Evaluation of Cross-coupling Inside Gap-waveguides

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***Abstract*—With the introduction of new transmission line technology called gap-waveguides it is necessary to develop analytical solutions for various interactions between lines and other elements within the structure. Here we focus on the interaction or cross-coupling between neighboring transmission lines as a first step towards the analysis of gap-waveguide fed aperture arrays. Analysis is performed in the spectral domain using the Green's functions approach, with the crosstalk current on the unexcited (victim) transmission line calculated using even- odd transmission line approach. The analysis results are verified by comparison with measured results obtained from the developed prototype.**

***Index Terms*— cross-coupling, waveguides, gap-waveguides, spectral domain analysis**

INTRODUCTION

The development of future transmission line technologies at high frequencies (above 30 GHz) has spawned interest for various structures that could have substantial benefits compared to existing solutions in the form of classical waveguides, microstrip lines and similar technologies. First of these, Substrate Integrated Waveguides (SIW) have been introduced in 2001 [1] to produce low cost high-frequency waveguides. With very simple manufacturing process and possibility to create entire circuits in the substrate, this technology has many advantages over existing solutions. Possible problems for SIW are dielectric related losses and also applications that prohibit the use of dielectrics, like space applications. As an alternative technology a concept called gap-waveguides has been suggested in 2009 [2]. The idea is to guide quasi-TEM waves along ridges or strips inside parallel- plate waveguides where one wall is replaced by some realization of artificial PMC. The working frequency region is limited by the height of the waveguide, which should be less than a quarter wavelength. This ensures that no global parallel-plate modes can propagate, and the only possibility for the waves is to follow inserted ridges or strips. This is because parallel-plate cut-off introduced by the artificial PMC creates imaginary lateral walls around the ridges or strips that prevent field leakage to the sides.

Different realizations of artificial PMCs for this purpose were studied parametrically in [3], and the first ridge gap waveguide with artificial PMC realized with pins was experimentally verified in [4]. Metallic pin realization is also chosen for the present study. Detailed analysis of these structures has been conducted in [5][6] providing dispersion characteristics, field profiles, characteristic line impedance, etc.

Furthermore, using numerical tools, efforts have been made also in the design of microwave circuits in this technology [4]. However, apart from studying different microwave circuits no detailed study of the coupling mechanisms between neighboring transmission lines has been conducted. This is of great importance since this technology theoretically allows very dense packaging of parallel transmission lines and therefore the limits of this need to be addressed. Furthermore, careful study of cross-coupling is one important step towards a full analysis of gap-waveguide fed aperture arrays, since in that application multiple interactions between lines and apertures will have to be modeled.

ANALYTICAL MODELLING OF CROSSTALK

The initial step required in our analysis is to determine the Green's function of the studied structure which is shown in Fig. 1. in top-view (the top cover is assumed on height h above the lines) To derive the spectral-domain Green's functions for this structure one should follow the procedure shown in [5].

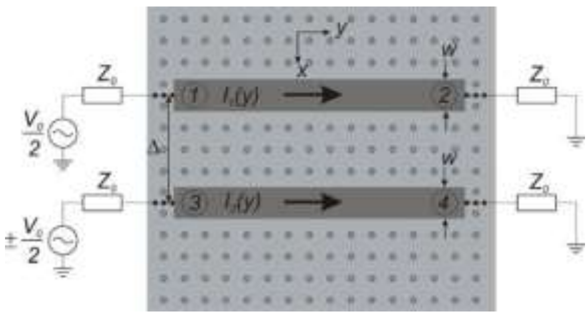

Figure 1. Two coupled gap waveguide transmission lines.

The cross-coupling problem is also illustrated in Fig. 1. The first line with the current $I1$ is the excited or the primary line, and the second line with current $I2$ is the "victim" or the secondary line. The objective of the analysis is to determine the voltage at port 4 belonging to the microstrip line which is only electromagnetically coupled to the primary line, or in other words to determine the coupling. Since this problem is essentially a transmission line theory problem, the most practical way of approaching it is through even-odd mode analysis [7]. In more details, the input impedance at port 1 for the even/odd mode is equal

where $Z0^e$ and Z_0^o are characteristic line impedances for even and odd modes, and k_{eff}^e and k_{eff}^o are corresponding effective wave numbers.

To determine these unknown wave numbers the equivalent approach will be applied that was used in the single line case [5]. The tangential electric field at the top of the primary line is forced to zero (in averaged sense) and it results in two integral equations, for even and odd mode cases. The difference with respect to the single line case is that the field this time has two contributions; the main contribution as before is from the current on the primary line itself and the "coupled" contribution is from the secondary line. The characteristic line impedances are then determined by using the following definition of the impedance $Z^{e/o}$ $2P^{e/o}/I^2$, as suggested in [6]. Once the impedances are known it is straightforward to determine the cross-coupling levels at the desired ports.

RESULTS

The structure used for verification of the analytical procedure was based on a bed-of-nails with rectangular shaped pins with the following dimensions; periodicity of the pins is 7.5 mm, pins width is 3.5 mm, and the height of the pins is 10 mm. Lines have 10 mm width and are lying on a very thin low-permittivity substrate. They are arranged so that there are two and three rows of pins between them, i.e. the distance between the line centers is 28 mm and 35 mm, respectively.

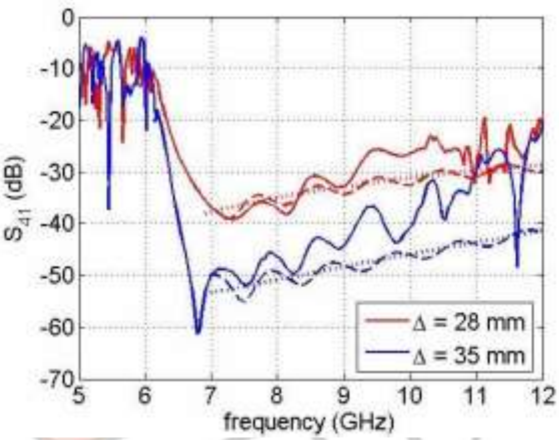

Figure 2. Cross-coupling between the neighboring strip lines (gap height h = 2 mm) for two (mm) and three mm) pin rows between them; solid line - measurements, dashed line - even/odd analysis, dotted line - asymptotic coupling.

The comparison between the calculated and the measured results for cross-coupling ($S41$) between the neighbouring lines is shown in Fig. 2. From the measured results it is possible to estimate that the level of coupling decay is close to 10 dB per row of pins, which corresponds to approximately 50 dB per wavelength at 8 GHz in the case of 2 mm gap height. The decay rate is slightly higher in the calculated results, but the agreement between the results is quite good and can be very useful for initial design studies. Also in Fig. 2. an approximation of coupling level (dotted line) is given based on the study presented in [8]. Although the excitation model used in [8] does not describe the actual measurements on our experimental model, it is possible to use their findings for weakly coupled transmission lines.

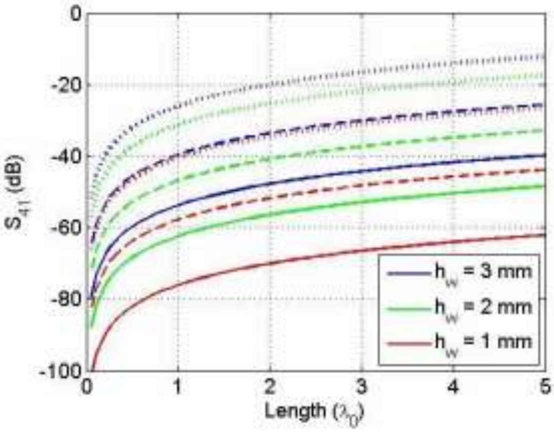

Figure 3. Calculated cross-coupling between the neighboring lines as a function of line length, spacing between the lines and waveguide height; (a) dash-dotted lines correspond to = 21 mm (one line of pins between the transmission lines), (b) dashed lines correspond to = 28 mm (two lines of pins between the transmission lines), (c) solid lines correspond to = 35 mm (three lines of pins between the transmission lines).

In Fig. 3 the magnitude of the *S41* parameter is shown as a function of gap height, line length and separation between the lines. It can be seen that strong isolation between the lines can be achieved for only two rows of pins between the lines. Furthermore, the coupling level is much smaller for small values of waveguide height since the electromagnetic field in this case is more tightly confined to the transmission line.

REFERENCES

[1] D. Deslandes and K. Wu, "Integrated microstrip and rectangular waveguide in planar form," *IEEE Microwave and Wireless Comp. Lett.* vol.11, no.2, pp.68-70, Feb 2001.

[2] P.-S. Kildal, E. Alfonso, A. Valero-Nogueira, E. Rajo-Iglesias, 'Local metamaterial-based waveguides in gaps between parallel metal plates,' *IEEE Antennas and Wireless Prop. Lett. (AWPL)*, 2009, 8, pp. 84-87.

[3] E. Rajo-Iglesias, P.-S. Kildal, "Numerical studies of bandwidth of parallel-plate cut-off realised by a bed of nails, corrugations and mushroom-type electromagnetic bandgap for use in gap waveguides," *IET Microwaves, Antennas & Prop.*, vol. 5, pp.282-289, March. 2011.

[4] P.-S. Kildal, A. Uz Zaman, E. Rajo-Iglesias, E. Alfonso, A. Valero- Nogueira, "Design and experimental verification of ridge gap waveguides in bed of nails for parallel plate mode suppression", *IET Microwaves, Antennas & Prop.*, Vol. 5, pp. 262-270, March 2011.

[5] M. Bosiljevac, Z. Sipus, P.-S. Kildal, "Construction of Green's functions of parallel plates with periodic texture with application to gap waveguides – a plane wave spectral domain approach," *IET Microwaves, Antennas & Prop.*, vol. 4, pp. 1799-1810, Nov. 2010.

[6] A. Polemi, S. Maci, "Closed form expressions for the modal dispersion equations and for the characteristic impedance of a metamaterial-based gap waveguide," *IET Microwaves, Antennas & Prop.*, vol. 4, pp. 1073 – 1080, Aug. 2010.

[7] D. Pozar, *Microwave engineering*, John Wiley and Sons, New York, 2005.

[8] J. Bernal, F. Mesa and D. R. Jackson, "Crosstalk Between Two Microstrip Lines Excited by a Gap Voltage Source," *IEEE Transactions on Microwave Theory and Techniques*, vol. 52, no. 8, pp. 1770 – 1780, Aug. 2004.