Beamforming Radiation Properties of Absorbing/Transparent Zones-Added Horn Antenna

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Highlights

• Nanoparticles are synthesized by a citric-acid assisted sol-gel method.
• Concentric zones are fabricated with MSF NPs that are blended with MWCNTs.
• Beamforming properties are obtained by scattering parameters.
• Results indicated that suppressed side lobes are generated using an absorber layer.

Abstract

In this study, we present beamforming of radiation patterns on a transmitter horn antenna by mounting an electromagnetic wave absorber, in which electromagnetic wave absorber is fabricated as concentric zones. The concentric zones consist of an absorbing material of manganese soft spinel ferrite blended with multi-walled carbon nanotubes with the thickness of 1 mm installed on the aperture of the antenna working in Ku-band. We have experimentally measured scattering parameter of transmission, S_{21}, using a vector network analyser to perform radiation patterns in polar coordinates. As compared to the radiation properties of air horn antenna and absorbing/transparent zone-added horn antenna produces an appreciable effect to concentrate radiation beam in the main, side and back lobes with reducing side and back lobe levels for each frequency in H-plane. For the radiation pattern in E-plane, we have observed the suppressed side lobes at three frequencies of 15 GHz, 17 GHz and 18 GHz. The results indicate that the absorbing/transparent zone keeps an important role for further development of the applications of directional antennas so that the effective radiation is to be significantly concentrated.

1. INTRODUCTION

There has been a long-standing attention in the research of absorbing materials and propagation in mediums for many applications. Magnetite nanocrystals on multi-walled carbon nanotubes (MWCNTs) as a synergistic microwave absorber have been studied in [1]. Coated magnetic nanoparticles polyacrylonitrile textiles as a microwave absorber have been studied in [2]. In the relation to [1], A. Teber et al. have studied on knitted radar absorbing materials coated with nickel-cobalt magnetic materials [3]. He and his colleagues on their own research papers also have synthesized soft-skin radar absorbing materials for morphing applications [4-6]. Besides that, they have investigated propagation of microwaves in periodic layered media [7], in which different type of absorption measurements as a coaxial line technique have been used [8]. As seen from the research papers above, microwave absorbers are widely used in various defense and aerospace applications. Nevertheless, there exist rare applications of absorbing materials by scientists in the technology of antennas such as Fresnel Zone Plates (FZPs) antennas and their lenses [9-11]. In general, FZPs are frequency dependent with narrow band. In this study, we performed a structure using the principles of FZPs to observe how half-power beam widths change in the GHz region.

In antenna technologies, many claims about directivity of antennas radar, direction-finding equipment, indoor applications are for improving their side lobe performances [12]. Absorbing materials in the field of antennas are relatively new to concentrate the desired radiation without reducing distortion and bending with narrower beam-width. In this study, absorbing materials are arranged in concentric annular zones on

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a transparent tape, which is inspired by FZPs. Therefore, absorbing materials are such that a structure can be used to exhibit properties of radiation as a flat surface lens.

Here, we present an experimental study of a structure including only absorbing material designed to reduce/control the main, side and back lobes while increasing the radiation characteristics of a transmitter (Tx) horn antenna in Ku-band. As in FZPs, the structure is fabricated as a structure consisting of concentric annular zones whose radii are calculated for F=0. This study is structured as follows: In the design of absorbing/transparent zone section, we discuss the design conditions under geometrical limitations based on the principles of FZPs. Based on such the description, concentric zones are molded as toroid-shaped pellets with 1 mm thickness on a transparent tape. In the section of materials and preparation of electromagnetic wave absorbers (EMWAs), we describe how manganese soft spinel ferrites blended with MWCNTs as a soft-skin electromagnetic wave absorber which is synthesized and fabricated. The section of experimental setup is introduced by using antenna parameters in the region of far-field. Then, the radiation effects of mounting the absorbing zones on the horn antenna are reported in results and discussions section. The absorbing zones-added horn antenna produces an appreciable effect to concentrate radiation beam in the main, side and back lobes with reducing side and back lobe levels for each frequency in H-plane. For the radiation pattern in E-plane, we observe the suppressed side lobes at three frequencies of 15 GHz, 17 GHz and 18 GHz. Conclusion section summarizes this study that describes measureable features of the side lobe reduction once EMWA is used.

2. DESIGN OF THE EXPERIMENT

2.1. Design of Absorbing/Transparent Zone

The applications of FZPs in millimeter/centimeter wave regions were uncommon in the past researches because of comparatively their relative low gain with the application of parabolic reflector antennas [13, 14]. Engineers have been implementing different type of FZPs to deal with that problem by installing structures on an antenna. The concentrating effect is produced by the diffraction or the second radiation on the open and solid zone surfaces. Absorbing/transparent zones can be envisaged by using the essential principles of FZPs for achieving beamforming response. Therefore, the geometrical parameters of a design of zones should be suitably selected. The zones in this study are fabricated as a set of concentric annular strips of EMWA layer. The zones are then arranged on a flat surface of a transparent tape. The absorption of incoming wave will only result from the absorber material because of a transparent feature of the tape against to the electromagnetic wave. A geometrical configuration is illustrated in Figure 1.
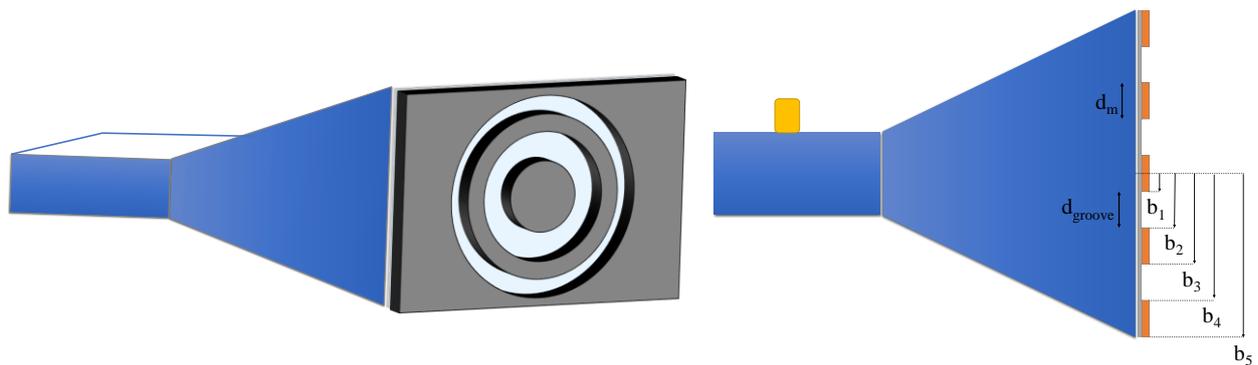
Figure 1. *The illustration of the absorbing layer on a transparent tape mounted the horn antenna*

The design parameters of zones including radius, the zone width, and the zone groove depth for n values are listed in Table 1. The design parameters are determined with the nth radii, b_n, given by [11];

$$b_n = \sqrt{2n\lambda/P \ (F + n\lambda/2P)} \tag{1}$$

where F, the focal length of the zone plates and λ is the wavelength (λ=1.66 cm). Since there is no any gap between antenna aperture and the FZP zones, F value equals to zero. According to the geometrical configuration of the Fresnel antenna [11], focal distance is assumed to be zero. In this aspect, the structure performed is not defined as a FZP. Because the FZP lens in this study is attached to the feed (transmitter (Tx) horn antenna) without any distance. Thus, the successive radii are calculated by using the Equation (1) whereas F is zero as a lower limit for the differences between successive radii λ/P (F=0). The design wavelength is chosen at the highest frequency of the horn antenna. According to the distance from a selected focal point, the consecutive radii of these zones are chosen on the central axis increase by a value of λ/P from the inner to the outer radius of any zone. There exists a lower boundary limit for the difference between two consecutive radii: dgroove=λ/P in [11]. P equals two for the FZPA absorbing / transparent (a/t) zones [15] . It means that if a plane wave normally reaches to the zone plate, the portions of the radiation penetrate the various transparent regions. All reach the focal point with related phases by diffraction that differ less than 180 degrees. In this study, the odd-numbered zones are covered with the absorbing material. The difference between our work and [11] is that we have not consider the influence on the radiation pattern of Fresnel zones of which the width of zones ($d_m = (b_{n+1}-b_n)/2$) is in the order of a few wavelength or even smaller. It is worth noting that Equation (1) applies for the case when the transmission by FZPs concentrates power of the incident wave from on one side to focus on the other side. The design parameters are calculated by using Equation (1) in Table 1.

**Table 1.** *Design parameters of absorbing/transparent zones*

n	2n	b_n	d_{groove}	d_m
1	2	0.83	0.83	0.415
2	4	1.66	0.83	0.415
3	6	2.49	0.83	0.415
4	8	3.32	0.83	0.435
5	10	4.29	0.97	0,970

2.2. Materials and Preparation of Absorbing Material

The EMWA resulting from manganese soft/spinel ferrite nanoparticles (MSF NPs) with MWCNTs were used in this study. The absorbing NPs have been synthesized by a citric acid assisted sol-gel method whereas MWCNTs are purchased from US Research Nanomaterials, Inc., USA. The crystal structure, morphology, magnetic properties and the behavior of microwave absorption characteristics have been extensively discussed in [8]. According to the zone sizes, the absorber zones have been created with 1 mm thickness using the fabrication tools [8]. The designed absorbing layer is mounted to the horn antenna as shown in Figure 1.

2.3. Experimental Setup

The radiation pattern reveals the strength of radiation for a horn antenna as a function of both frequency and direction. Throughout this paper, patterns are separately plotted for θ and φ angles [16]. The experimental setup of radiation pattern measurements are demonstrated in Figure 2.
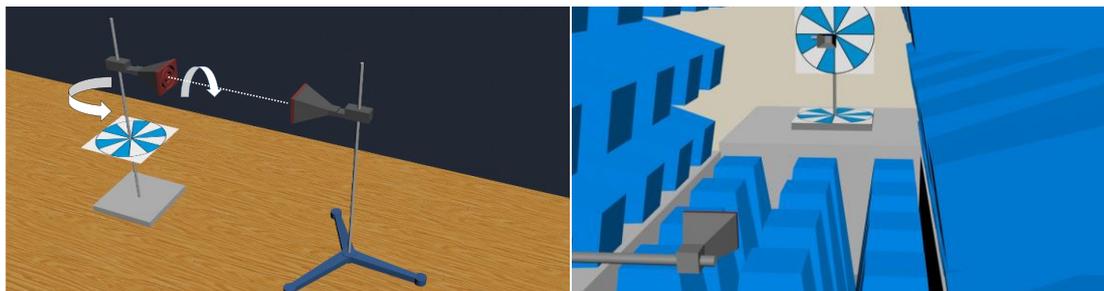
Figure 2. *The illustration of an experimental setup of radiation field using pyramidal absorbers*

All directivity measurements were carried out with the quasi-anechoic environment setup that is covered by pyramidal absorbers to reduce reflections from the walls, except on top of the measurement platform. The transmitter and the receiving antennas are set up about an appropriate distance (approximately 1 meter). A receiving antenna is taken into consideration to be in the far-field of the device under test (DUT), transmitter antenna. The distance with the transmitter and the receiving antennas is formulated on the condition of far-field region:

$$R = 2D^2/\lambda \tag{2}$$

where R shows the distance a transmitting antenna from the receiving antenna, D (3.32cm x 4.29cm of inside dimensions of the horn antenna of WR62-15 dB) is the largest dimension of the receiver and transmitter horn antenna [13], and λ is the wavelength in cm. The antenna is located for maximum meter reading and marking this position of the receiver antenna as 0 degree. The distance between the antennas is kept constant and sufficiently large. Receiving horn antenna is rotated clockwise continuously in steps of 2 degrees, to cover 360 degrees including the main, side and back lobes. At each position, we have taken care of keeping the initial setup of the calibrated vector network analyzer (VNA) to restore the 2 degrees' scale deflection. Then we have returned to the position 0 degree and repeated for in steps of 2-degree scale deflection on clockwise until completion of the 180 degree. In order to obtain the entire radiation pattern for E-plane on x-z plane, we have taken the symmetry all acquired data, which is field strength versus angle in the polar coordinate platform. The same procedure with E-Plane has been repeated for y-z plane to demonstrate data of H-plane pattern. We finally plot the radiation pattern in the above manner for both E- and H-plane after providing the acquired data for H-Plane.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. E- and H-Plane Beam-widths

An experimental study of the beamforming in the far-field region have been performed on the horn antenna (unloaded) and the horn antenna with absorbing layer in the frequency range of Ku-band when the absorbing layer is attached to the transmitter horn antenna. The azimuth and the elevation half-power beam-width angles (in degrees) in E- and H-plane, respectively are listed in Table 2.

Table 2. *E-plane and H-plane beam-widths angles (in degree)*

	E-Plane		H-Plane	
Frequency (GHz)	Transmitter (Tx) Antenna	Transmitter (Tx) Antenna with EMWA Layer	Transmitter (Tx) Antenna	Transmitter (Tx) Antenna with EMWA Layer
12.4	30.48	33.36	34.80	27.60
13	26.14	31.92	34.80	26.14
14	27.36	27.58	30.48	23.26
15	21.82	30.48	30.48	23.26
16	18.94	27.58	30.48	21.82
17	23.26	24.70	26.14	21.82
18	24.70	17.50	18.94	13.18

In E-Plane, the beam-width of the horn antenna with the absorbing layer has the same values (34.80 degree) at the frequency of 12.4 and 13 GHz and (30.48 degree) at the frequencies through 14 GHz-16 GHz. In addition, the radiation patterns with the scenario of a far-field region on the horn antenna (unloaded) and the horn antenna with the absorbing material at the frequency of Ku-band are plotted in Figures 3 and 4.
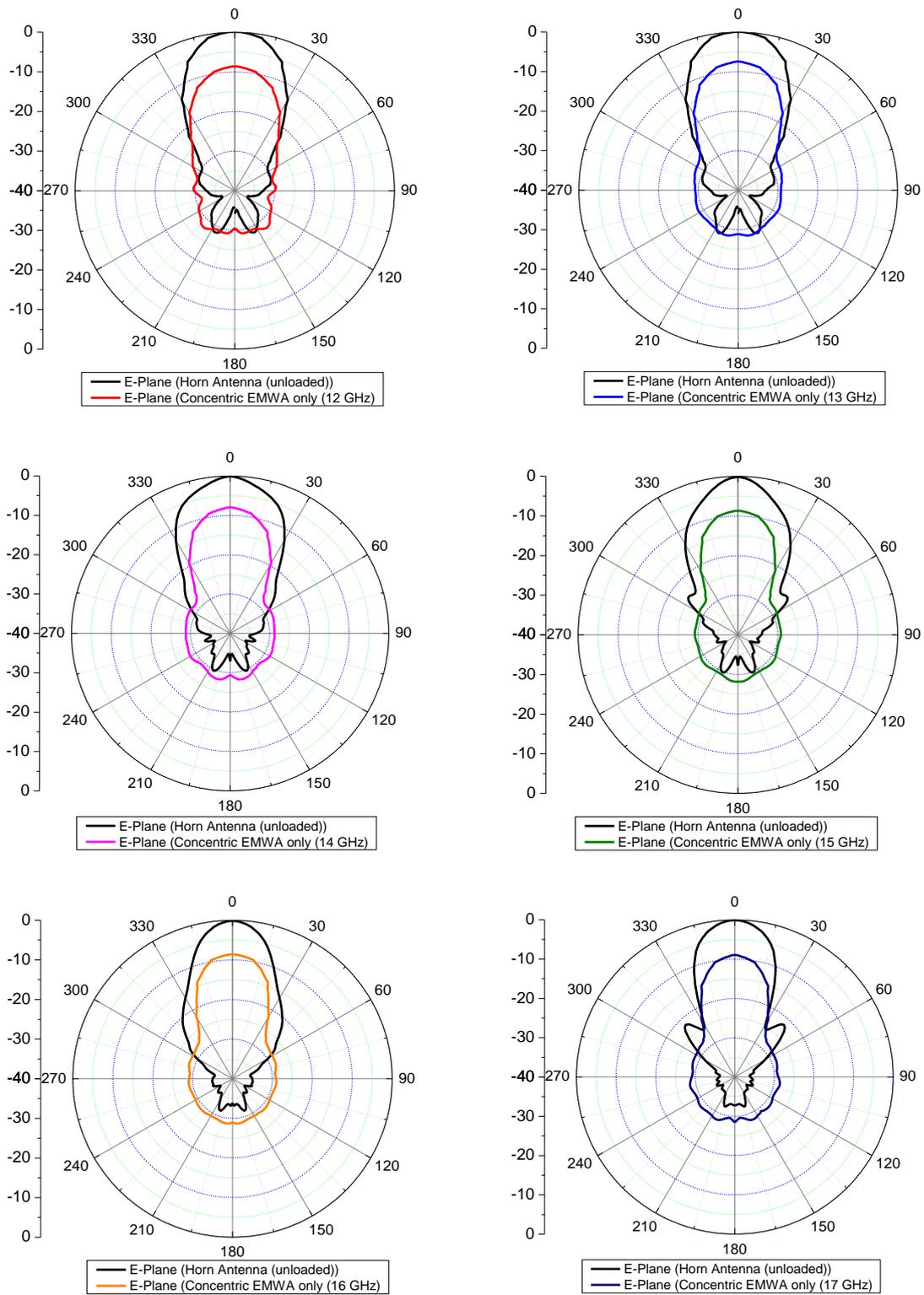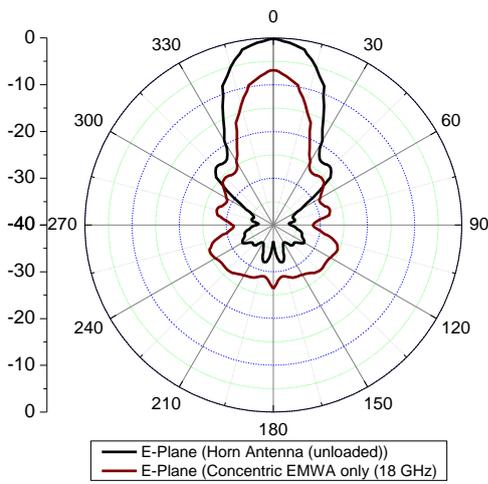
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Figure 3. *The comparison of the radiation patterns in E-plane including transmitter (Tx) antenna (unloaded), the transmitter (Tx) antenna with EMWA Layer.*
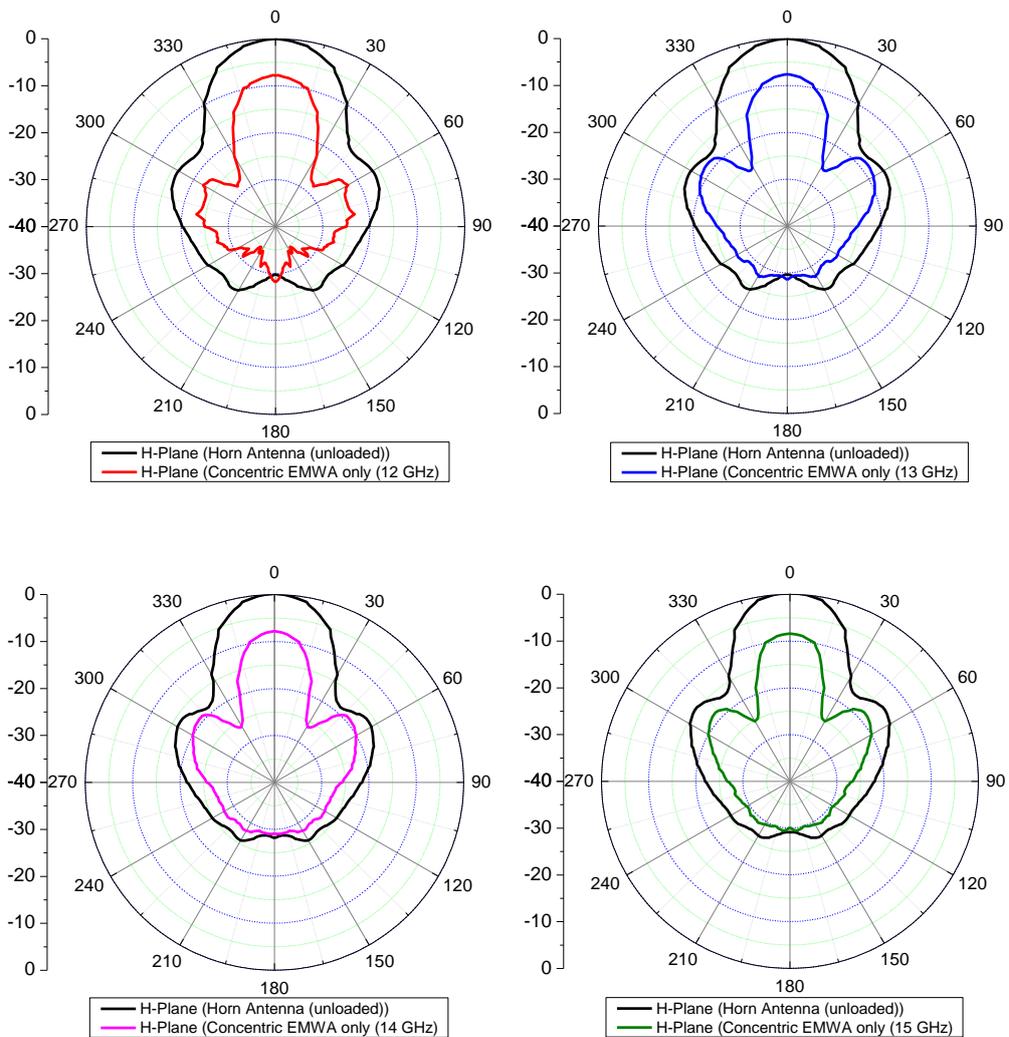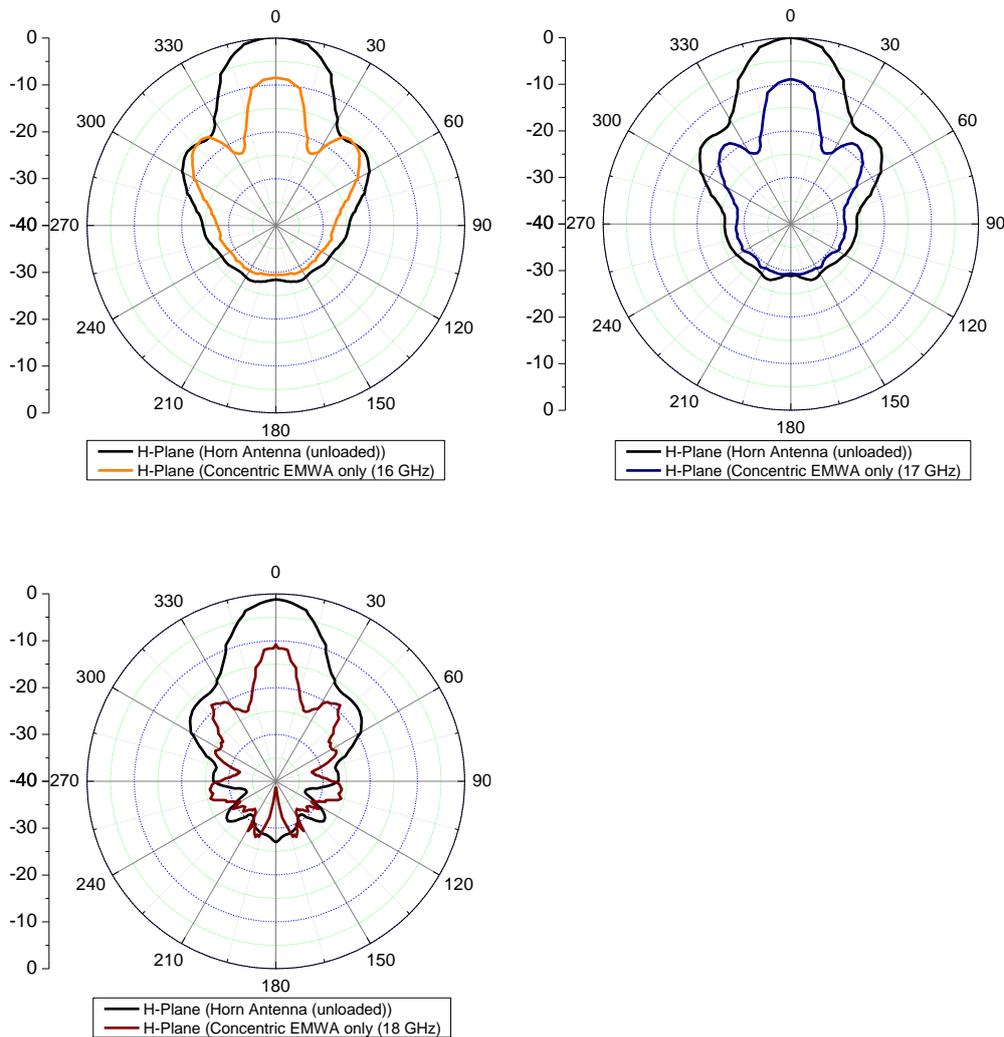

Figure 4 is continued from here

Figure 4. *The comparison of the radiation patterns in H-plane including transmitter (Tx) antenna (unloaded), the transmitter (Tx) antenna with EMWA Layer*

According to the angles of two orthogonal planes, the elevation angles of a horn antenna with the absorbing layer are obtained less than the transmitter (Tx) horn antenna (unloaded) in H-plane that means the suppressed side and back lobes are obtained. It has apparently lower side-lobes compared with the horn antenna (unloaded) in the H-plane, demonstrating that an absorbing material can effectively be used to reduction of side lobes and concentrating the main lobe in the forward direction.

4. CONCLUSION

In this study, we have investigated how the manganese soft spinel ferrites with multi-walled carbon nanotubes as an electromagnetic wave absorber from our published article that affects the radiation patterns in Ku-band. For the radiation pattern in E-plane, we have observed the suppressed side lobes at three frequencies of 15 GHz, 17 GHz and 18 GHz. Therefore, the study suggests that absorbing material as thin layer can play a role on beamforming while controlling side and back lobes in Ku-band.

CONFLICTS OF INTEREST

No conflict of interest was declared by the author.

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