A Novel Multi-Slot Antenna for Wireless Communication

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Abstract

The paper presents a new antenna design that utilizes waveguide properties of cylinders with longitudinal slots to achieve optimal efficiency. Numerical analysis and experimental data presented in the article show that when the length of the antenna slot approaches the wavelength in free space, the field in the antenna aperture approaches the optimal distribution. Consequently, the antenna with slots and opened cylinders of optimal length can reach the maximum efficiency.

Keywords : Antennas Slot antennas Antenna efficiency MIMO antennas

1. Introduction

Slot antennas have been extensively investigated for applications in various airborne and satellite communications systems because they satisfy the requirements of flush mounting, low cost and light weight. A single slot antenna (Figure 1) is a bi-directional radiator. To re-direct the radiation into a half-space, the slot in the antenna is usually backed by a ground reflector or by a conductive cavity [1]. In a common antenna design approach, the length of the basic radiator is small compared to the wavelength in free space (λ_0): less or equal to $\lambda_0/2$. A counterintuitive idea is to introduce slots of lengths substantially larger then $\lambda_0/2$ and utilize the fundamental mode of slotted cylindrical waveguides. The analysis below will show that antenna design with large slots have merit and can achieve substantial efficiency increase.

The basic single-slot antenna layout is the following. The slot of the antenna is backed by a cylinder. The cylinder, the antenna ground plate, and the slot form a slotted waveguide. The resonant frequency, at which input impedance of the slot is equal to 50 Ohm, shifts into higher frequency range, making antenna longer than $\lambda_0/2$ and creating more optimal amplitude and phase distribution on the slot. In contrast with conventional cavity-backed slot antenna designs, the considered antenna design does not use cavity resonances. The cylindrical screen that backs the slot and re-directs radiation into the upper half-space has open ends. Conditions to support a fundamental mode of a closed waveguide are not required. The cross-sectional dimensions of the cylinder have to be chosen in such a way that the cylinder with the part of the ground plane and the slot of the antenna form a slotted cylindrical waveguide that supports the basic H_{00} mode.

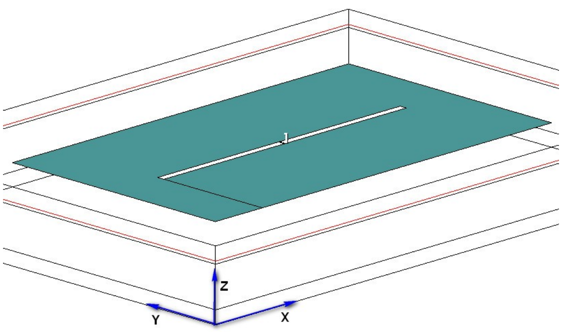

Figure 1: A resonant narrow slot antenna (a magnetic dipole)

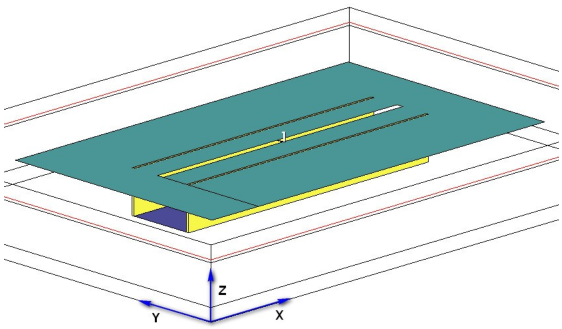

Figure 2: Single-slot antenna with the slot backed by a cylinder (open slotted waveguide).

Characteristics of the open cylindrical waveguide with a longitudinal slot were studied in [2]. The analysis shows that H_{00} mode excited in the waveguide has a cut off frequency. Consequently, when an antenna has a cylindrical screen attached to the conducting plane with a longitudinal slot (Figure 2) and the dimensions of the screen are such that only the H_{00} mode exists, the radiation properties of the slot change dramatically. The H_{00} mode is associated with the low frequency scattering resonances studied in [3]. The difference between cut off frequencies of the H_{00} mode and the fundamental mode of the waveguide, formed by the cylinder without the slot, depends on the slot width and the geometry of the cylinder cross section [4]. This difference can be made large enough to design an antenna operating in the single mode band and radiating only in a half-space. Numerical simulations of the antennas were performed using the EM solver AXIEM from the AWR Microwave Office [5].

2. Single Slot Antenna

The single-slot antenna with open cylindrical waveguide was simulated with a full-wave EM solver and a prototype was manufactured and its radiation characteristics were measured in a standard anechoic chamber. Radiation patterns of the antenna can be compared with the corresponding characteristics of a conventional slot antenna. Figures 3 and 4 show the radiation patterns of the antennas in $\varphi=0^o$ and $\varphi=90^o$ planes. In the EM simulations the antennas were excited by a current source across the centre of the slot. The simulation results were in good agreement with the measured data.

In the antenna prototype the feeding network is manufactured on a 30mill RO4350B high frequency laminate with the ground plate size of 150*90mm. The cylinder backing the slot has a rectangular shape (15x24mm) and 108mm long, the backing cylinder has open ends and electrically connected to the top side of the ground plate of the antenna via holes in 4 points on each side. The slot has length of 108mm and width 2.7mm. It is important to note that the slot is longer than half wavelength and is equal to $0.8*\lambda 0$, which agrees with the dispersion properties of the slotted cylinder. Some preliminary measurement of the 5GHz slot antenna with 40mm slot can be found in [6].

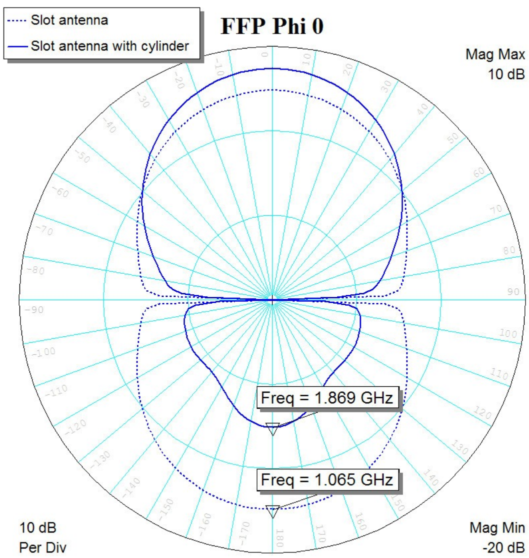

Figure 3: Radiation patters of the antennas in $\varphi=0^o$ plane.

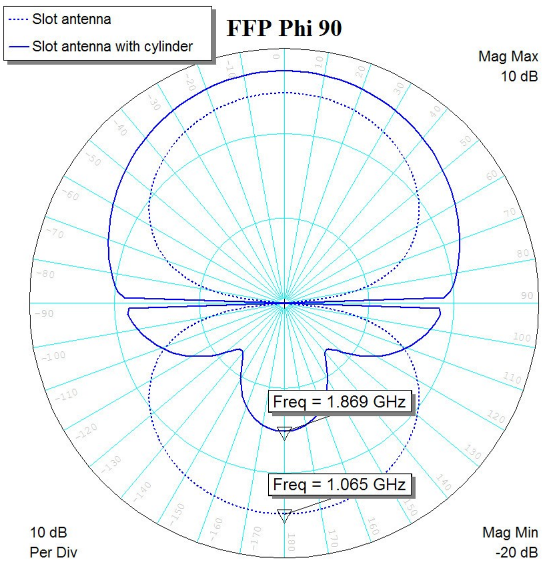

Figure 4: Radiation patters of the antennas in $\varphi=90^o$ plane.

3. Four Slots Antenna

The back-side view of the four slot antenna is shown on the Figure 5. The antenna is designed to operate at the 2.4GHz band. In this antenna, four slots are cut out in the ground plate parallel to each other at half wavelength distance, and a corporate feeding network is etched on the opposite side of the 40mill RO4350B laminate, with backing cylinder forming slotted transmission line made of a brass shim.

The dimensions of the ground panel of the antenna are 150*270mm. Figure 6 shows antenna return loss versus frequency, the S11 is below -10dB in the range [2.325; 2.58] GHz. Antenna has a peak gain of 14.5dBi at 2.5GHz. Figure 7 and 8 show far field patterns in the horizontal and vertical planes with corresponding Half Power Beam Widths (HPBW) of 50^0 and 23^0. Antennas front to back ratio is below -20dB. The antenna has no side lobes in the horizontal plane and in the vertical plane the first side lobe level is below -14dB. Antenna efficiency compared to theoretical maximum which can be achieved for the given aperture with uniform field distribution is over 94%.

The antenna was put to the test in two practical experiments. The goal of both experiments was to compare actual performance of the slot antenna to the performance of conventional antennas available on the market. In the first experiment, the slot antenna was connected to a generic wireless access point and signal strength measurements were taken on a wireless client at various distances from the wireless access point. The experiment was repeated with a Cisco antenna and a Hawken antenna. The second experiment followed the same setup measuring the actual transfer speeds instead of signal strength. Significant increase of the indoor/outdoor range (high quality IEEE 802.11g connection) has been demonstrated.

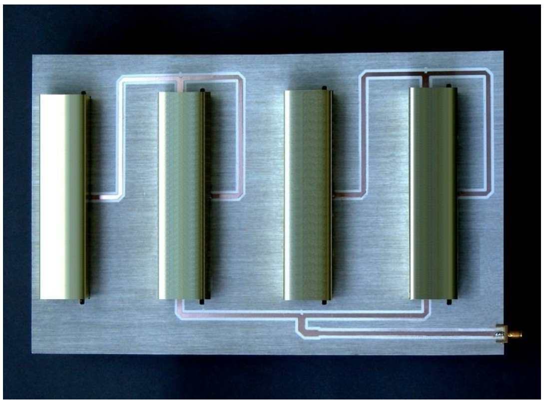

Figure 5: The four slot antenna (back-side view)

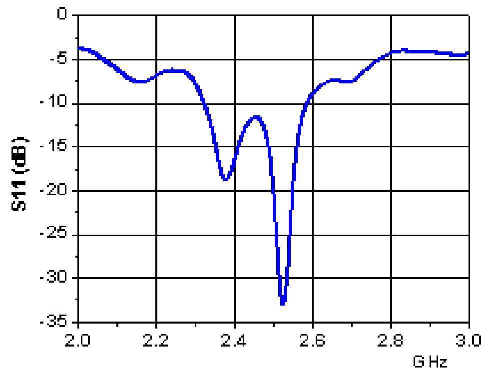

Figure 6: Measured $|S_{11}|$ of the four slot antenna.

4. Coupled Slot Antennas for MIMO

Modern communication systems use multiple antenna structures. It is very important to build compact antenna structures for MIMO and if we use closely packed antennas the risk of mutual and parasitic coupling between them is very high. Slot antennas of various configurations are attractive since they belong to the flush mounted structure that make it low profile. Wider bandwidth, less interaction via surface waves, better isolation and negligible radiation from feed network make radiating slots very attractive for MIMO antenna configurations.

Mutual coupling between radiating elements of two antennas has been analyzed using the 3D EM solver (AXIEM). A low profile two-slot antenna on 30mill RO4350B high frequency laminate with the copper plate size of 150*160mm was used as an element in a two-antenna configuration. The gain of the two-slot antenna at the operation frequency (with 50Ohm feeding network) of 1.8GHz is 5.6dBi. The novel two-slot antenna with the cylindrical screens that back the slots has the gain of 11.2dBi. It has been shown that the coupling between antennas of the novel design can be reduced dramatically. With |S41| and |S31| below -38dB the two closely located antennas can function independently with very high level of isolation.

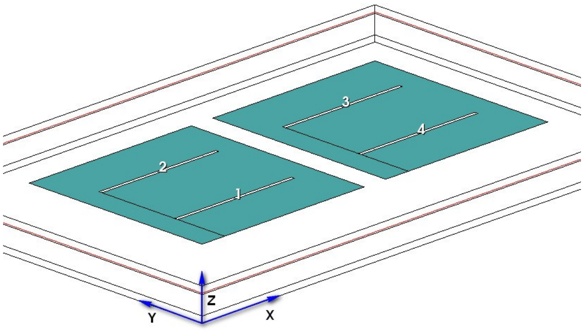

Figure 7: Two dual-slot antennas

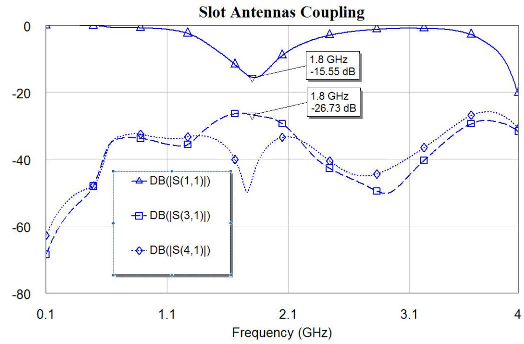

Figure 8: Mutual coupling between radiating elements of two dual-slot antennas

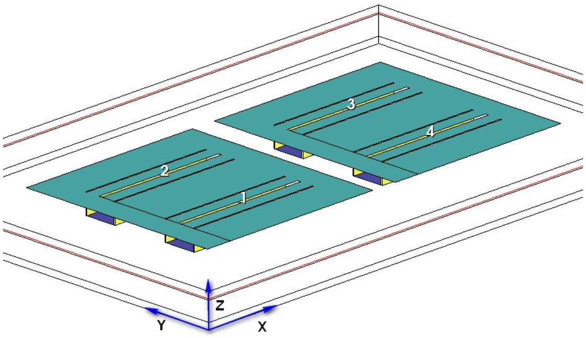

Figure 9: Two dual-slot antennas with the slots backed by cylinders (open waveguides).

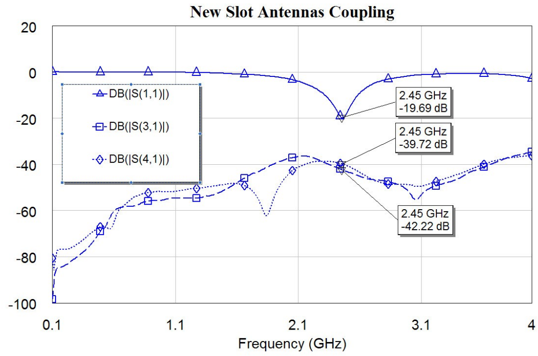

Figure 10: Mutual coupling between radiating elements of two dual-slot antennas with the slots backed by cylinders.

5. Conclusions

Proposed design yields a highly efficient and low cost antenna. The multi-slot antenna can be used as a principal radiating element in low, medium, and high gain directional panel antennas as well as a basic element in base station or smart antenna designs. The antenna is suitable for MIMO applications because of good isolation, below -35dB, and frequency range of the antenna impedance match is up to 22% ($|S_{11}| < -10$dB). Active components such as phase shifters, amplifiers, or switches can be easily integrated in the antenna feeding network.

References

[1] S. A. Long, “Experimental study of the impedance of cavity-backed slot antennas,” IEEE Trans. Antennas Propagation, vol. AP-23, pp. 1-7, Jan.1975.

[2] A. Nosich and A. Svezhentsev, "Principal and Higher Order Modes of Microstrip and Slot Lines on a Cylindrical Substrate", Electromagnetics, Volume 13, pp.85-94, 1993.

[3] V. Veremey, “Superdirective Antennas with Passive Reflectors”, IEEE Antennas and Propagation Magazine, vol. 37, pp. 16-27, 1995

[4] A.V. Sulima, "Scattering of TE Waves by Cavity Backed Slots" Proceedings of the 32nd European Microwave Conference, 2002, Milano Italy

[5] AWR Corp. “Planar Antenna Simulation in AXIEM”, Microwave Journal, July 2010

[6] A.V. Sulima, V. Veremey, “A Highly Efficient Slot Antenna”, 2010 IEEE AP-S International Symposium on Antennas and Propagation , Toronto, ON, Canada, July 11-17, 2010

[7] A.V. Sulima, V. Veremey, “Transmission Line Slot Antenna”, Patent Application Pub.No. US 2011/0090128 A1