Reduction of Coupling between Flush-Mounted Antennas

Prathap Valale Prasannakumar, Mohamed A. Elmansouri, Maxim Ignatenko, and Dejan Filipovic
Department of Electrical, Computer, and Energy Engineering
University of Colorado, Boulder
Boulder, Colorado, USA, 80309
{Prathap.Valaleprasannakumar, Mohamed.Elmansouri, Maxim.Ignatenko, and Dejan.Filipovic}@colorado.edu

***Abstract*—This paper discusses some numerical aspects of the coupling study between two flush-mounted antennas. It is shown that a bed of nails embedded between flush-mounted quad-ridge horns separated by 20 cm ($4\lambda_{6\text{ GHz}}$) edge-to-edge greatly reduces coupling by about 17 dB at lower frequency end, where the electrical distance between antennas is the shortest. The considered antenna system operates from 6-19 GHz and has $|S_{11}| < -10$ dB, and coupling < -60 dB. The numerical modelling is carried out using MoM and FEM solvers. The computed results are in good agreement with measurements.**

***Keywords*—Bed of nails, coupling, method of moments.**

I. INTRODUCTION

Coupling between antennas sharing common platform is a critical parameter in the design of in-band full duplex systems. Often, coupling < -60 dB (or isolation > 60 dB) is desired from the antenna layer itself to achieve total system isolation in the order of 110-140 dB [1]. Minimizing the coupling for an electrically-short separation between transmitter (TX) and receiver (RX) is a challenging task. Various techniques to improve the antenna layer isolation are considered in open literature including recessing the RX antenna in absorber, the use of band-gap structures, and the implementation of high impedance surfaces (HIS) [2,3]. High impedance surfaces (capacitive or inductive) can be implemented over an octave bandwidth by means of a bed of nails [4,5]. The practical realization and fabrication of these structures are relatively easy and cost effective. However, numerical modelling and solving of the bed of nails (312 nails/unit cells in this paper) requires intricate meshing and thereby, considerable computational resources. Moreover, computation of the expected low level of coupling can be challenging because of high required accuracy. Further, the reflections from absorbing/radiation boundaries could influence the calculation of low level of coupling, when finite element method (FEM) solvers are used. In this work, coupling between two quad-ridge horns operating in 6-19 GHz is considered using commercially available method of moment (MoM) solver – Altair FEKO. In spite of numerical challenges, good agreement between measurements and simulated results is achieved. It is demonstrated that 17 dB reduction in coupling can be obtained by embedding bed of nails between the antennas separated 20 cm edge-to-edge.

This work is supported by the Office of Naval Research (ONR) # N00173-15-C-2021.

Submitted On: September 26, 2018
Accepted On: October 3, 2018

II. ANTENNAS COUPLING MECHANISM

Radiation is the main path of coupling between two co-located antennas in free space. Hence, the coupling is proportional to the gain in the direction between the antennas. When the antennas are flush mounted on a metallic ground plane, surface currents provide an additional path for coupling. Specifically, when two WR90 (X-band) open-ended waveguides (OWG) oriented in **E**-plane are flush mounted on a metallic ground plane, the coupling due to surface currents alone is approximately 10% of the total coupling at 8 GHz, as shown in the Fig. 1. This coupling is calculated in FEKO using currents on the ground plane as a source of the received power at the RX aperture. Suppressing these currents will reduce coupling. It should be noted that manipulating the surface currents will also affect the electromagnetic waves above the surface, and thus much stronger than 10% impact on coupling is expected.

The predominant E_z amplitude at the surface in the E-plane of the antennas (x-axis in Fig. 2) is in accordance with the study in [3] that TM waves are supported over a metal with finite conductivity. TM surface waves have capacitive wave impedance, and hence a capacitive surface will inhibit its propagation. Desired capacitive impedance is realized by using $\lambda/4$ (at 8 GHz) grounded metallic nails arranged in double-periodic structure [4]. To reduce computational requirements, pins are modeled as wire segments of radius 1 mm in FEKO. As seen in Fig. 2 (d), the bed of nails reduces E_z at the RX aperture by 18 dB. This clearly demonstrates that the bed of nails can be effectively used to reduce coupling between flush-mounted antennas, as further discussed in Section III. The CAD model of the bed of nails consisting of 0.93cm ($\lambda_{8\text{ GHz}}/4$) long metallic pins is shown in Fig. 2 (b).

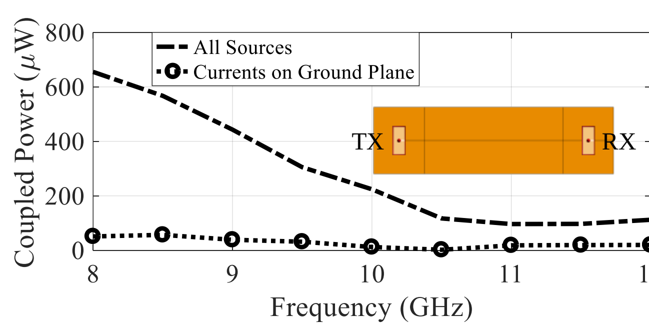

Fig. 1. Power coupled through the RX aperture when 1 W power is fed at the input of TX antenna. Antennas are mounted on a metallic ground plane with 14 cm separation from edge-to-edge.

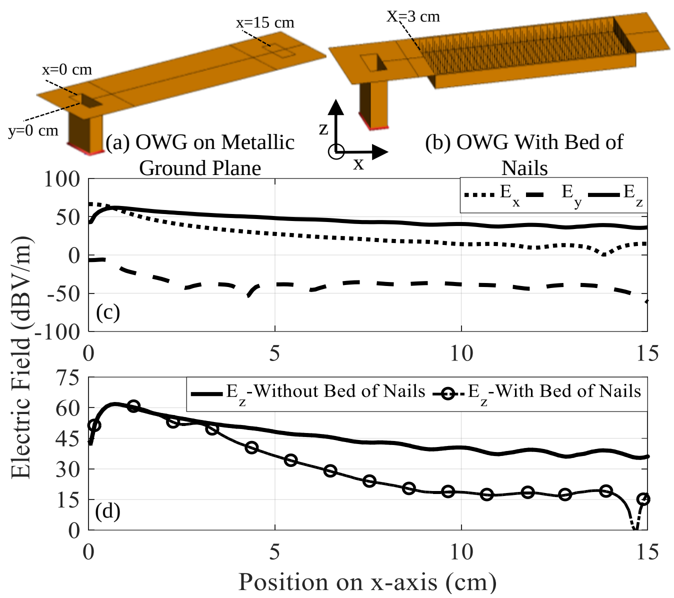

Fig. 2. CAD model of open ended waveguide flush mounted on: (a) metallic ground plane, and (b) with bed of nails. Magnitude of electric field components over the ground plane: (c) without, and (d) with bed of nails at 8 GHz.

III. Flush-Mounted Quad-Ridge Horns

The considered quad-ridge horn (QRH) antenna supports dual-polarization operation, and can handle high power [5]. Impedance match of the antenna is a crucial parameter for high power applications. Therefore, to reduce the reflections from the aperture, the ridges of the horn are shaped as a Klopfenstein taper. Moreover, the edges of the horn aperture and the ridges are rolled into semielliptical shape to reduce the reflections resulting from the edge diffraction. The designed horn is 8cm long and has an aperture of 3 cm × 3 cm. FEM and MoM hybridization supported by FEKO is used in order to excite quad-ridge waveguide cross-section. Adaptive mesh shown by green bubbles in the inset of Fig. 3 was found to be critical for achieving good accuracy. The antenna has reflection coefficient ($|S_{11}|$) < -10 dB (< -20 dB for 94% of the bandwidth) when fed at the quad ridge section (see Fig. 3 (a)). The designed quad-ridge to double-ridge transition used in measurements has $|S_{11}|$ < -10 dB over 98% of bandwidth. Good agreement between simulation and measurement is observed.

The QRHs are flush mounted on a metallic ground plane of size 13 cm × 38 cm (Fig. 4 (a)), which corresponds to 8 λ_{19GHz} × 24 λ_{19GHz}. Also, QRH with the transition is about 10λ_{19GHz} in z-axis which results in a computationally-large problem. The system has coupling < -40 dB at 6 GHz over a metallic ground plane and < -60 dB when the proposed bed of nails is embedded between the antennas oriented 45° to each other, as seen from Figs. 4 (b) and (c). Good agreement between the measured and simulated results highlights the ability and accuracy of numerical solvers in handling complex and electrically-large problems. The model solved using MoM in FEKO, meshed at 19 GHz, has 51,616 triangles, 758 FEM surface triangles, 624 metallic segments, and 28,658 tetrahedral.

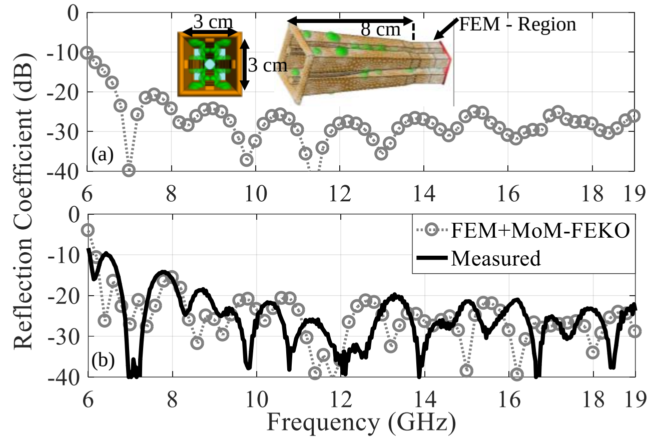

Fig. 3. Reflection coefficient of quad-ridge horn: (a) fed at the input of quad-ridge section (simulated results), and (b) fed using quad ridge to double ridge section (FEKO, and measured results).

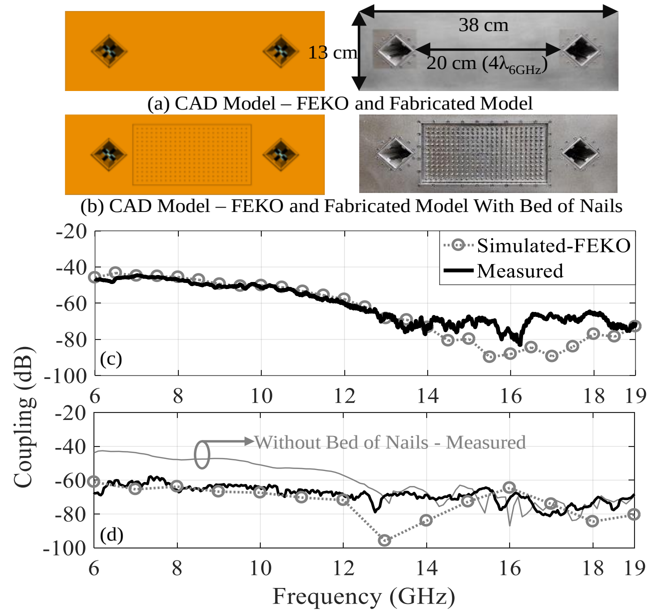

Fig. 4. CAD and fabricated models of QRH over metallic ground plane: (a) without and (b) with bed of nails. Simulated and measured coupling: (c) without and (d) with bed of nails.

References

[1] D. Bharadia, E. McMilin, and S. Katti, "Full duplex radios," Proc. SIGCOMM'13 Conf., China, pp. 375-386, 2013.

[2] J. A. M. Lyon, C. J. Digenis, W. W. Parker, and M. A. H. Ibrahim, "Electromagnetic coupling reduction techniques," The University of Michigan, Ann Arbor, MI, USA, AFAL-TR-68-132, June 1968. Available: https://deepblue.lib.umich.edu/handle/2027.42/6402

[3] D. Sievenpiper, "High-Impedance Electromagnetic Surfaces," Ph.D. dissertation, Dept. Elect. Eng., Uni. California, Los Angeles, CA, 1999.

[4] R. J. King and K. S. Park, "Synthesis of surface reactances using grounded pin bed structure," in Electronics Letters, vol. 17, no. 1, pp. 52-53, Jan. 1981.

[5] P. Valale Prasannakumar, M. A. Elmansouri, and D. S. Filipovic, "Wideband decoupling techniques for dual-polarized bi-static simultaneous transmit and receive antenna subsystem," in IEEE Trans. Antennas and Propag., vol. 65, no. 10, pp. 4991-5001, Oct. 2017.