Dielectric Loading Effect on Periodic Microstrip Structure

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***Abstract*—Digit-like periodic structures have demonstrated overtly multiple resonances that almost disqualify them as good candidates for microwave circuits, since it is rather difficult to identify their resonance at the dominant mode practically. In this work, an alternative solution to mitigate these spurious resonances is investigated. The dielectric loading effect is examined to determine its efficacy and extent. The results have been validated numerically using the commercially available finite integration technique solver. The findings indicate that the proposed alternative solution is promising. A wide impedance bandwidth or dual-band is achievable, depending on the location of the loading relative to the periodic structure and the feed system.**

I. Introduction

The quality (Q) factor of a small microstrip structure increases with a decrease in its aperture dimensions. Incidentally, the Q factor is substantially constrained by the structure's electrical dimensions, in particular by value $2\pi a/\lambda$, where λ is the guided wavelength and a indicates the dimensions of the structure circumscribed by the radius of the sphere where the structure is located [1]. The Q factor increases if the structure is prototyped on a suspended substrate or a low-loss tangent dielectric material. Moreover, it is as if it is a high-conductive material, multilayer structure, or micro-machined. Because of the meagre size of the proposed structure, it has been very challenging to achieve adequate impedance matching, as in most cases the impedance match network is either bigger than the structure or there is insufficient interface for the feed connection to be implemented. In effect, the performance parameters to assess the structure's efficiency in terms of impedance bandwidth, directivity, and radiation efficiency become onerous. More importantly, the structure becomes difficult to match specifically at the resonance frequency of interest. This scenario tends to be aggravated if the structure exhibits periodic characteristics, as applicable in this proposed structure, where two intrinsic resonances were observed, such that the first resonance was a result of the inherent spatial wavelength of the proposed structure and the second is due to its radiation wavelength [2]-[5]. The effects of these increase the structure's periodicity, and consequently degrade its impedance bandwidth.

In [6], the authors investigated the dielectric loaded quasi-lumped element resonator antenna circuit model for wireless applications. In this work, an equivalent circuit model was characterized that would be able to predict empirically the effect of dielectric loading on an antenna made of a periodic geometrical structure. Since the analysis was based on the lumped element equivalent circuit representation of the structure, and not on the electrical (or physical) structure; the accuracy of such a model is questionable, in particular where the equivalent circuit could not take into consideration the electromagnetic and fringing field effects around the interacting subcomponents of the periodic structure. Therefore, we present the dielectric loading effect on a periodic structure, using a full-wave finite-element computer code.

II. The Periodic Structure

Fig. 1 depicts the proposed digit-like periodic structure using a commercially available full-wave numeric solver, such that Fig. 1(a) represent the geometry of the structure, and Fig. 1(b) is the prototype. The details of the operational dynamics of the periodic structure have been reported in [7]. Fig. 2 demonstrates the frequency response (in particular the reflection coefficient ($|S_{11}|$) in dB) of the coaxial-excited digit-like periodic structure depicted in Fig. 1(b). It is evident that the depicted response does not demonstrate unique resonance, and the impedance bandwidth can therefore not be determined. The -10 dB standardized reference is not achievable, as the response moves down to about -15 dB. The first reason for this could be the possibility that the structure is not accurately matched. To avoid such a situation, the structure is magnetically excited.

Fig. 1: The proposed periodic structure. (a) Geometry, (b) Prototype

To achieve such excitation, the coaxial feed probe is consciously located at an offset position to the structure. This way, the excitation is done by the magnetic field, and a physical interface with the feed is hence unnecessary. Using this method of excitation therefore overcomes the associated challenge of exciting small antennas as a result of the small form factor. Unfortunately, the reflection coefficient ($|S_{11}|$) proves otherwise, as the value is substantial and can moderately be put at -30 dB. Subsequently, the dielectric layer (DL) dime-

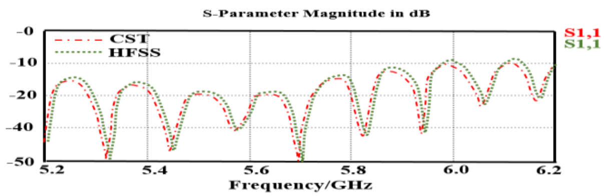

Fig. 2: The frequency response of the digit-like periodic structure.

sion was determined at dominant mode using Equation (2) reported in [8], such that both the width and height aspect ratio p = b/a, and q = 2h/a respectively, were obtained to be in ratio 1:3, where a_{DL}, b, c = $2h_{DL}$ are the DL physical dimensions in *x*, *y* and *z* directions respectively. The DL is made of $CaCu_3Ti_4O_{12}$ material with a dielectric permittivity of $\varepsilon_r = 55 \pm 0.05$. The periodic structure (with a target frequency of 5.8 GHz) is then top-loaded by the DL, as shown in Fig. 3(b). The horizontal distance of the DL (ρ_f) with respect to the feed probe shown in Fig. 3(a) is varied parametrically in order to determine the optimal coupling position and its effect on the reflection coefficient and impedance bandwidth. Fig. 3(c) shows the coupling excitation. The resonance is a result of the structure and not the DL. This is determined by mode analysis.

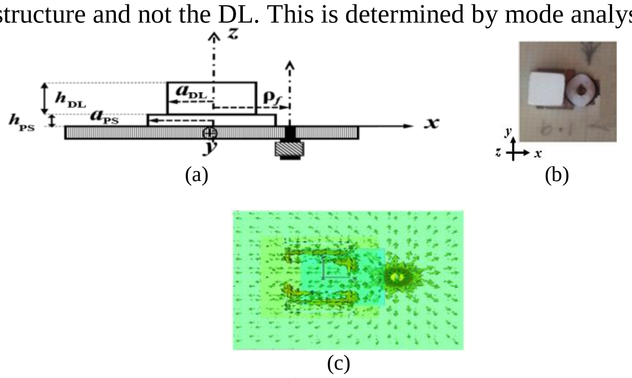

Fig. 3: The loading geometry of the proposed design (a) Geometry, (b) Dielectrically loaded structure, (c) 2D color map of field and current densities

III. Results and Discussion

Fig. 4 demonstrates the simulated and measured reflection coefficients of the dielectric loaded microstrip structure. In this case, the resonance is fundamental, and occurs at dominant mode. This is established using a tool available in the full-wave numerical solution. The impedance bandwidth is substantial, and so is the gain. The frequency pattern is 5.65-5.90 GHz, with

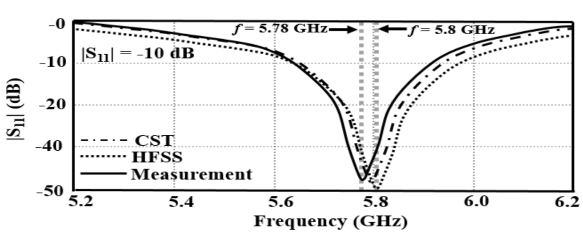

Fig. 4: Reflection coefficient

a radiation magnitude of about 7 dBi on both *xy*- and *yz*-planes, as shown in Fig. 5. Moving the DL horizontally leftward, and away from the feed, demonstrates the possibility of 1) a dual band, 2) a very wide impedance bandwidth, and finally, 3) a lower resonance shift notwithstanding the dimensions of the structure. Table 1 shows other performance benefits of the proposed design.

TABLE I. THE DL-FEED DISTANCE EFFECT ON RESONANCE.

ρ_f (mm)	Resonance f_1 (GHz)	Resonance f_2 (GHz)	$\lvert S_{11} \rvert$ (dB) f_1	$\lvert S_{11} \rvert$ (dB) f_2	Bandwidth (MHz) f_1	Bandwidth (MHz) f_2
0.10	5.80	—	-47.01	—	250	—
0.15	5.74	—	-46.13	—	227	—
0.20	5.73	—	-40.19	—	189	—
0.25	5.69	—	-40.70	—	187	—
0.30	5.62	5.44	-37.67	-12.90	184	25
0.35	5.60	5.42	-28.14	-27.04	180	103
0.40	5.59	5.40	-21.32	-31.01	110	179
0.45	5.54	5.39	-20.22	-39.92	93	207
0.50	5.51	5.39	-11.03	-40.32	75	220

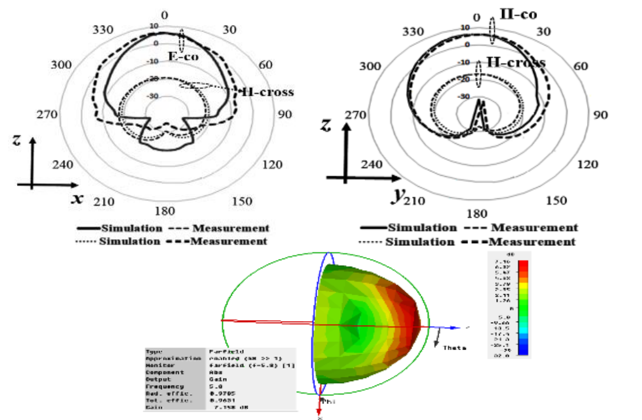

Fig. 5: The radiation pattern (a) *xy*-plane, (b) *yz*-plane, (c) 3D

IV. Conclusion

The effect of dielectric loading on an inter-digit finger structure is examined. The findings indicate that damping of spurious harmonic responses is achievable through dielectric loading.

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