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ISBN
978-1-4244-3646-0

Authors
Hosseini, S Ali
Capolino, Filippo
De Flaviis, Franco

Publication Date
2009-06-01

DOI
10.1109/aps.2009.5171772

Design of a single-feed all-metal 63 GHz Fabry-Perot cavity antenna using a TL and a wideband circuit model

S.Ali Hosseini, Filippo Capolino, and Franco De Flaviis
Department of EECS, University of California, Irvine, CA 92697-2625
E-mail: {sahossei, f.capolino, franco}@uci.edu

Abstract

In this paper, we show a wideband transmission line (TL) model for a Fabry-Perot cavity (FPC) antenna which is designed at a center frequency of 63 GHz using a thick and slotted metallic partially reflective surface. Then, by using the proposed wideband circuit model, we predict the gain and 3dB gain bandwidth of the antenna, assumed as infinitely large in the transverse domain (for the modeling purposes). Finally we compared the circuit model results to the full-wave ones for a FPC antenna of finite extent.

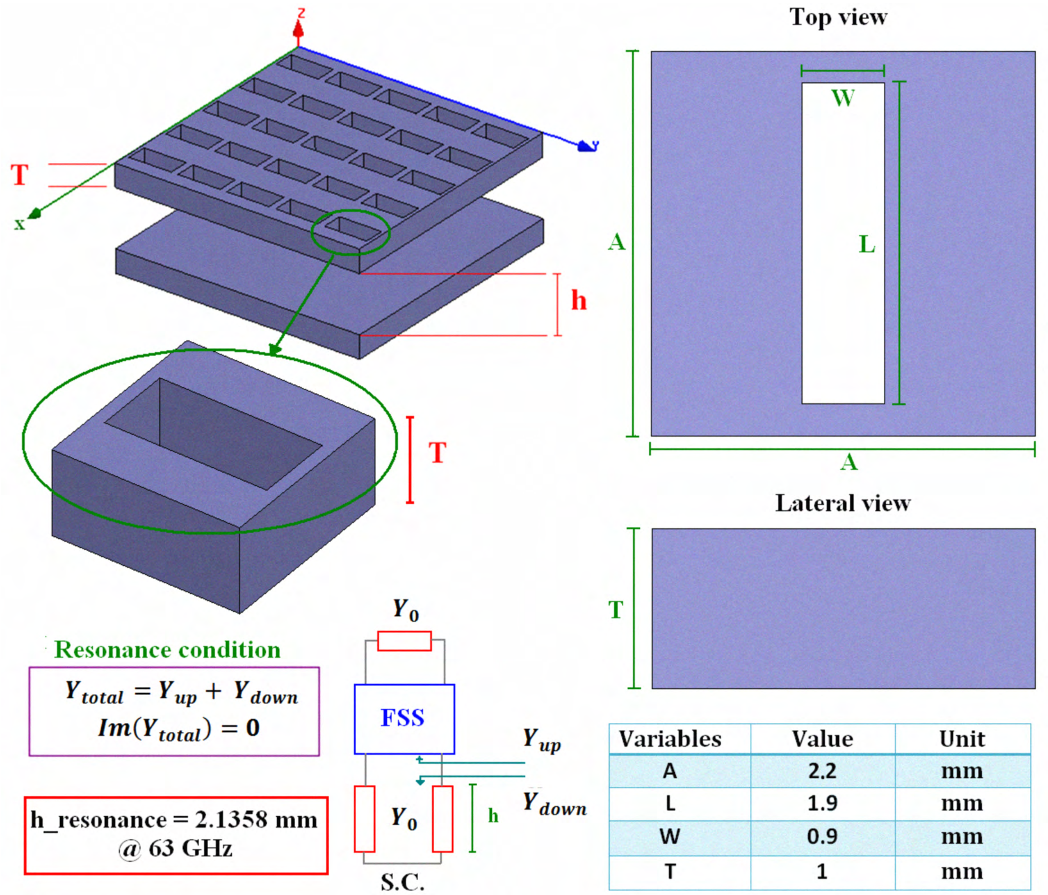
Introduction

According to FCC regulations, from 59 GHz to 67 GHz holds a free band for future wireless applications which already created a center of attention for new antenna research at the mentioned band. At these high frequencies, the losses of the antenna structure, substrate and feed network become a serious concern. One way to overcome these problems is to avoid use of a large feeding network, possibly with a single source, and make the antenna structure as simple as possible. One of the promising methods to design the antenna is to use the radiation produced by a leaky wave [1-2] excited by only one feed. Here we use a leaky wave antenna which consists of a frequency selective surface (FSS) as a partially reflective surface above the ground plane, to form a FPC, as in the pioneering design by Von Trentini [3]. In more recent years the leaky wave antenna theory has significantly advanced, including that for FPC antennas [4, 5, 6 and 7]. Here we use and extend some of the concepts to design a high gain antenna at 63 GHz (the middle point of mentioned band from 59 GHz to 67 GHz) made by a FPC that uses a thick FSS. Therefore we extend the design procedure that has been developed for thin FSS [4, 5, 6 and 7] to the case of thick screens, and we include Ohmic losses, that at these frequencies may play a significant role. We propose a wideband equivalent circuit for the thick FSS layer to be used in a TL model. Under this approximation, the antenna is assumed as having an infinite extent. However, because of the attenuation of the leaky wave excited by the feed, after a certain distance from the feed the field is so attenuated that the structure can be truncated. This model has been used to find the gain of the proposed FPC antenna. The results have been compared with the full wave ones for the case of a FPC of finite extent (truncated laterally) showing good agreement. Because of the high path losses at 63 GHz compare to path losses at low frequency wireless band, 5 GHz, the antenna gain is fixed at 20 dB to compensate the path loss difference between these two frequencies.

978-1-4244-3647-7/09/$25.00 ©2009 IEEE

Antenna Design

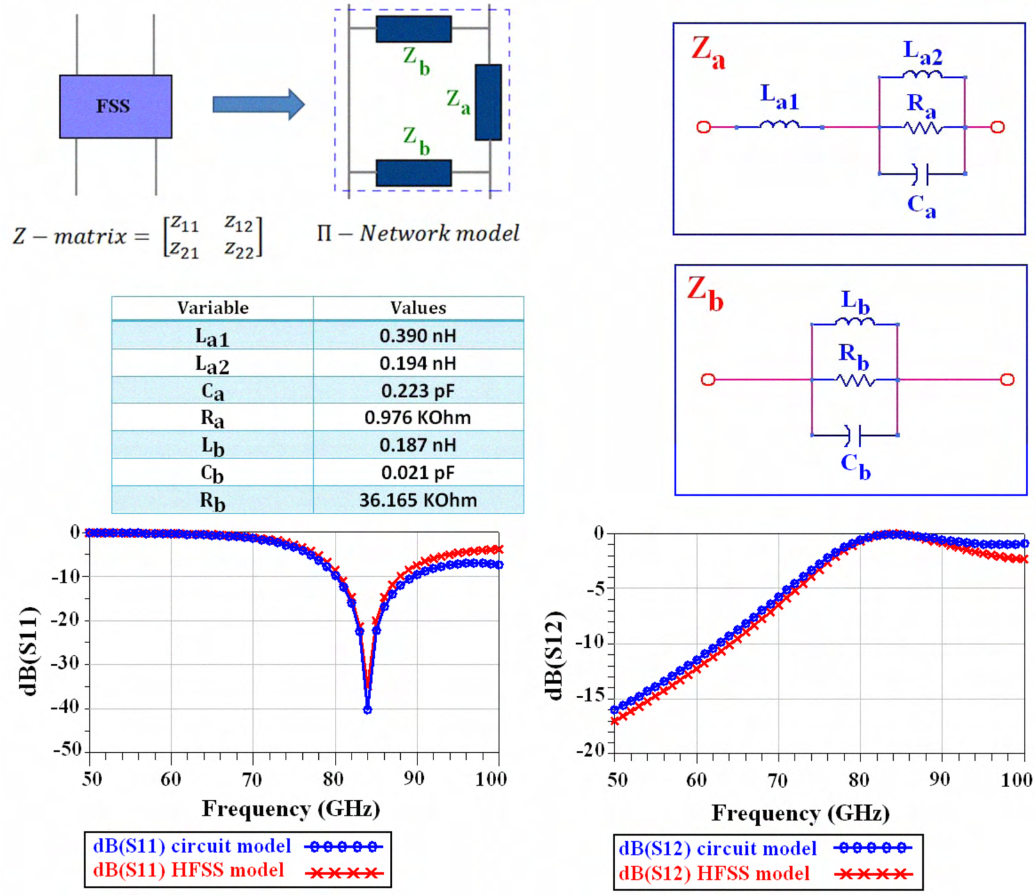
The goal is to design a 20 dB-gain antenna at 63 GHz using FPC model in which a metallic FSS has been placed over a ground plane to form FPC cavity (Fig.1). The main cell dimension (A = 2.2 mm) is chosen to be less than half a wavelength of the maximum frequency to avoid grating lobes. The dimensions of the slot (L=1.9 mm and W=0.9 mm) are selected in order to fix the gain of the structure at 20 dB. To set the resonance height of the cavity at 63 GHz, we choose a point in the TL model at the interface of FSS and cavity. We calculate the Y_{up} and Y_{down} values (Fig.1) and by using the resonance condition for the entire system (shown in Fig.1) at 63 GHz we determine the height of cavity (h = 2.1358 mm).



Variables	Value	Unit
A	2.2	mm
L	1.9	mm
W	0.9	mm
T	1	mm

Fig.1 the antenna topology and the process of finding the resonance height of cavity

The thickness of the metal is chosen to be T = 1 mm to provide mechanical stability however this is comparable to the wavelength at 63 GHz (4.76 mm). Hence the FSS cannot be modeled just by a simple shunt lumped element as in [4-7]. To model the thick FSS we select the Π-model structure (though other configurations may work as well). As shown in Fig.2, the Π-model is a satisfactory choice to model this thick FSS structure and also gives us a better understanding of the FSS properties. Fig.2 shows the comparison between the S-parameter results obtained via full-wave simulation of the FSS and the proposed circuit model. The agreement is satisfactory over a wide band, from 50 GHz to 100 GHz. The FSS pass-band resonance is at 83.9 GHz and for this FPC application we use it at lower frequencies where it has a significant reflection. The lumped element values to model the FSS are shown in a table in Fig.2.



Variable	Values
L_{a1}	0.390 nH
L_{a2}	0.194 nH
C_a	0.223 pF
R_a	0.976 KOhm
L_b	0.187 nH
C_b	0.021 pF
R_b	36.165 KOhm

Fig.2 the proposed circuit model for the thick FSS and the simulation results of the circuit model compared to the S-parameters achieved from HFSS

We have used the proposed circuit model to find the gain and also the 3dB gain bandwidth of the FPC antenna in entire band by using the TL method used in [6]. A waveguide feed, feeding the structure through a slot on its ground plane, can be used to excite the FPC antenna. The slot excitation is here modeled by a magnetic current source on the ground plane, which is represented by a voltage generator in the TL model. The S-parameters of the FSS layer calculated via HFSS simulations are used in TL model of the FPC antenna. The maximum gain of the antenna at broadside has been calculated, using the method used in [6], over the frequency band. Then, the proposed circuit model is used in place of the numerical S-parameters of the FSS, and we have calculated again the gain of the antenna over its frequency band, still using the TL model [6]. Finally, to verify the results gained form TL method we have performed full-wave simulations of the FPC antenna with finite transverse dimensions (44 mm by 44 mm) with HFSS. The gain values obtained with these three different methods are shown in Fig3 (a) versus frequency. Both max gain and the 3dB gain bandwidth BW = 1 GHz are well predicted by the TL model. The E-plane and H-plane radiation patterns of the antenna are shown in Fig3 (b), evaluated via the HFSS full-wave simulation of the finite size FPC antenna. The full-wave result of the gain shows a little bump at 66 GHz which may be caused by lateral truncation of the antenna.

Conclusion

In this paper, a thick FSS is used to from a FPC antenna with 1 GHz 3dB gain bandwidth and 20 dB gain at 63 GHz. To model the FSS thickness comparable to the wavelength we have used a two-port Π-model. Its elements Z_a and Z_b can be determined over a wide band from 50 GHz to 100 GHz. The proposed model is used to calculate the gain and the 3dB gain bandwidth of the antenna. All the TL simulation results have been compared to the full-wave ones. In future works, FSS thickness, using the accurate circuit model, will be investigated to improve the characteristics of the FPC antenna (e.g. gain bandwidth, efficiency).

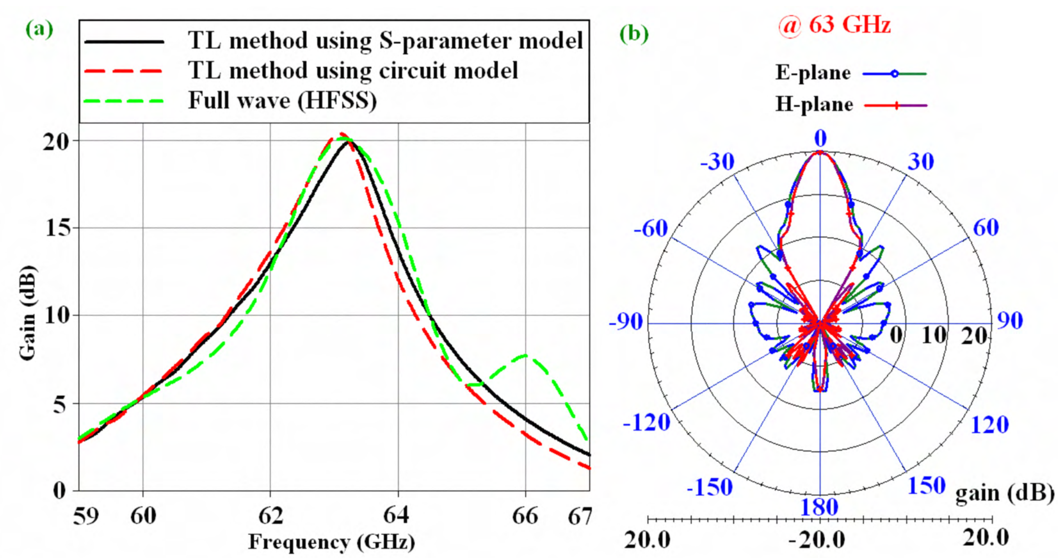


Fig.3 (a) The gain versus frequency; (b) the E-plane and H-plane radiation patterns

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