Miniaturized SIW Filter Antenna with Loadable Sensor for Various Microwave Sensing Applications

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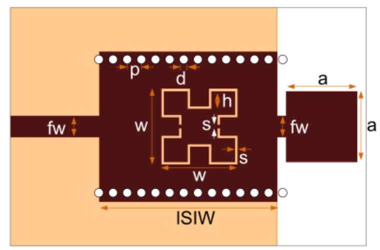
***Abstract*—In this paper, a novel substrate integrated waveguide (SIW) based filter antenna has been proposed for wireless sensor network applications. The proposed antenna consists of a fractal slot loaded miniaturized high-Q evanescent mode SIW bandpass filter section which provides a narrow pass band before the cut-off frequency of the unloaded SIW. A square patch monopole with partial ground plane, acting the radiating element, is cascaded to the filter. The sensor element can be integrated to the antenna on the slot area according to choice of applications. Depending on any measurable physical parameter, the dielectric constant of the sensor element changes and it affects the resonant frequency of the loaded filter antenna which can tune over a wide range. The antenna provides narrow band, high tuning range and easy integration to active circuits.**

Keywords—Bandpass filter; evanescent mode; filter antenna; fractal slot; monopole; sensor; SIW.

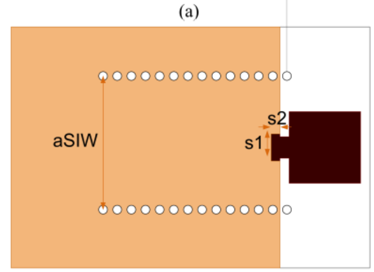
I. Introduction

The wireless sensor networks are growing in rapidity at present along with the number of nodes in each network. Thus very cheap, miniaturized, robust and integrated sensor antennas are very essential for application to Internet of Things (IoT). Many efficient sensor antennas have been proposed for multitude of applications. Microstrip patch antennas have been proposed to work as temperature [1] and soil moisture sensor [2]. Electrically small antennas are also investigated for sensing applications [3, 4]. An SIW based eighth mode sensor antenna has been reported for ethanol sensing application [5].

In this work an integrated filter antenna has been proposed which can be customized for different sensing requirements. The proposed design consists of a slot on SIW section, which interacts with the sensor material exposed in physical environment to sense the change in its dielectric constant by altering pass-band frequency. A partial grounded monopole is integrated to the structure, which is the radiating element. With the change of physical parameter and in turn the dielectric constant of the sensor material, the radiating frequency of the integrated structure changes. An on-site measurement of the antenna characteristic can thus give precise information of the measureable physical parameters like humidity, temperature etc. when the variation of permittivity characteristic of the sensor material is known for variation of ambient physical parameters to me measured. An empirical relation between radiating frequency and dielectric constant has been given here.



(a)



(b)

Fig. 1: Structure of filter antenna (a) top view, (b) bottom view.

II. Filter Antenna Design

A. SIW Band Pass Filter (BPF)

The antenna shown in Fig. 1 consists mainly of two sections- an SIW BPF and a monopole. The SIW upper plate is loaded by a first iteration Minkowski fractal loop slot with symmetrical openings on both sides. A similar technique was investigated in [6]. From similar analysis it is observed that via walls here act as shunt inductance (L_v) and the single metal resonating section inside slot (equivalent L_r, C_r) support TEM mode which allow pass band before unloaded SIW cut-off frequency and thus miniaturize the band-pass structure. The slotted structure also allows field lines to fringe around and thus allows interaction with any dielectric placed on it.

B. Monopole

The antenna element, cascaded with the BPF, is a square patch monopole with partial ground plane. A rectangular area of cross section s1×s2 is etched out from ground just below the antenna feed line, which provides broadband. Hence it supports the filter pass-bands tuned over broad frequency range. Good matching is ensured by optimizing the width of the antenna feed line, the position of the slot and also the dimension of the partial ground plane and ground slot.

III. Simulation Result

The antenna is designed on RT/Duroid 5880 substrate with dielectric constant 2.2, loss tangent 0.0009 and substrate height 0.787 mm. Antenna dimensions in mm are {aSIW,d,p,fw,w,h,s,s1,s2,a}={14,1,1.6,2.4,8.6,2,0.4,3,1,8}. The dummy sensor material put on the slotted structure affects the pass-band frequency which varies from 4.5 to 2.5 GHz with variation of permittivity of loaded dielectric from 1 to 16. Greater dielectric constants produce harmonic in desired range. The equivalent circuit of the bandpass filter section is

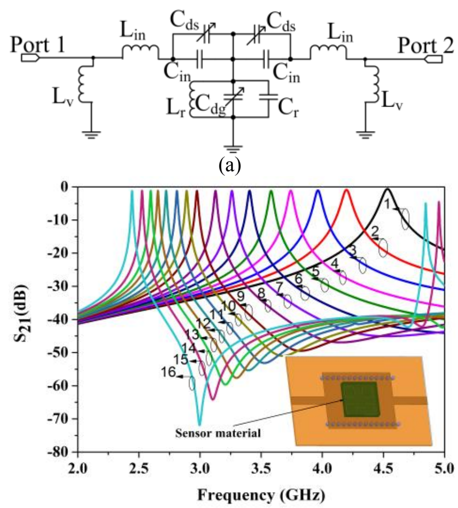


Fig. 2: (a) Equivalent circuit of sensor dielectric loaded filter, (b) pass band tuning with variation in dielectric constant.

shown in Figure 2(a). The dielectric loading (C_{dg} and C_{ds}) effectively increases the shunt capacitance of the resonating section and the pass-band shifts downwards as depicted in Fig. 2(b). Since the antenna is cascaded to the filter section, the radiating frequency also changes with the change in filter pass-band. The monopole bandwidth is optimized to provide pass-band tuning range from 4.5 GHz down to 2.5 GHz. The simulated S_{11} graph of the antenna is shown in Fig. 3. The variation of resonant frequency with dielectric constant can be shown to be given by a third order polynomial considering C_{dg} variation and neglecting variation in C_{ds}. However the inverse relation (Fig. 4) ε_r in terms of f_0 is more reasonable for sensor application and is given by (1).

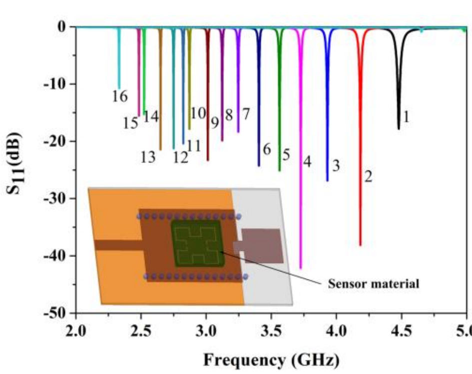


Fig. 3: Variation of S_{11} response with dielectric constant.

$$\varepsilon_r = 113.89 - 71.52 f_0 + 15.94 f_0^2 - 1.25 f_0^3 \qquad (1)$$

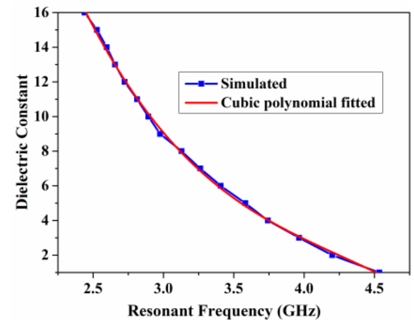


Fig. 4: Cubic polynomial fitting of dielectric constant with resonant frequency variation.

3D radiation pattern of the unloaded antenna is shown in Fig. 5 at resonant frequency 4.452 GHz. The achieved peak gain of the antenna is 4.2 dBi. The antenna is nearly omni-directional in XZ plane.

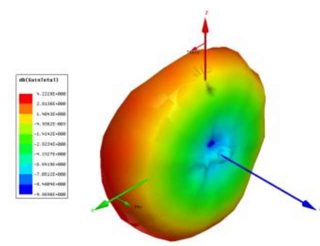


Fig. 5: Simulated 3D radiation pattern at 4.452 GHz.

IV. Conclusion

The filter antenna design proposed here may act as versatile sensor antenna with different loadable sensor dielectric material for different applications. The proposed antenna is low profile, nearly omnidirectional, has very narrow bandwidth, high tuning range and supports permittivity variation from 1 to 16. The antenna may be integrated with oscillator for stand-alone sensing applications.

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