Inline Ka-band Transitional Combline / Evanescent-Mode Filter in Conventional RF Substrate Using Grounded Vias

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Abstract — The Ka-band is considered a viable band for future 5G backhaul links. Planar filters in this frequency range have low aspect ratios for substrates thicker than 10 mil, since the required 50 Ω line width becomes comparable to a guided wavelength. This paper proposes the use of grounded through-hole plated vias as transitional combline / evanescent-mode resonators. The principle is demonstrated with a 4th order, 27.5 – 29.5 GHz filter in a conventional 32 mil thickness RF substrate. The simulated filter features below 2 dB insertion loss across the band and occupies 3.8 x 1 mm board space.

Index Terms — Microwave filters, microstrip filters, substrates.

I. INTRODUCTION

Millimeter wave frequencies have received recent interest as band of choice for future 5G communication networks [1], with the Ka-band channels at 28 GHz and 38 GHz exhibiting favorable propagation characteristics in urban environments. Although filters at these frequencies have been successfully demonstrated in conventional metal waveguide [2], on-chip [3], LTCC [4] and LCP [5] media, conventional PCB processes on RF soft substrates are cheaper for low production volumes.

Millimeter wave planar transmission line resonators are typically realized on 10 mil [6] or 5 mil [7] substrates because the guided wavelength becomes comparable to the width required by a 50Ω transmission line on thicker substrates. This leads to low aspect ratio resonators. The use of substrate integrated waveguide [8] is a viable solution to this shortcoming, but these occupy significantly more board space than a coplanar waveguide (CPW) or microstrip transmission line filter of equivalent frequency and order.

Grounded via holes in conventional soft substrates [9][10] have been shown suitable for realizing resonators in conventional soft substrates, occupying less space than horizontal etched lines [11] or capacitively loaded SIW resonators [12] that delimit cavities with via holes. The most important shortcoming to the state-of-the-art on this filter topology is, however, that neither the use of either coupled TEM line [13] nor coupled resonator [12] synthesis techniques have been demonstrated in realizing these filters.

This paper contributes to the state-of-the-art of coupled grounded via resonator filters by presenting a coupled resonator synthesis, demonstrating implementation in a conventional two-layer substrate, and first time implementation at K_a-band frequencies. In all cases, full-wave EM simulation is performed with CST Microwave Studio 2014 using the general purpose frequency domain solver with tetrahedral mesh.

II. FILTER GEOMETRY

The proposed filter geometry is shown in Fig. 1. The filter is implemented on a single substrate of height h and fed by a grounded coplanar waveguide line of width w_f and gap width g_f. Each resonator consists of a rectangular patch of width w_n and length l_n grounded in the center by a through-hole plated via of diameter d_{vn}, with resonators n and $n+1$ separated by a gap $d_{n,n+1}$. The upper grounded shields are connected to the lower ground by vias of diameter d_s and pitch d_p such that the two opposing via rows form a channel too narrow to support a TE_{10} substrate integrated waveguide (SIW) mode

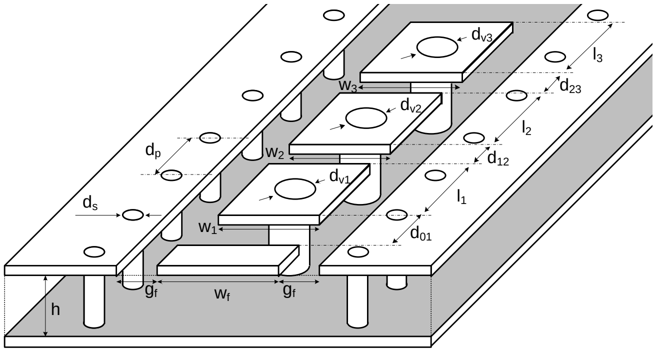

Fig. 1. Basic filter geometry.

The categorization of this filter as transitional combline / evanescent-mode filter is in keeping with the nomenclature established in [14]. The resonant E-field plot in Fig. 2 indicates a coaxial resonance as opposed to a cavity resonance observed in evanescent-mode SIW resonators [12] or evanescent half-mode resonators [15].

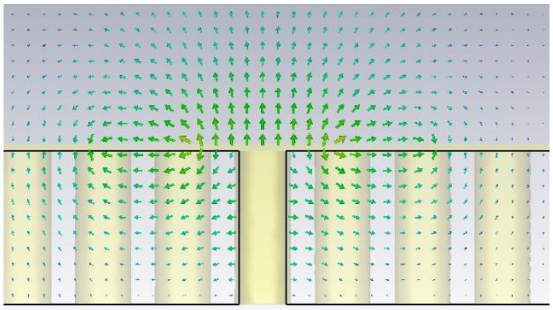

Fig. 2. *yz*-plane cross section of *E*-field at resonance.

The resonant frequency is therefore not only controlled by the size of the capacitive load (as set by the size $d_n = w_n = l_n$) but also the height of the substrate (Fig. 3). This supports the coupled resonator (as opposed to coupled TEM line, as is used for true combline filters) design approach, with full-wave EM CAD tools used to evaluate the mixed electric/magnetic coupling between adjacent resonators.

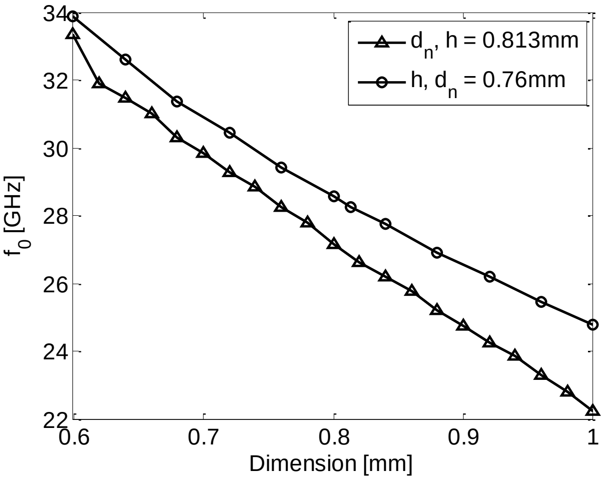

Fig. 3. Variation in resonant frequency by altering d_n (for constant h) or h (for constant d_n).

III. SYNTHESIS AND SIMULATION

To demonstrate the design, a 4th order Chebyshev filter is synthesized to cover the FCC and ITU regulated 27.5 – 29.5 GHz fixed microwave communications band. Following the conventional CAD-assisted synthesis of microwave coupled resonator filters [16], the theoretical synthesis requires resonator coupling values $k_{12} = k_{34} = 0.0563$, $k_{23} = 0.0451$ and external Q-factor Q_e of 17.04. The filter is simulated on Rogers RO4003C of thickness 32 mil (0.813mm).

As is expected with electric coupling, Q_e is proportional to d_{01} (Fig. 4) while $k_{n,n+1}$ is inversely proportional to $d_{n,n+1}$ as shown in Fig. 5.

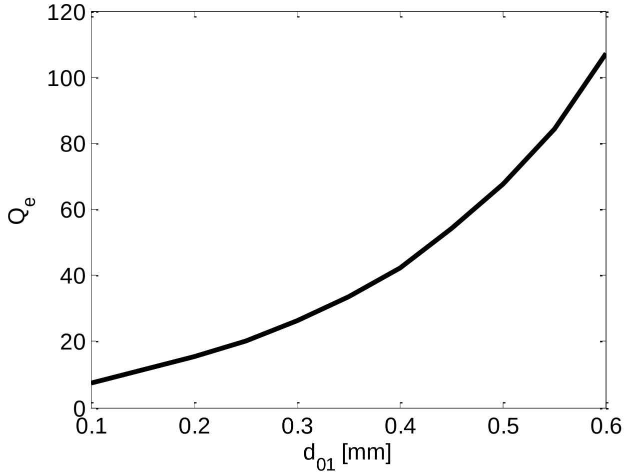

Fig. 4. Q_e vs. d_{01}

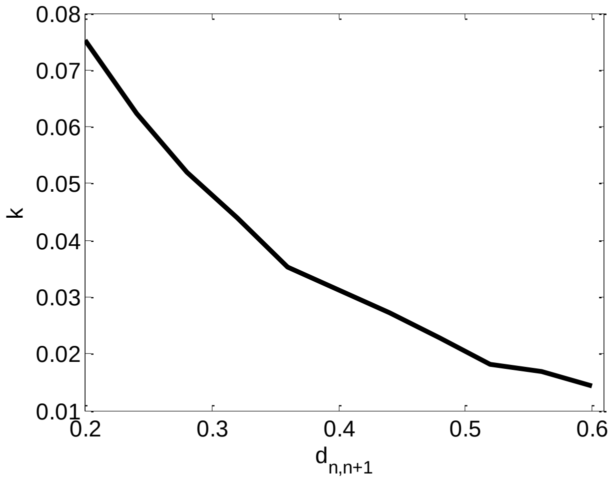

Fig. 5. k vs. $d_{n,n+1}$

The final filter is dimensioned as shown in Table 1, with simulated results shown in Fig. 6. The filter exhibits below 2 dB insertion loss across the band of interest, and occupies 3.8 x 1 mm board space. Compared to other single layer soft substrate filters (Table II) is evident that, not only is this the first time a Ka-band filter has been presented in a substrate thicker than 0.5mm, but that it represents the state-of-the-art in footprint size for filters around 28 GHz.

TABLE 1: FINAL FILTER DIMENSIONS

Dimension	Value [mm]
h	0.813
d_{01}; d_{45}	0.11
d_{12}; d_{34}	0.17
d_{23}	0.21
$w_{1,4}$; $l_{1,4}$	0.75
$w_{2,3}$; $l_{2,3}$	0.77
d_{v1-4}	0.25
d_s	0.3
d_p	0.45
w_f	0.95
g_f	0.15

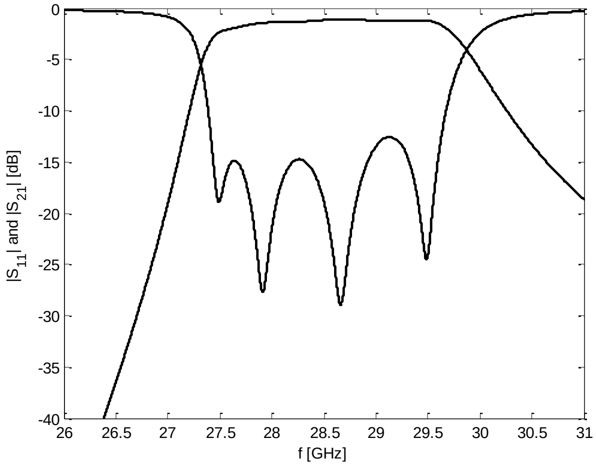

Fig. 6. *Simulated S-parameters of filter*

TABLE 2: COMPARISON TO OTHER SINGLE LAYER KA-BAND SOFT SUBSTRATE FILTERS

	f_0 (GHz)	FBW	Filter order	IL (dB)	Substrate ε_r	Height (mm)	Size (mm^2)
This Work	28.5	7%	4	2	3.55	0.813	3.8
[6]	35	7.1%	3	2.5	2.2	0.25	585
[17]	35.8	33%	6	0.74	2.2	0.25	174.4
[18]	28.9	4.5%	3	0.8	2.2	0.25	8.5
[19]	31.5	41%	5	0.5	2.2	0.25	4.0
[20]	38.5	2%	2	1.85	2.2	0.25	229
[21]	36	5%	2	3	2.2	0.25	3.6
[22]	28	2.2%	2	4.7	2.2	0.13	7.6
[23]	28	3.5%	3	1.1	2.2	0.51	80.8
[24]	35	3.7%	4	1.25	2.94	0.51	75.7

IV. CONCLUSION

Grounded vias in conventional RF substrate have been shown an effective resonant structure for transitional combline / evanescent-mode filters. The class of filter represents the state-of-the-art in compactness and easy to construct in conventional RF PCB processes. Future work will include introducing cross-coupled structures and extending the work to E-band frequencies on conventional 10 mil substrates.

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