2023 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (USNC-URSI) | 978-1-6654-4228-2/23/$31.00 ©2023 IEEE | DOI: 10.1109/USNC-URSI52151.2023.10238318

A MIMO Monopole Antenna for Harsh Conditions

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Abstract—**In this paper, a Multi-Input Multi-Output (MIMO) antenna of 4 monopole elements is presented on Zirconia Ribbon Ceramic (ZRC) substrate. Utilization of this substrate material allows an implementation of an antenna system that is able to withstand harsh environments and high temperatures due to inherent substrate characteristics. The proposed MIMO design supports an operational antenna bandwidth from 2.44 GHz to 2.55 GHz with a center frequency around 2.5 GHz covered by all 4 antenna elements. High antenna isolation below –15 dB is obtained among the ports. The antenna also provides a peak gain over 3 dB through the entire band of interest (3.34 dB at 2.5 GHz) and low cross-polarization.**

I. Introduction

Advancement of wireless devices and quick progress of their development leads to production of novel concepts for advancement of existing technologies. A suggested application includes the implementation of antennas within higher temperature and harsh chemical environments. The focus of improving wireless technologies within this area led to the proposal of new substrates. Zirconia Ribbon Ceramic (ZRC), a substrate based on the structure of Yttria-Stabilized Zirconia (YSZ), provides tolerance of high temperatures, resistance effects of moisture, strong physical structure at thin substrate levels, and properties that allow substrate behavioral stability at higher temperatures [1], [2]. In addition, applying this substrate to a MIMO antenna structure would allow for the possibility of utilizing the advantages of stronger signals, not having clear line of sight for signal reception, and better throughput [3]. Recent MIMO research includes the application of this technology on other novel substrates, however, without the application of high temperature [4]. Additionally, high temperature and harsh condition elements, such as a waveguide element are presented, without the application of patch antenna or MIMO Technology [5]. The ability to combine the benefits of both MIMO, patch antenna technology, and harsh environmental resistance would provide a beneficial antenna that combines these technologies for a more compact, low-frequency antenna for related uses. In this study, a 4-element MIMO patch antenna is proposed on ZRC substrate for high-temperature and harsh environments with better performance without line-of-sight. The antenna operates within 2.44 GHz - 2.55 GHz frequency range and can be used for various S-band applications within the given range.

II. Design Process

The robust ZRC substrate utilized within this design has a material thickness of *h,* 0.15 mm, a dielectric constant, ε_r, of 22 and dielectric loss tangent, tan(δ), of 0.001. The other substrate parameters are based on a physical sample material, reflected within simulation, exhibit a width, W_1, of 100 mm, and length, L_1, of 100 mm, forming a square substrate for the antenna creation.

The proposed geometry of the antenna is presented in Fig. 1. This image provides a top view of the antenna design with a visible ground structure. As seen in the image, the main radiator of the 4 elements has a rectangular design that ends with a combined ellipse structure forming a unique shape. In addition, the ground, patch antennas, and combination of the ground plane have been optimized to achieve a working frequency of 2.5 GHz with a workable range. The antenna is also symmetrical with a 90° rotation about the center of the substrate. The dimensions seen within the antenna in Fig. 1 are as follows: feed line has a width (W_2) and length (L_2) of 2 mm and 17 mm, respectively. The patch has insets with dimensions of W_3 at 0.5 mm and L_3 at 4 mm. The combined length of the patches include L_4 and L_5 at 12.532 mm and 10.393 mm, respectively, for a combined length of 22.925 mm against a width, W_4, of 17.321 mm. The base ground dimensions yield a width, W_5 and L_6, of 18.221 mm and 13.202 mm, respectively. With ground alterations and connections, the final dimensions yield d_1, d_2, d_3, d_4, and d_5 to be 12.681 mm, 3.917 mm, 1 mm, 40.89 mm, and 10.432 mm.

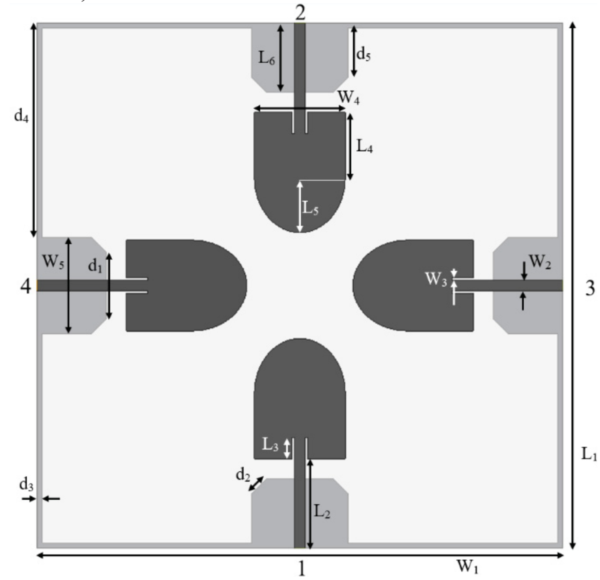

Fig. 1. MIMO Antenna Geometry and Parameter Lengths with Labelled Port Numbers

III. SIMULATION RESULTS AND DISCUSSION

The MIMO antenna is designed and simulated using ANSYS HFSS simulation software. Fig. 2 shows the simulated return loss of each antenna element. As can be observed, the -10 dB impedance bandwidth is 4.4% for the frequency range from 2.44 GHz through 2.55 GHz. It also shows a good impedance matching at the center frequency of 2.5 GHz. Additionally, every element has an almost identical behavior throughout the working band, which excludes only the slight difference in resonance strength at 2.5 GHz.

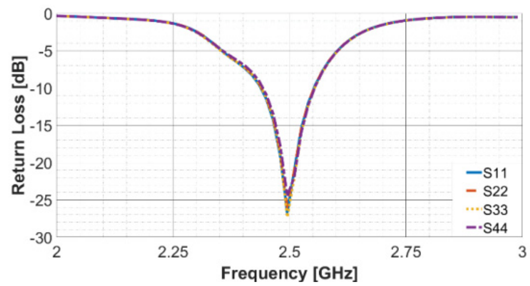

Fig. 2. Return Loss for Ports 1 (S_{11}), 2 (S_{22}), 3 (S_{33}), and 4 (S_{44})

Within Fig. 3, the isolation levels from port 1 is seen. This result is also reflected for every port in relation to the positions of the neighboring ports. That is, the opposite element (port 2 in Fig. 1), shows isolation of less than -17 dB and the side elements showing a fairly similar pattern with high isolation levels lower than -15 dB in the band of interest.

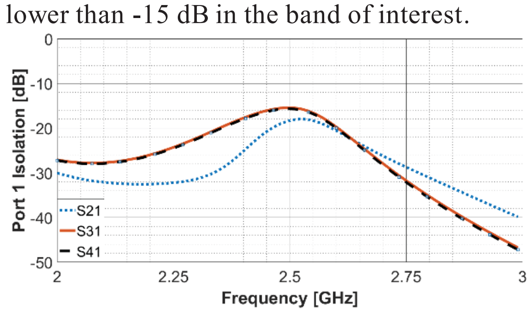

Fig. 3. Port 1 Isolation related to Ports 2 (S_{21}), 3 (S_{31}), and 4 (S_{41})

Fig. 4 shows the peak gain and efficiency overlayed in the same plot over frequency. The peak gain shows an increase in gain within the shown range peaking around the center frequency at 3.34 dB. The peak gain also maintains a gain over 3 dB throughout the working range. The efficiency shows a similar pattern as well. The peak efficiency of 84% is observed around the frequency of 2.5 GHz and maintains above 82% efficiency throughout the working range.

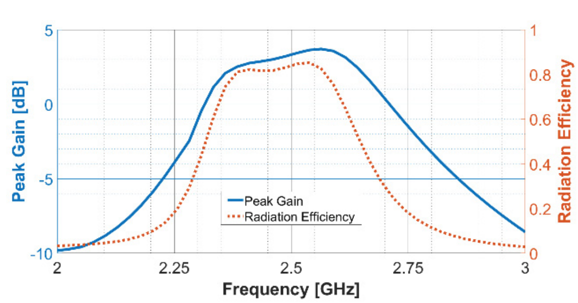

Fig. 4. Peak Gain and Radiation Efficiency over Frequency

The radiation patterns at 2.5 GHz are presented in Fig. 5. The radiation patterns presented show a pair of patterns covering the x-z ($\phi = 0°$) and y-z ($\phi = 90°$) planes. As seen, cross-polarization fields for the x-z plane have a general difference of 10 dB throughout, between the cross- and co-polarization fields, and a difference of around 50 dB at the boresight. The y-z plane presented shows a cross-polarization that is significantly lower than the co-polarization radiation field with a similar 50 dB (as the x-z plane) difference at the boresight.

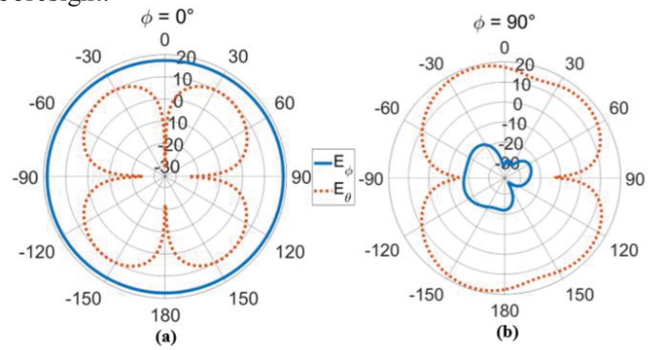

Fig. 5. Radiation Patterns at (a) Phi = 0° and (b) Phi = 90°

IV. CONCLUSION

This paper presents a 4-element MIMO planar monopole antenna. The substrate used allows this antenna to account for uses within harsh environments. The antenna design features a ground plane structure optimized for each antenna element with resonating connections between the four individual ground structures. The return loss and isolation responses of each element present a strong performance for antenna operation. Efficiency is solid within working range with the radiation patterns confirming strong monopole behavior containing low cross-polarization fields. Finally, the range of the antenna provides for possible applications specifically around 2.5 GHz in the S-band. The combination of MIMO technology and high-temperature substrate aims to further the workable possibility of the substrate. Further design optimization will focus on improving isolation and a physical antenna to follow for design validation. MIMO antenna parameters such as envelope correlation coefficient and diversity gain will also be presented.

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