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Investigation of the Use of Amorphous Nanocrystalline Ribbons as EMI Shielding and Microstrip Patch Antenna

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Summary: Electromagnetic interference (EMI) refers to the magnetic interference generated by electronic devices on each other, which can affect the operation of these devices. Unwanted interference among devices operating within a system is undesirable. To prevent undesired interactions between devices, EMI shielding methods are used, including techniques like shielding and grounding.

When considering flexible antennas, the demand for high-speed communication has led to the necessity of downsizing communication devices. As devices become smaller, they face design limitations. Consequently, there is a need for components that can adapt to a system's design requirements or changes. Flexible antennas, which can accommodate the mechanical design constraints of smaller devices, address this need.

Within the scope of a project investigating two different areas, the first area involves examining the EMI shielding effectiveness of plates produced by attaching single and double layers of strips to an insulating plate. The study found that the shielding effectiveness at around 10 GHz was 17 dB.

In the second area, the project aimed to use the ISM frequency band in flexible antenna applications. Strips were produced using predetermined production methods for this purpose. Two types of antennas were manufactured using these strips and DiClad880 printed circuit boards. The S11 values of Cu antennas and amorphous nanocrystalline antennas were compared, with the amorphous nanocrystalline antenna exhibiting an S11 value of -30 dB at a frequency of 7 GHz.

I. INTRODUCTION

Various shielding materials and shielding methods are available for the purpose of preventing electromagnetic interference, such as aluminum strips, silver-aluminum-nickel particle gaskets with silicon or fluorosilicone elastomers, and nickel-plated aluminum cages. However, it is observed that conductivity is primarily achieved using aluminum, silver, and copper. Strips based on Co or Ni have advantages over commonly used metals in shielding, such as occupying 1/10th of the volume and providing 8 dB more shielding effectiveness than aluminum strips. [1]

Soft magnetic materials have low core loss. Core loss is the sum of losses caused by hysteresis and eddy currents. Materials with low core loss and high magnetic carrying capacity provide solutions to energy problems. Fe has low core loss. Si has a high saturation value, making it capable of carrying high currents. [8]

Soft magnetic materials have high magnetic permeability and low coercivity (magnetization). This means they quickly magnetize and demagnetize when exposed to an external magnetic field. Additionally, when hysteresis curves are examined, their high permanent magnetization and low remanence properties assist in easily detecting varying magnetic fields at various frequencies. They have relative permeabilities of approximately 10^{4-5}. When examined for shielding effectiveness, they can be used as a good filler material. [6]

II. EXPERIMENTAL METHODS

A. Cu Antenna CST Simulation Result

According to the simulation results, the S11 value obtained is shown in Figure 1. In accordance with the design, a value of -17.758 dB was achieved at a frequency of 2.432 GHz. This value corresponds to the point where the power transmitted at 2.4 GHz is at its maximum, and the reflection is at its minimum.

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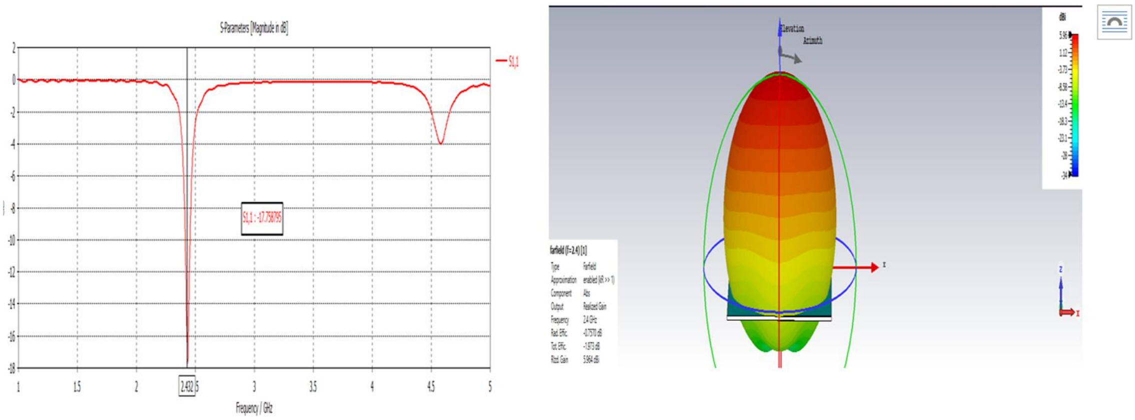

Figure 1 Cu Antenna CST Simulation

The simulation results for the Cu antenna show that the antenna gain and beam pattern are similar to Figure 1. According to the CST simulation, the antenna gain value is 5.964 dBi.

B. CoFeSiB Antenna CST Simulation Result

To design the antenna with CoFeSiB strips, it was necessary to define material properties in CST. The required electrical conductivity value for the CST design of the patch made with CoFeSiB strips was set to $9.75 \times 10^5 \frac{\Omega}{m}$. Another parameter essential for the design, the magnetic permeability (µ) of the strips, was defined as 1600. The design was carried out with the dimensions being the same for both antennas. Figure 2 provides the S11 graph from the simulation results of the antenna constructed from CoFeSiB strips. The S11 value obtained from the simulation is 2.408 dB, corresponding to -14.426 dB. At the same frequency (2.4 GHz), the power transmitted is lower, and the reflected power is higher compared to copper.
However, the gain value for the CoFeSiB antenna presented in Figure 2 is more advantageous compared to the copper antenna. The gain value obtained from the simulation is 6.141 dBi. This suggests that the CoFeSiB antenna has a higher directional characteristic compared to the copper antenna.

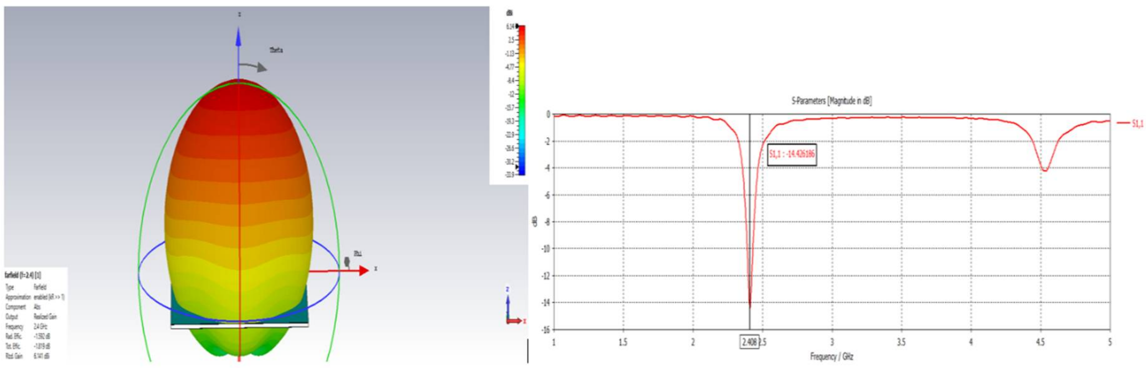

Figure 2 Cu Antenna CST Simulation

C. Production

The antennas were etched on a base material of DiClad880 using the "LPKF Protomat S104" device. A two-layer (copper-dielectric) structure was obtained by etching the base material in a square shape with one side measuring 10 cm. RO4000, a dielectric compatible adhesive, was cut to suitable dimensions and placed on top of this two-layer structure (copper-dielectric) (Figure 3-e). Strips cut to the dimensions of the antenna were arranged on top of the adhesive (Figure 3-b). The four-layer structure (copper-dielectric-adhesive-strips) was heated to 290°C to melt the adhesive and then pressed together.

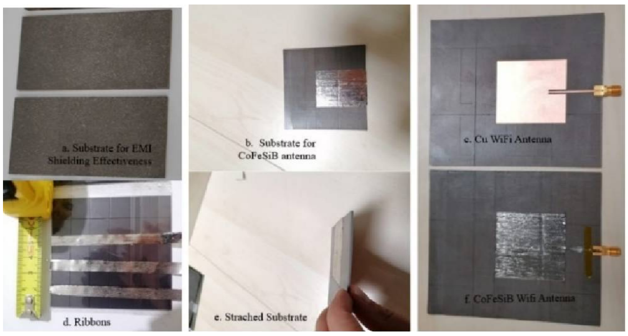

Figure 3 Steps of Production

The obtained plate design was cut to fit the dimensions using a craft knife and a micro cutter (Figure 3-f). To verify the presence of electrical conduction on the CoFeSiB strips that make up the patch, a short-circuit test was conducted at various points using a multimeter.

D. Test Results

The completed antennas were tested using the "Agilent Technologies-ENA Series-E5071C-300kHz-20GHz Network Analyzer" (Figure 4-c). Prior to testing, Agilent and Keysight brand calibration kits were used to calibrate the device and account for any losses or noise (Figure 4-a). The antenna was connected to the VNA (Vector Network Analyzer) (Figure 4-b, d). The frequency was set to a range of 1-8 GHz, and the calibration power, or power from the VNA, was adjusted to -5 dB. It was observed that there was a gap between the feedline and the dielectric, so Kapton tape was used to ensure that the line adhered completely to the dielectric to prevent any losses (Figure 4-b).

Figure 4 Steps of Test

The test result for the copper antenna shows an S11 value of -14.820 dB at 2.45 GHz (Figure 5-a). At the resonance frequency of 2.4 GHz, it is observed that the reflected power is minimized, and the transmitted power is maximized. This point is also referred to as the point where the antenna impedance matches the load impedance most closely. Based on this result, it can be concluded that the copper antenna radiates at 2.4 GHz.

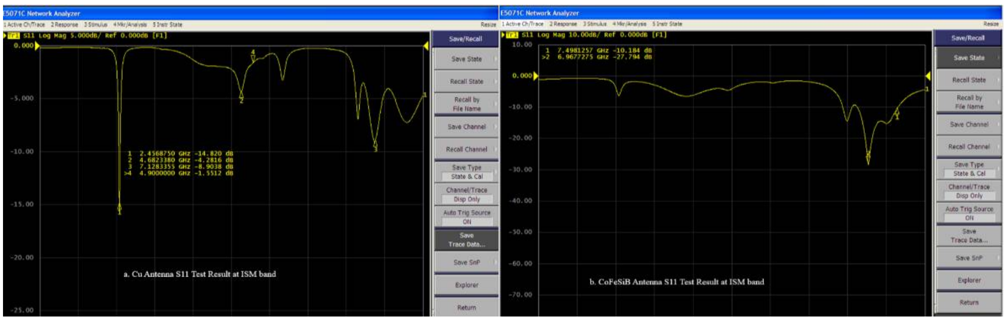

Figure 5 Antennas Test Results at ISM Band

According to the test results for the CoFeSiB antenna, a result of -5.82 dB was obtained at 2.4 GHz, but at 6.96 GHz, a result of -27.794 dB was obtained. Based on these results, the antenna exhibits radiation properties at its second resonance point, which is at 6.96 GHz (Figure 5-b). At this point, there is an improvement in impedance matching, and a significant portion of the power transmitted from the source to the antenna does not return. The reflection phenomenon is minimized at this frequency. By examining the S11 graph, it can be stated that the antenna radiates at this frequency.

III. RESULT AND DISCUSSION

When the simulation results of the copper patch antenna are compared with the physical test, it is observed that there is a difference of -2.938 dB between the simulation and the physical test result. Due to the LPKF device used operating outside the tolerance range, the total gap should have been 2 mm, but it was etched to 2.2 mm. It is believed that the approximately 3 dB loss is due to production tolerances.

The CoFeSiB patch antenna was designed based on the electrical and mechanical parameters of cobalt-based alloys obtained from the literature (Figure xx). The parameters required for designing in the CST simulation program, such as electrical conductivity and magnetic permeability values, do not match the information obtained from the test. This is believed to be due to the structure of the alloy. The parameters obtained for the design are not measured values on nanocrystalline ribbons. The design was made using the parameters of cobalt-based alloys, while production was achieved using nanocrystalline amorphous ribbons. This is the most obvious explanation for the difference between the test and simulation results. Furthermore, the dielectric of the base material and the dielectric value of the adhesive used between the strips create a relative dielectric between them. This necessitates the approximate calculation of the dielectric constant.

Another requirement highlighted by the difference between the test and simulation is the need to measure the electrical conductivity, magnetic permeability, and magnetic conductivity values of the nanocrystalline CoFeSiB strips. On the other hand, the brittle nature of the strips has led to production outside the design dimensions due to the consumable materials used in production (scalpel, micro scalpel, scissors, etc.) Although the S11 graph obtained from the test does not clearly indicate the operating frequency of the nanocrystalline CoFeSiB strips, it approximately shows impedance matching at 6.69 GHz according to equation xx. The impedance matching frequency, according to equation xx, is the lowest dB point of the S11 graph. This indicates that the power transmitted from the source is highly distributed over the antenna without reflection (or with very little reflection). As a result, it can be inferred that the CoFeSiB patch antenna radiates at around 7 GHz.

When the tests of the copper patch antenna and the CoFeSiB patch antenna are compared, both antennas have been calculated to be dimensionally the same with a 5% tolerance physically. When the S11 graphs of the antennas are compared, it is observed that the CoFeSiB antenna does not exhibit antenna behavior at the resonance frequency (2.4 GHz) due to the lower electrical conductivity of CoFeSiB, differences in production methods, and the thicker CoFeSiB strips. However, the CoFeSiB patch antenna exhibits radiation characteristics with a value of -27 dB at 6.69 GHz (at the 2nd resonance point). From this, it is determined that CoFeSiB strips tend to exhibit optimum radiation behavior around 7 GHz. This inference is supportive of the literature. [13] Furthermore, when the behavior of copper at 2.4 GHz is compared with the behavior of CoFeSiB strips at 7 GHz, obtaining a better S11 with copper and thus providing a volumetric advantage compared to other conductors is also supported by the literature. [1]

In order to achieve better results, it is essential to obtain the electrical and mechanical parameters of CoFeSiB nanocrystalline amorphous ribbons and create an appropriate antenna design.

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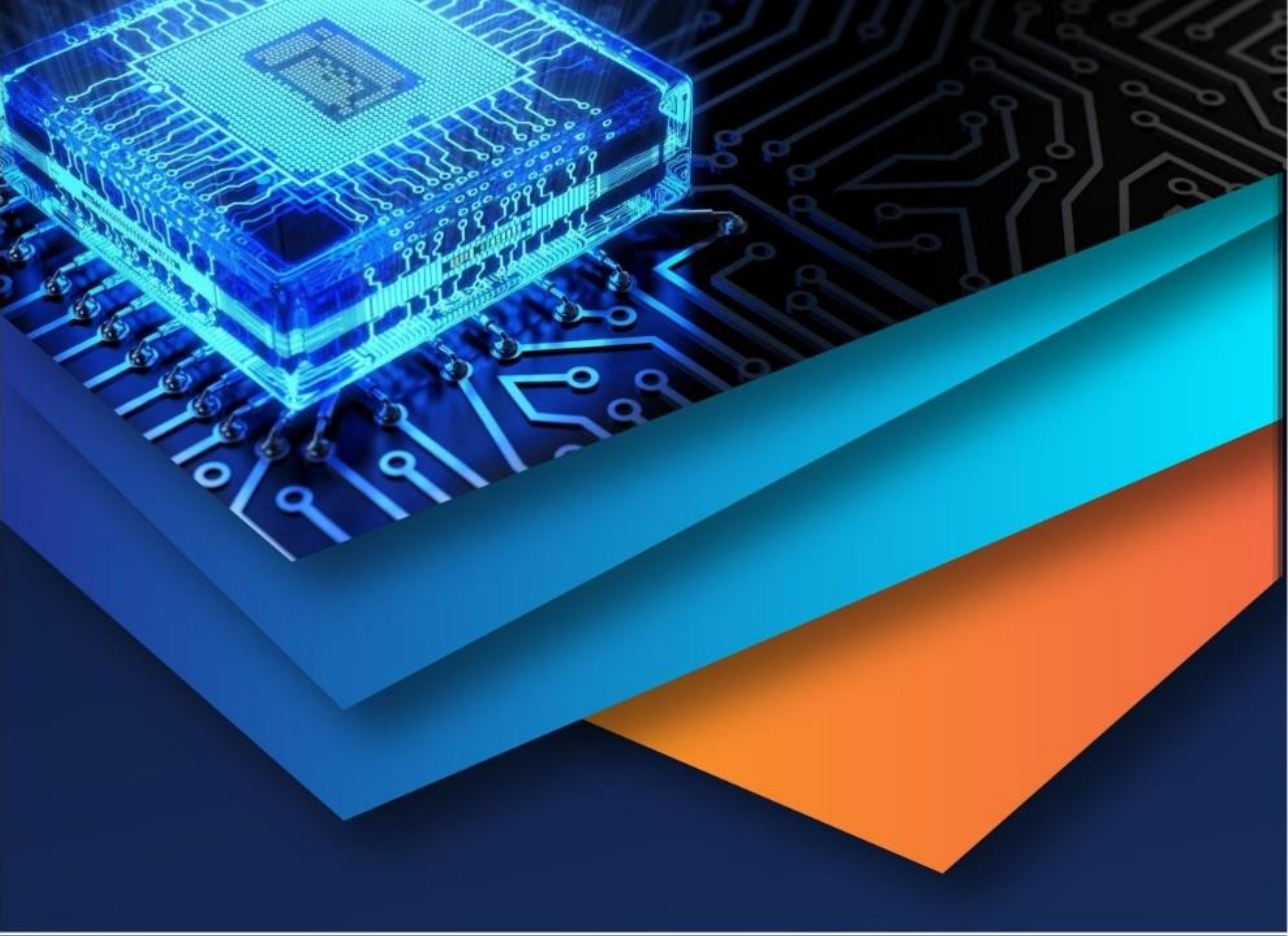

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