown with the TEM-SIW cavity [11]. Another way of decreasing the width of SIW resonators is using half-mode guide (HMSIW) [12] which, unlike folded SIW [4], does not require multiple metalized layers. HMSIW has been successfully combined with

II. GEOMETRY

CSRR [13], external capacitive loading [14] (to create a second transmission band), and fractal pattern miniaturiza-

tion [15], but not with internal capacitively loaded resonators.

ization properties of both HMSIW and capacitively loaded

EMC resonators (similar to TEM-SIW resonators). The

filter size is reduced further by removing the via fences still

used in [10, 11] that demarcate separate cavities, relying

solely on the capacitive load plate to define the resonator area.

This paper presents a novel combination of the miniatur-

nected to ground by a post of diameter d_p . The plate is separated from the edge of the SIW cavity (defined by a via fence of

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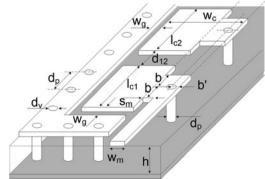


Fig. 1. Two cascaded resonators, with microstrip coupling to the first.

The structure of the capacitively loaded HMSIW is shown in Fig. 1. The first resonator is formed in a substrate of height hby a capacitive plate of width w_c and length l_{c1} , and is con-

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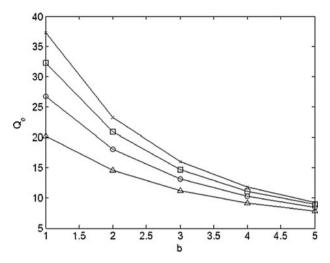


Fig. 2. External Q-factor variation versus b. $-\Delta -: s_m = 0.5; -\bigcirc -: s_m = 1; -\Box -: s_m = 1.5; -X -: s_m = 2.$

diameter d_{ν} and pitch d_{p}) by a gap w_{g} . The resonator is tapped-fed externally by a 50 Ω microstrip line of width w_m , with the feed defined by a slot of width s_m terminating a distance *b* from the post. The capacitive plate is connected to the center post by a septum of width 2b, with the post a distance b' from the edge of the metallization. The second resonator is formed by a plate of length l_{c2} and width w_c , which couples to the first across the gap d_{12} . It is important to note the absence of via fencing between the resonators, further reducing the length of the final filter. Major changes to the external Q-factor of the resonator is achieved by varying the septum width 2b (Fig. 2), while minor alterations may be accomplished by varying the slot width s_m . Coupling k between resonators is electric, with the distance separating them (d_{mn}) controlling capacitive coupling. Coupling values of $k = 0.01 \rightarrow 0.09$ are possible (Fig. 3).

III. SYNTHESIS AND SIMULATION

A third-order filter is synthesized with a passband to cover LTE channel 43 from 3.6 to 3.8 GHz, with - 15 dB pass-band input reflection. This filter requires external resonator loading of

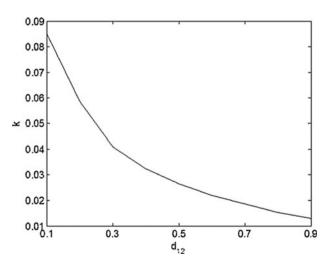


Fig. 3. Coupling k versus d_{mn} .

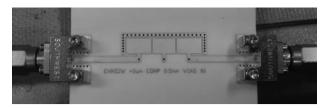


Fig. 4. Photographed filter under test.

 $Q_e=$ 20.7 and internal coupling of $k_{12}=k_{23}=$ 0.0476. Both parameters are related to geometric dimensions through the use of full-wave eigenmode solvers provided in CST Microwave Studio. The external Q-factor is determined by varying s_m and b (with variation in l_{c1} to ensure resonance at $f_0=$ 3.7 GHz), and calculating the external Q-factor at the port of excitation. The even-mode and odd-mode eigenmode resonances f_e and f_o are used to calculate k in a simulation, with d_{12} varied to achieve the required value. After assembly and simulation of a full finite element method (FEM) model in CST, the filter is tuned to final dimensions in mm, as referenced to Fig. 1, of $w_m=1.67$, $w_g=0.50$, $w_s=1.00$, $w_c=7.00$, b=0.53, b'=0.84, $d_v=0.50$, $d_p=1.00$, $d_{12}=d_{23}=0.32$, $l_{c1}=l_{c3}=7.40$, $l_{c2}=6.90$, and $s_m=0.75$.

IV. MANUFACTURING AND MEASURED RESULTS

The prototypes were manufactured on Rogers RO4003C of thickness 0.813 mm, using 1 oz. copper deposition, as shown in Fig. 4. The artwork exported from CST Microwave Studio was compensated for $+9~\mu m$ over-etch on the copper tracks and $+50~\mu m$ over-drill on the vias. These changes resulted in a manufactured filter with negligible center frequency offset from the simulated result (Fig. 5). The additional 1.1 dB insertion loss is attributed to lower than expected resonator Q-factor, an assumption substantiated by the rounded filter response at the upper and lower cut-off frequencies. The lower Q-factor is attributed to the electroless nickel immersion gold surface finish, which is known to

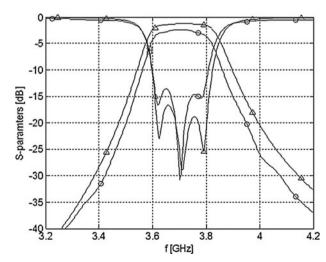


Fig. 5. Simulated $-\Delta$ - and measured $-\bigcirc$ - filter responses.

Table 1. Comparison of this work to the state-of-the-art in uni-planar LTE filters.

	ϵ_r	Size (mm²)	f _o (GHz)	FBW (%)	Loss (dB)	Order
This work	3.55	225	3.7	5.5	2.3	3
[17]	3	528	3.5	6	1.45	4
[18]	2.55	203	3.1	10	2.8	3
[19]	3	255	3.45	8.7	1.7	3
[20]	2.65	1697	3.3	14.3	1.8	3

cause larger than anticipated insertion loss in planar filters [16].

This work is compared in Table 1 to the state-of-the-art in compact LTE filters on conventional RF substrates. For comparable filter order, fractional bandwidth (FBW), and frequency, the filter occupies less board space than state-of-the-art solutions at the expense of higher insertion loss.

V. CONCLUSION

A miniaturized SIW filter, suitable for LTE and IEEE 802.11y applications, has been presented. The filter measures 225 mm² and features 2.3 dB insertion loss across a 5.5% FBW for upper LTE channel frequencies. Good first-iteration agreement between simulated and measured results is obtained, both in center frequency and bandwidth.

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