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Design and Simulation of Wide band Horn Antenna for NDT System

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Index Terms

Horn antenna, Nondestructive testing system, finite element technique, CST.

Abstract

This paper presents the utilization of a wideband horn antenna to work in the nondestructive testing system (NDT) operation frequencies. Which used as detection of cracks in different materials, and materials properties. The proposed structure based on a horn antenna works at frequencies of 4.5GHz until 6GHz. The proposed structure designed using microwave equations and simulated using CST (computer simulator technology) using finite element technique. Two samples, one without defect and the other with a defect 10%, 20% and 30%, will investigate for comparing the microwave characteristics of the antenna. The results show that a horn antenna can used to detect the material properties by observing the reflection coefficients and electrical field distribution inside the material.

تصميم ومحاكاة هوائي بوقي واسع النطاق لتطبيقات الفحص غير الائتلافي

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الكلمات المفتاحية

الهوائي البوقي، أنظمة الاختبار الغير ائتلافي، تقنية العناصر المحدودة، برنامج محاكاة CST.

الملخص

تقدم هذه الورقة البحثية تصميم ودراسة حول استخدام الهوائي البوقي عريض النطاق للعمل ضمن ترددات تشغيل أنظمة الاختبارات الغير ائتلافية. والتي تستخدم في الكشف عن الشوائب في المواد الهندسية المختلفة. تعتمد الورقة على الهوائي البوقي يشتغل في نطاق ترددي يمتد من 4.5 الى 6 جيجاهرتز. تم انجاز التصميم باستخدام معادلات الكهرومغناطيسية واستخدام برنامج التصميم CST عبر تقنية العناصر المحدودة (Finite Element Technique). لتقييم ومقارنة خصائص الكهرومغناطيسية للمواد تحت الدراسة، جرت دراسة عينتين أحدهما سليمة والأخرى بها شوائب 10%و 20% و30%. النتائج أظهرت تغير معامل الانعكاس S_{11} باختلاف الشوائب وبالتالي نستنج انه باستخدام هذا النوع من الهوائيات يمكن استخدامه للكشف عن الشوائب في المواد الهندسية.

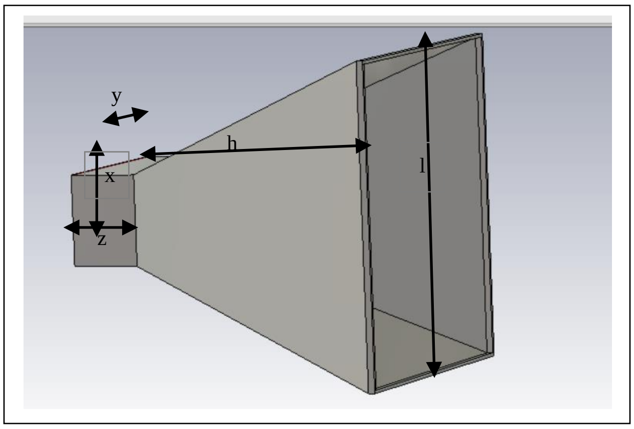
I. Introduction

The domain of evaluation and nondestructive testing has been developing and its applications fields are varied for several years. Antennas are the basic element of these structures, which has different properties based on each application. Those characteristics are defined using parameters such as efficiency, gain, radiation patter. With the increase in bandwidth, the amount of information needed to design an antenna becomes very important. Solutions are being studied to compact this information, including the use of resonance poles [1]. The microwave horn antenna is widely used for many microwave applications as wireless communications, electromagnetic sensing, radio frequency heating, biomedicine and recently evaluation and nondestructive testing, where reasonable levels of directivity needed. There are several types including, the pyramid horn antenna, conical horn and the corrugated horn antenna [2], Pyramidal horn antenna is one of the most important parts of a transmission chain, it widely uses in various applications in the Microwave range [3],due to their advantages: high gain, moderate bandwidth and low voltage standing wave ratio VSWR [4]. In recent research, different approaches are used for NDT applications, they include focusing lens such as capacitively loaded metallic rings (CLRs), that employed between the antenna and the subject to be tested, which have received a lot of attention because of its ability to create a higher gain compared with the conventional antenna without material ring. The study in [5] found that the ultrasonic NDT could achieved by using wireless sensor. In [6] the researcher used a horn antenna to test the dielectric defects by comparing the reflection parameters S_{11}. The results show that observing changings of the antenna operation frequency, the defects in material could be detected. This was the same principle as the acoustic horn. The horn serves as adevice of adaptation between the impedance of the horn and that of the vacuum front of material to be tested. In a very natural way, the radiation takes place in the axis of the waveguide then transport to material. The waveguide method used for DNT applications; however, a horn antenna is widely used because of its low losses caused by the propagation in the material, even at high frequencies and, its ability to withstand the power. In the literature, the first concept of the horn antenna was proposed by the Indian Radio Researcher, Sir Jagadish Chandra Bose in 1897, his novel work in his pioneering experiments with microwave frequency [8]. In this paper the performance investigation is achieved by four features, which are directivity, return loss, gain and bandwidth. The NDT system at 4GHz to 6 GHz is considered in this paper. The performance analysis of the horn antenna using the Roger 3880 as a dielectric substrate is assumed in this paper to enhance overall efficiency of the antenna. Because this material is most commonly used in fabrication of the antenna. The purpose of this study was to investigate the potential benefits of the use of designing and simulation of a horn antenna at 4-6 GHz for NDT system. This paper demonstrates, through numerical simulations, (CST-MW-2022) and two scenarios were investigated, pure iron, and iron with defects.

II. HORN ANTENNA CONCEPTS AND DESIGN

1. THE ANTENNA CONCEPS

Fig.1 illustrates the proposed horn antenna which consists of a rectangular waveguide at one end and flared at the opposite end forming a Horn shape. The waveguide needed a coaxial feeding to get the excitation and the forward waves radiates from the open aperture of the Horn antenna. The radiated wave forms a very narrow beam and the antenna was high directivity and gain[3].



The antenna dimensions can be designed using equations (1), and (2) [3].

$$w = \sqrt{2\lambda h} \quad (1)$$

$$l = \sqrt{3\lambda h} \quad (2)$$

Table1. shows the calculated dimensions to achieve the required operating frequencies and bandwidth.

Table1. Calculated dimensions in (mm)

F_o(GHz)	x	y	z	h	L	w
4.7 -6	20	28	60	100	100	90

2. THE ANTENNA PROPERTIES

The performance of the patch antenna can be characterized by these essential parameters which are: a directivity, gain, bandwidth, and return loss. Directivity can be outlined as the ratio of the power intensity in a given direction from the antenna to the power intensity averaged from all directions. The directivity can be expressed as (3) [7].

$$D = \frac{U_{max}}{U_0} \quad (3)$$

where U_{max} is the maximum radiation intensity (W/unit solid angle) and U_0 is a radiation intensity of the or an isotropic source (W/unit solid angle). The antenna gain is similar to directivity however it measures considers the efficiency of the antenna and also the directional capabilities. The gain can be calculated by (4) [8].

$$Gain = \frac{power\ intensity}{total\ accepted\ power} \quad (4)$$

The horn antenna bandwidth is the range of frequencies within the performance of the antenna, with respect to some characteristics. For the wideband antenna, the bandwidth is expressed as a percentage of the frequency difference over the centre frequency for bandwidth. The bandwidth of the antenna can be determined by (5) [7].

$$Bandwidth = \frac{HF_c - LF_c}{F_0} \quad (5)$$

where HF_c, $LF_c$are the higher cut-off and lower cut-off frequencies respectively. F_0 is an operation frequency of the antenna and this frequency is considered to be 4 to 6GHz in this paper. The reflection coefficient or return loss can be defined by (6) [8].

$$\Gamma = \frac{Z_{in} - Z_o}{Z_{in} + Z_o} \quad (6)$$

where Z_{in} and Z_o are the input antenna impedance and characteristic impedance, respectively, which depends on the substrate.

3. APPLICATION TO THE NDT SYSTEM.

Fig.2 shows a schematic of NDT system, which uses for detection of defects in dielectric and metallic materials. The antenna is placed facing the material under test at a distance of 3mm. The dimensions of the material under test assumed to be 10cm^3. The distance between antenna and material under test assumed to be10cm for the horn antenna reason.

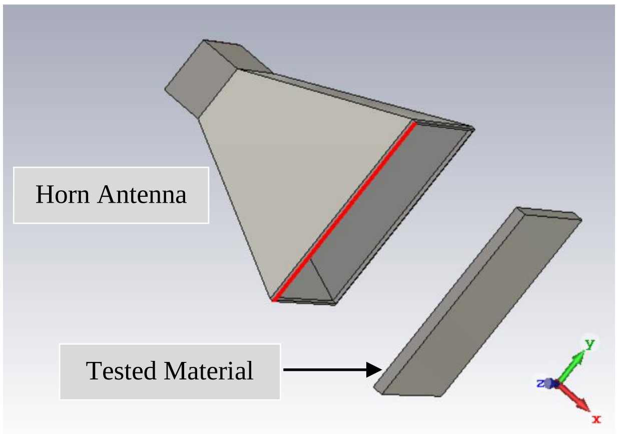


Figure 2. Full CST simulation model

4. Full field simulation results

A. Antenna Reflection Coefficient and Bandwidth of NDT

Fig.2 shows the full simulation model that has achieved by (CST-MW). The Far Field Directivity plot is shown in Fig.3 and Fig.4, where the result is satisfactory at NDT band frequencies. Fig.5 illustrates the magnitude of surface current through the thickness of the horn antenna in the 3D plane. It is clear that the absolute current of the horn antenna at near of exited port is larger than that with the side horn. The S_{11} results show in Fig6. That illustrates by increasing percentage of defects in materials (%) shifts the amplitude of the operation frequency by (Δ%) as shown in table2. The horn antenna can measure the defects in material by shifting the operation frequency. Such as when the percentage in defects was 10%, the amplitude of the operation frequency shifted by 20% dB.

Table2. Calculated dimensions in (mm)

Defects (%)	10	20	30	40
Shifting (Δ%) Amplitude (dB)	20	28	40	52

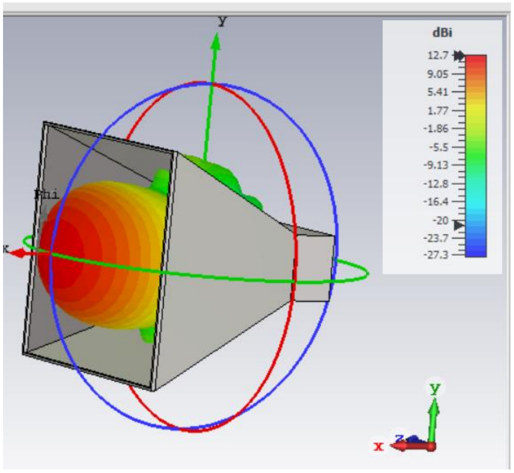


Figure 3. Far field beamforming at NDT operation frequency

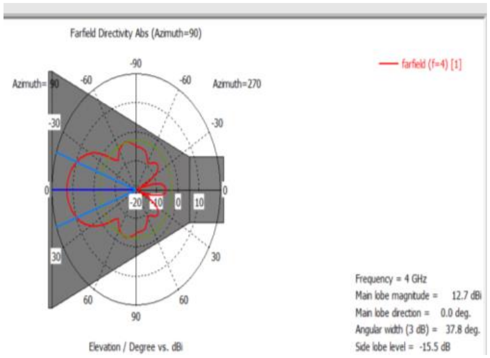


Figure 4. Two dimensions Fairfield directivity plot

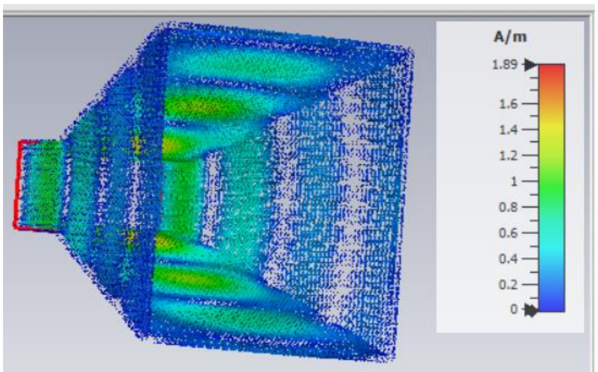
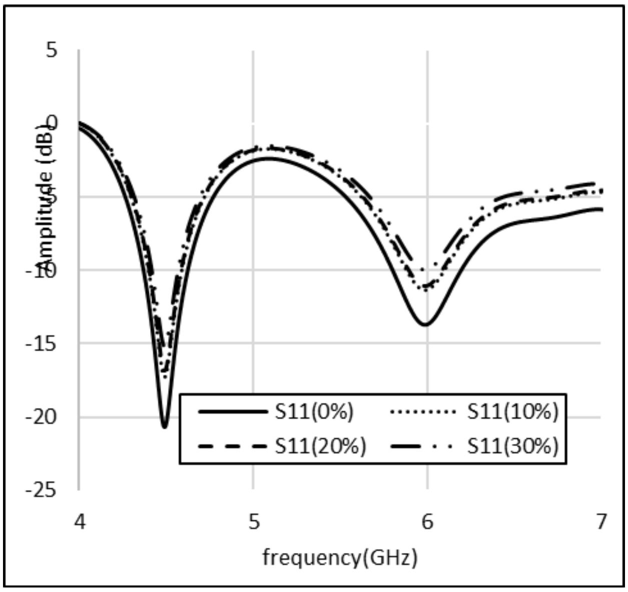


Figure 5. Absolut value of the surface current



5. Conclousions

This paper shows the potential for designing and the simulation results of horn antenna for routine NDT applications which operates at 4-6GHz. This paper has investigated the gain provided by horn antenna and the results demonstrate that our proposed method can work with NDT system. The proposed design the antenna shown good characteristics in terms of S_{11}, bandwidth, Radiation characteristics, Directivity. The antenna can sense the defects in material by shifting the amplitude of the operation frequency.

In further work we are investigating the horn antenna in future for the benefit of the communication networks.

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Biographies

Ismail Masoud Issa received the BSc. degree from University of Omer-Almukhtar, Libya in 2004, MSc degree from University of Technology Mara, Malaysia in 2011 and PhD degree from the University of Sheffield, UK in 2018, all in electrical and electronic engineering. His research interests include antenna design, metasurface and metamaterial structures and their applications in MRI systems. He works as a Lecturer in electrical and electronic engineering department, University of Misurata.