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Miniature 4-Element MIMO Antenna System Designed From Transparent Glass Substrate and Aluminum Foil Radiator

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Abstract The use of transparent antennas has been gaining popularity in recent years. Today many types and designs of display apparatus can be seen along city streets and for buildings as a backup power supply. Transparent antennas can be used for cladding the modern glass buildings. Transparent antennas also can be placed directly on top of solar cells and resolve the issue of competing for limited surface real estate. Like integration with the solar panels of small satellites, where limited surface area is an issue for mounting antennas, solar cells, and space instruments. This paper discuss the methods and materials used to design a transparent antennas that can be integrated with solar cells to solve the issue of competing for limited surface real estate and backup the short of electricity in the sunny country Sudan. In this paper a proposed a 4-element meander line MIMO Multiple Inputs Multiple Outputs antenna system designed from Aluminum foil radiator over transparent glass substrate this design is transparent partially. Despite of the unfamiliar materials used for the antenna design and it is a limited size MIMO system the simulated and measured results showed XBand matched bandwidth. In this work the antenna is designed and the solar cell module has been proposed theoretically.

Keywords: *MIMO, Transparent substrate, XBand, Integrated Glass buildings*

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1. Introduction

The invention of transparent antenna innovated by the National Aeronautics and Space Agency (NASA) in the late nineties [1]. The first material used for this study by NASA is the patented AgHT-8 [1], the first of the two types of the AgHT performance film trademark which is a transparent electrically conductive film made of silver sandwiched between two layers of tin oxide. Since then, researchers have used semiconducting oxides of indium, zinc and cadmium and metals such as gold and titanium nitride. A figure of merit for these transparent conductive materials is the ratio of the electrical conductivity to the optical absorption factor of the film [2], The small value of the resistivity, higher the conductivity of the AgHt film must be but with a compromise on transparency. For this reasons the proposed MIMO antenna system designed from Aluminum foil over transparent glass substrate. The design gains the 100% transparency of the glass and the good conductivity of the Aluminum. Antennas developed so far have shown to have better gain by virtue of having a glass substrate or superstrate as an RF lens [2]. On the other hand, for a film antenna in cellular, wearable and other non-glass applications where discreteness is warranted, a single transparent antenna with improved features such as gain and efficiency is needed. In 1958, the invention of the first important application of solar cells as a back-up power source to the Vanguard I satellite, which made it to continue sending for over a year after its chemical battery used [3]. The successful of solar cells on this task was repeated in many other American and Soviet satellites, and by the late 1960s, photovoltaic (PV) technology had become their main source for power until now [4,5,6,7]. Electrically conductive materials used for microwave antennas are typically metals which are opaque to visible light. Fortunately, materials that are both transparent conductive have been made by cladding clear polyester sheets with very thin layers of metal oxides [8,9] or carbon nano tubes [9,10]. Many transparent antennas have been proposed which show promising results, but gain data was not reported [11,12] very lower gain for transparent antennas compared to their copper and other conductive materials counterparts; a transparent PIFA designed on a sheet of resistivity 20 w/sq gave approximately 10 dB lower gain at 2.4 GHz [13]. And planar monopole UWB antenna on AgHT-4 gave 5 dB lower gain because of the inherent low conductivity of the transparent film [14,15]. Transparent patch antennas, as a special class of micro strip patch antennas have been studied for more than twenty years. Their typical shape consists of a top-layer conductive path, bottom-layer ground, and dielectric substrate in between. The integration of photovoltaic with antenna technology needs special ways for implementation since the necessities of photovoltaic are often in opposite to antenna requires. The researches have shown that integration is possible if all requirements are considered appropriately [16]. Current government policies in the world look for improving the use of renewable energy instead of the use of grid-supplied electricity to decrease carbon dioxide emissions, and so contribute to the alleviation of climate change. With rising fossil fuel cost solar energy becomes alternative good option for powering communication systems and it is really the first choice when it comes to powering tools in space or remote areas where grid power either is too expensive or it is not available to extend to . As an energy source, solar photovoltaic systems are reliable and incur minimum maintenance [17]. Antennas for communication and solar cells for energy are sharing a limited surface area which can be saved by suitably combining both technologies [18,19]. Also consumer electronics entertainment devices such as wireless headphones or mobile phones are increasingly powered with photovoltaic's (PV) [20,21]. In these systems, the communications antenna is typically displaced from the panel of photovoltaic cells. In addition, urban mobile cellular communications use an increasingly high number of limited-range building-mounted antennas operating at small power. The installation of microcell antennas on buildings often needs expensive and time-consuming retrofitting of electrical supply cables, which can guide to concern over visual amenity, vandalism and maintenance. Photovoltaic powered microcell transceivers with combined batteries offer a high inherent reliability and are insusceptible to grid-supply interruptions [22,23]. Vertical façade PV panels for building integration are shaped usually with a flat external shape [24,25,26,27] which helps integration with planar antennas. Figure 1 shows general flow chart for glass building clad with transparent antenna integrated with photovoltaic film the figure extracted from the literature survey.

2. Xband Antenna Design

In this section the two design methods (simulation and fabrication) used for designing the proposed model have been shown and discussed.

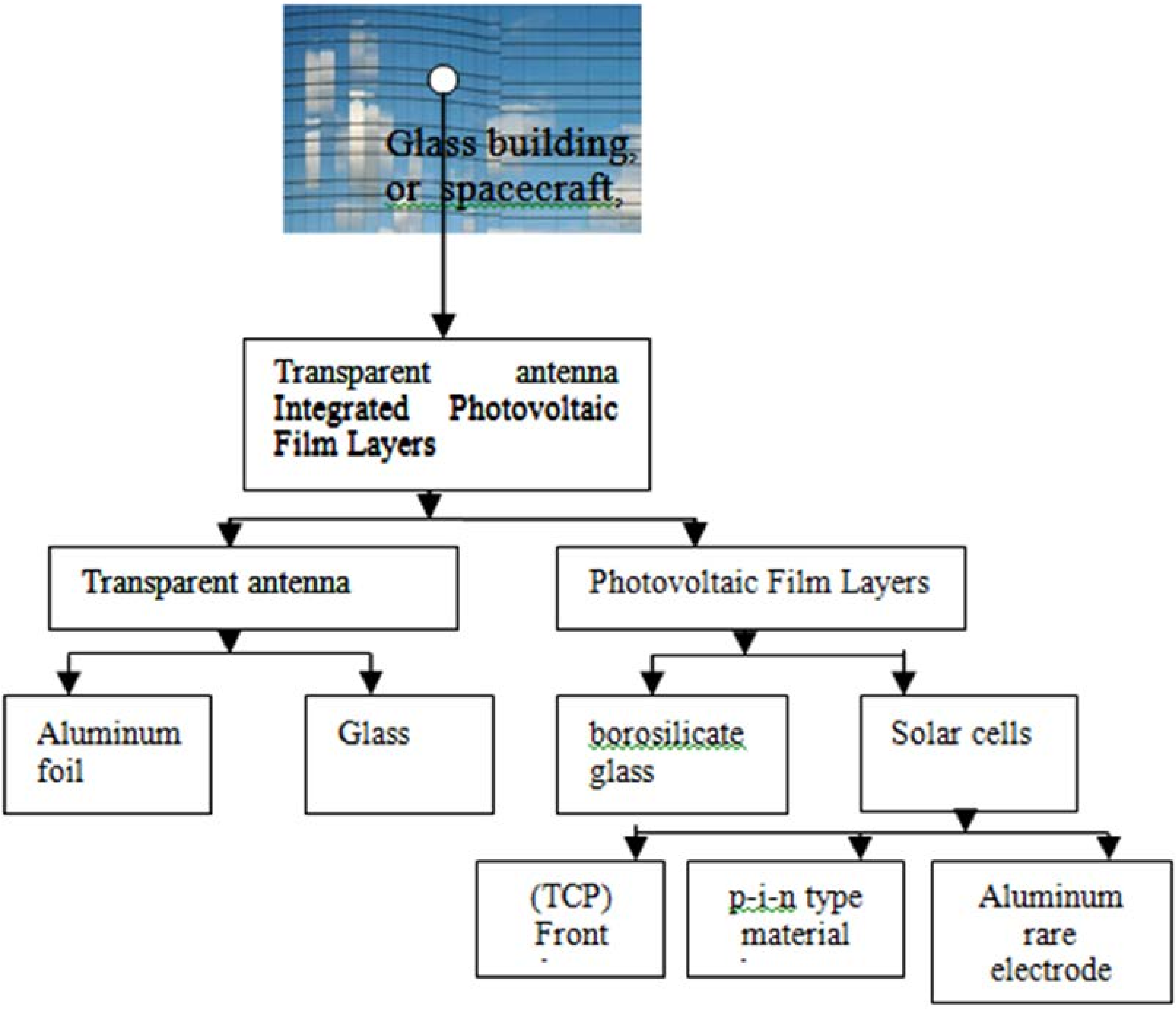

Figure 1. The general flow chart extracted from the literature survey

2.1. Simulation

CST (Simulation): is the imitation of the operation of a real-world process or system over time [28]. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviors functions of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time. Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training, education, and video games. Often, computer experiments are used to study simulation models. Simulation is also used with scientific modeling of natural systems or human systems to gain insight into their functioning [29].

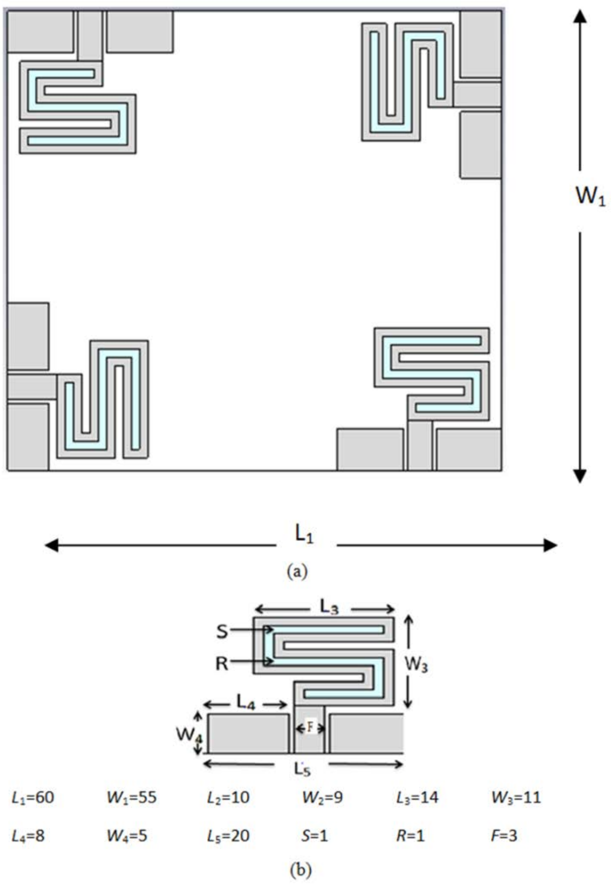

Figure 2. (a) Photo of prototype of simulated 4-element MIMO antenna system, (b) photo of one of the four symmetric antenna elements

The recommended 4-element MIMO antenna structure is designed as shown in Figure 2 (a) and (b). Four symmetrical meander line MIMO antenna elements have been used for designing the structure from aluminum foil over glass substrate. The MIMO antenna system design is not complete area transparent where the miniature meander foil line is an opaque material. The produced design is partially shaded glass, small area shaded and the remains has 100% transparency factor which is higher transparency than the AgHt-4 and AgHt-8 materials.

Making a monopole resonant frequency and matching it to the required feature impedance can be achieved by shaping the short monopole in inverted-L shape as mentioned in Paper [30]. Meandered antenna represents a developing configuration or modification of the inverted L-antenna. Meandering the horizontal part of the inverted L-wire antenna in any geometric configuration tunes the monopole antenna's capacitive reactance (or the total feeding point reactance is equal to zero) [31]. The purpose of initiating the technique of Slot Meander Patch (SMP) antenna, as a new design, is to decrease the size of the current available wire antennas like log-periodic dipole arrays antennas and Yagi-Uda. The proposed SMP antenna as stated in [32] was verified by altering the design's main variables such as the number of sections per wavelength (N) and antenna reduction ratio β (where β=l/L, l is the decreased length after meandering and L is overall length of the wire) [32].

The dielectric constant of an aluminum layer averages between 7 and 8 [33]. The overall length of each meander line of the 4 elements is optimized to 18 mm which is equivalent to 0.39 λ at 6.5 GHz. The antenna is designed to operate as multiband antenna at resonant frequency of 6.5 kHz by optimizing the meander line length.

The glass substrate has dimensions of 60 mm×55 mm, with thickness H=5 mm, and permittivity ε_r=7. A good impedance matching can be achieved by optimizing the antenna's overall length.

MIMO technique is considered as a solution to improve the low data transmission rates and channel bandwidth (BW). Moreover, it also addresses the problems of multipath fading. The proposed design suggests more than one antenna elements in transmitter and receiver terminals to improve the channel capacity in a high multipath environment [34]. Printed antennas with Co-planer Wave Guide CPW feeds have attracted a serious attention over the years. Compared with other printed radiating elements, CPW-fed antennas do not only possess a broad BW, but also a smaller mutual coupling between adjacent lines. Another advantage is the ease of integration with solid-state active devices [35,36,37,38,39]. Therefore CPW-fed antennas are promising candidates as elements for MIMO applications so it is useful to separate the 4 MIMO antenna system. Furthermore, positioning MIMO antenna elements orthogonally have no effects on the antenna size. These techniques could be used in designing a compacted MIMO system that has limited size element and high isolation.

Figure 3. (a) 4-element MIMO antenna system on a glass window

2.1. Fabrication

The proposed MIMO antenna structure is fabricated manually as shown in Figure 3. Four symmetrical miniature meander MIMO antenna elements have been used for designing the structure. The antenna is designed to operate at a resonant frequency of 6.5 GHz by optimizing the meander section to 0.39λ. The MIMO antenna system designed from Aluminum foil over transparent glass substrate. This design makes its transparent partially as it is a radiated element. The glass substrate has dimensions of 60 mm × 55 mm, with thickness H=5 mm, and the Aluminum foil permittivity is ε_r=7 [40].

3. Results and Discussion

The proposed design covers the X-band as verified by the simulated and measured results below. The main motivation and benefits of this prototype is building the unit can be used in cladding the glass building.

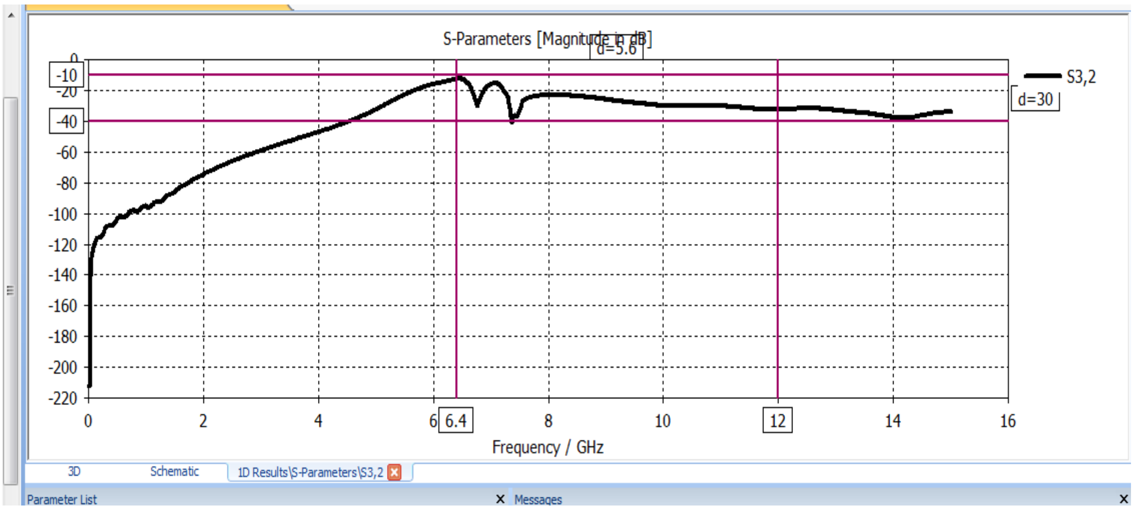

Figure 4. Simulated S-parameters for the optimized structure of the transparent 4-element XBand MIMO antenna

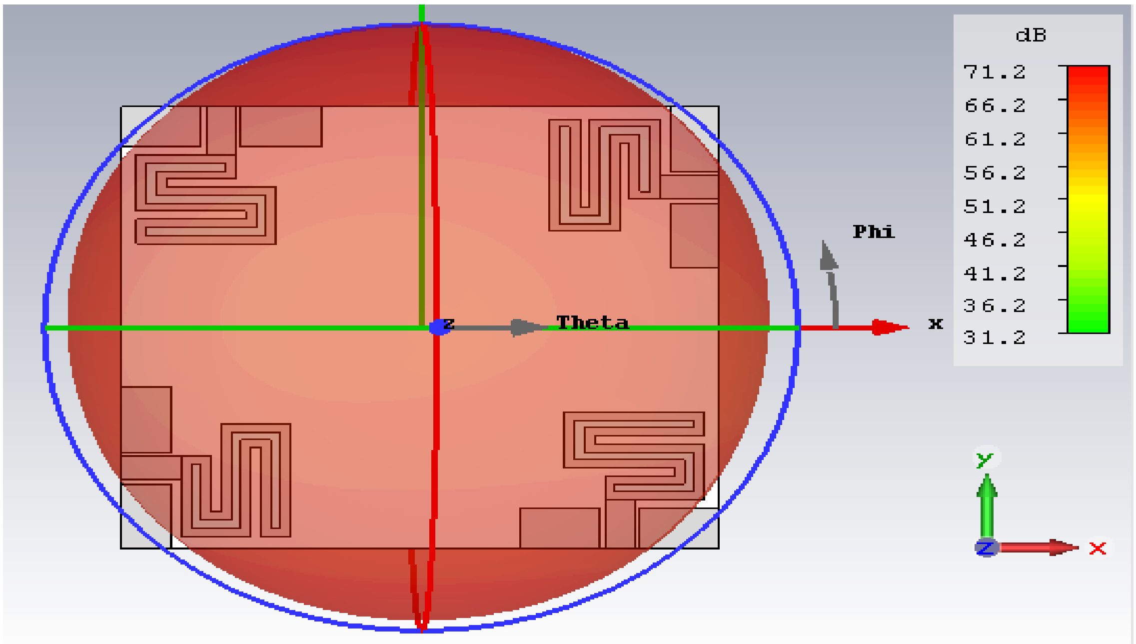

Figure 5. Simulated 3D radiation patterns of the transparent 4-element XBand MIMO antenna

3.1. Simulation Results

The CST simulator was used for measuring the simulated antenna's S-parameters and the radiated power as shown in Figure 4 and Figure 5. Figure 4 shows that the antenna covered the XBand (frequency range to 6.4 GHz to 12 GHz), and Figure 5 shows that the antenna radiating high power about 71 dB.

3.2. Measured Results

The model is miniature size this makes the manual fabrication so difficult and no way to make the slots over the meander shape as result the measured BW a little bit narrower than the simulated (Figure 6) results as mentioned in [32].

The R&S® PR100 used in measuring the matched BW is a portable receiver for radio monitoring in the wide frequency range from 9 kHz to 7.5 GHz. Whether used for monitoring emissions, detecting interference, or locating miniature transmitters, the receiver offers features unrivaled in its class. Together with the R&S® HE300 portable directional antenna, it forms a compact receiving system. The R&S® PR100 is notable for its wide frequency range, excellent receive characteristics, real time bandwidth of 10 MHz, and large 6” color display.

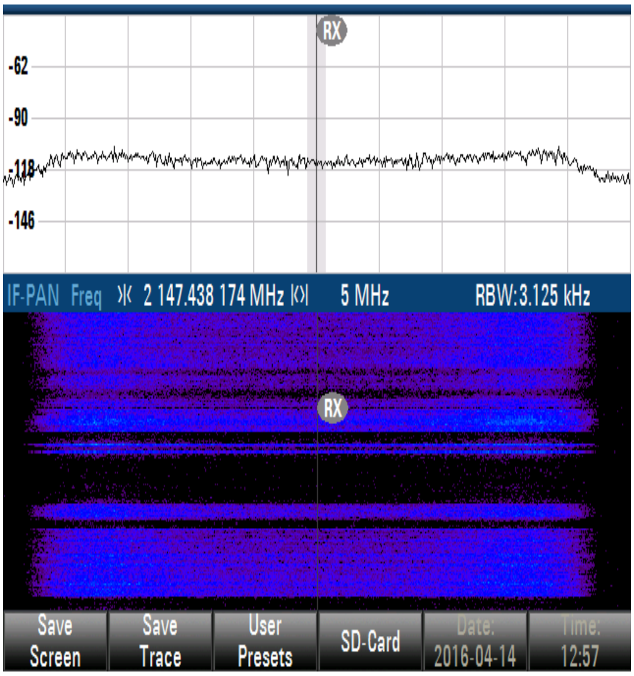

Figure 6. measured S-parameters for the optimized structure of the transparent 4-element XBand MIMO antenna

4. Conclusion

In this paper 4-element MIMO antenna system was simulated, fabricated, and measured. The results shows accepted characteristics despite the new materials (glass and foil) used. The measured BW is a little bit narrower than the simulated this because no way to make manually the slots over the miniature meander shape.

Acknowledgments

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