Ka-band Complementary Reflector Backed Slot Antenna Array for Soil Moisture Radiometer

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***Abstract*—This paper presents a high gain 4×4 slot antenna array designed to operate in Ka-band (in this case 35-40 GHz) as a soil moisture radiometer. Simulation result with measurement are presented for the slot antenna array. The main hind sight of a slot antenna is the radiated back lobe which can be improved using a reflector. A complementary patch array reflector is used to suppress back lobe radiation in simulation. Comparison of simulation as well as measurement with and without back-reflectors are discussed. Radiation patterns and different side lobe levels for different frequencies are justified.**

Keywords—Radiometer; Slot antenna array; soil moisture; back reflector; Ka-band

I. INTRODUCTION

The monitoring of soil moisture by means of microwave radar/radiometry technologies is important for the implementation of the earth observation programs [1]. Microwave radiometer is a passive sensors that measures the radiation from a radiating body in the microwave/mm-wave range (300MHz-300GHz) [2]. Dual polarized microwave radiometer plays an important role in remotely sensing sea surface wind vector from space; it gets all the polarization information of the target by measuring the stokes vector of the target, exploiting the complete usage of electromagnetic wave frequency, phase, amplitude and polarization in microwave remote sensing [3, 4]. On January 31, 2015 National Aeronautics and Space Administration (NASA) has launched Soil Moisture Active Passive (SMAP) as sequel to similar mission Soil Moisture and Ocean Salinity (SMOS) satellite to produce global map of soil moisture which works in both active and passive system to provide higher spatial resolution [5-7]. L-band is the optimal choice for soil moisture sensing because of its high penetration and less sensitivity from soil roughness, vegetation and atmospheric condition. However, L-band radiometer requirements for high spatial resolution result in a very large, bulky and heavy sensor and there is always trade-off between temporal and spatial resolution from satellite perspective. Contrary to this, radiometer design in the Ku- and Ka-bands can provide high resolution imaging of scanned plane with a much lighter, smaller and compact antenna size compared to that of the L-band. Thus, if these microwave bands can be combined into a single radiation aperture and can be made planar and conformal, it will bring significant advancement to the field which will allow the technology to be demonstrated from a small inexpensive platform such as that of a small airborne [8].

Slot antennas are quite popular because they can be cut out of any sort of surface they are to be mounted on and have radiation patterns that are roughly omnidirectional. They exhibit wider bandwidth, lower dispersion and lower radiation loss compared to that of the microstrip antennas. They also provide easy means of parallel and series connection of active and passive elements that are important for improving the impedance matching and gain [9]. Slot antennas are often used when greater control of the radiation pattern is required. The objective of this study is to design, construct and experimentally validate a Ka-band radiometer slot array antenna. Therefore, in this paper, the design of a high gain 4×4 element corporate feed slot antenna array for the Ka-band radiometer is presented. The proposed antenna offers a wide bandwidth starting from 35 GHz to 40 GHz. Fabrication and measurement for this linear polarized antenna are also presented in the article. The hind sight of slot antenna is large back lobe. To suppress the back lobe and enhance the main lobe radiation, a complementary copper patch array is introduced as a back-reflector and the simulation result is presented. Thus an improvement of 8 dB front–to-back (F/B) ratio is obtained. The remainder of the paper is organized as follows: Section II presents the theory and design of the single element antenna, feed line using multistage power divider and array design. Section III presents the measurements and comparison between simulation and measured result of the assembled antenna, which is followed by conclusion in section IV.

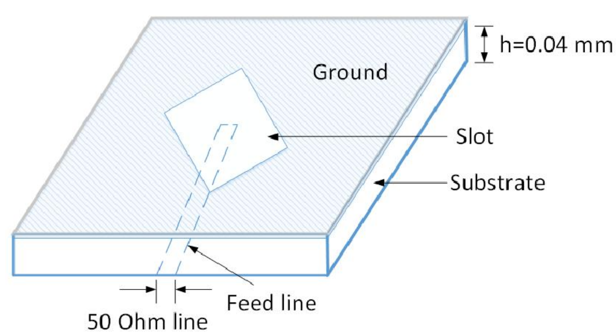


Fig. 1. Configuration of slot antenna.

II. Theory and Design

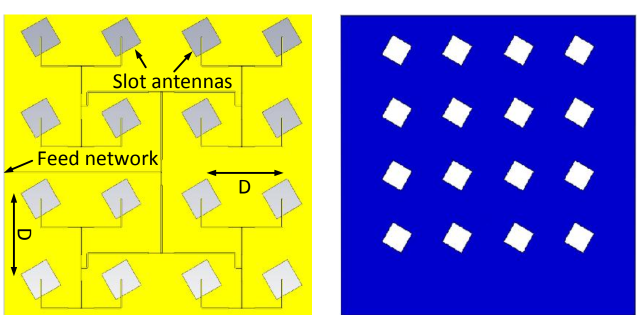
A. Single Element Antenna

A slot antenna consists of a metal surface, usually a flat plate, with a hole or slot cut out. The slot size, shape and the cavity offer design variables which can be used to tune performance [10]. The shape, position and orientation of slots also determine how they radiate since size of the edge determines radiation property. The slot radiates electromagnetic waves in a way similar to a dipole antenna and therefore it has the same radiation pattern of a dipole having its equal dimensions. Slot antennas are often used when greater control of the radiation pattern is required. They have wide application in radar and sector antennas used for cell phone base stations.

The F/B ratio is the ratio of the gain in the maximum direction of an antenna to that in the opposite direction (180 degrees from the specified maximum direction) . In case of an omnidirectional antenna, this ratio should ideally be ∞ dB. However, if a directional pattern is desired in a specific direction, a back reflector can be used to suppress the back lobe of the radiation pattern which will eventually enhance the front lobe magnitude. This will lead to an increase in the F/B ratio. The electromagnetic solver CST Microwave Studio is used to design and analyse the performance of the proposed antenna. The configuration of the single element slot patch antenna is shown in Fig. 1. The antenna consists of two layers. Here, Taconic TLT-7 substrate (permittivity, ε_r, = 2.6, loss tangent, tan δ = 0.0019) and thickness (h) of 0.04 mm is used for the mm-wave antenna to achieve the wide bandwidth. The ground layer of the antenna incorporates a rhombus shaped slot which is rotated with respect to the feed line by 30°. This slight rotation is expected to result in a wider bandwidth. However, it will not affect the polarization of the antenna.

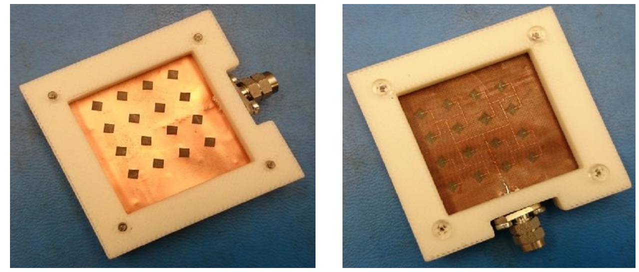
B. Feed Network

Antenna elements in a 4×4 element array is fed with a quarter wavelength power divider. The corporate (parallel) feed network is used for the proposed array. A multistage T junction power divider is used as a building block for the 4×4 parallel feed-networks, since it has a better bandwidth, return loss and insertion loss performance compared to that of the single stage power divider. Furthermore, it is much simpler and more compact than the Wilkinson power divider. In order to achieve the best result, the inter element spacing is kept as $\lambda_0/2$ and the length of the quarter wavelength section is optimized at 1.33 mm.



(a) (b)

Fig. 2. Layouts of (a) ground layer, (b) substrate layer



(a) (b)

Fig. 3. Photographs of fabricated 4×4 element slot array antenna, (a) ground layer, (b) substrate (Taconic TLT-7) layer feed network

C. Array Antenna

A slot antenna element has quite a wide radiation pattern, high F/B ration and provides low directivity which results in a very low gain. In order to increase the gain of the antenna, it is required to use an array. To achieve a desired directional radiation pattern, multiple radiating elements are needed to be configured providing interconnection between the elements. The interconnection between elements, called the feed network, can provide fixed phase to each element. The array antenna can be fed by using either the corporate or serial feeding technique. In this particular case, the corporate feeding is used. The reason for not using the serial feed is the impracticality of delivering the same amount of power to each element.

After designing the power divider and the single element, the 4×4 element slot array is constructed. The performance of an antenna array are affected by its geometric layout, relative amplitude excitation (A), relative phase excitation (β) and inter element spacing (D). All of these parameters are optimized in order to obtain the best result. The layout of different layers is hown in Fig. 2. The antenna array consists of a total of 16 (4×4) slots on the ground plane. The 50 ohm line that feeds the slots is centrally placed before being distributed to construct the corporate feed. To achieve the maximum bandwidth, the slots are rotated with respect to feed lines.

III. Simulation, Fabrication and Measurement Results

The following sections present the simulated and measured results of the 4×4 slot array antenna. The measurement is performed using a vector network analyser Agilent PNA E8361A with appropriate error correction calibration and confidence check. Thus the authenticity of the mm-wave measurement is ensured.

A. Fabricated Antenna and Experimental Set- up

Photographs of the fabricated array antenna with rhombus shaped slots is depicted in Fig. 3. The dimension of the array antenna is only 40×40 mm^2. The thickness of the copper layer is 17 μm which indicates that the structure of the proposed antenna is fully flexible with a total thickness of 0.057 mm.

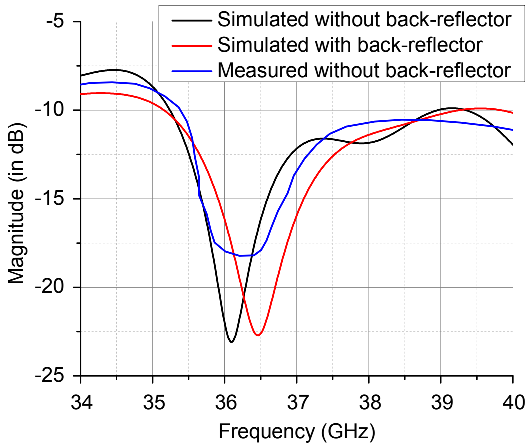


Fig. 4. Simulated and measured S11 (dB) versus frequency of the slot array antenna

In order to analyze the radiation performance of the designed antenna it is interrogated by a horn antenna. Both the antennas are placed in line of sight to facilitate the interrogation process. A thorough analysis on the measured results has been carried out using Matlab after extracting the data from VNA and plotted in Fig. 4.

B. Simulated and Measured Results

Firstly, the single element antenna is designed which is followed by the design of a complementary slot reflector to suppress the back radiation. The simulated and measured reflection coefficient versus frequency is depicted in Fig. 4 shows that the proposed antenna covers a bandwidth of 35 to 40 GHz with a return loss of greater than 10 dB for almost all the desired band. The measured result of the antenna shows a slightly poor return loss of less than 9 dB after 40 GHz which is acceptable. This deviation occurs due to the misalignment and/or feed line mismatch as the feed line is too tiny to connect the super SMA connector. The simulated and measured results are quite well matched to each other which validate the theoretical design of the antenna.

The result of the antenna radiation pattern of the single element antenna with and without back-reflector is shown in Fig. 5. Because of the omnidirectional nature of the slot antenna, it has almost the same front lobe and back lobe. Radiation due to the back lobe is just a waste of energy, hence comes the concept of back-reflector. In Fig. 5, which is for 36 GHz, it is seen that with introduction of the back-reflector, back radiation is supressed and an added amount of radiated power in the front lobe can be observed.

The radiation pattern depicted in Figs. 5 and 6 show that the designed slot antennas (both single and array) radiate in both directions. In order to suppress the back lobe a back-reflector is used. Back-reflector is an array of complementary patches placed directly opposite to the ground slots. The distance between the antenna and reflector should be ideally $\lambda_0/4$ corresponds to 36 GHz to ensure phase matching. In this case, 0.19 mm distance results in a reduction in the back lobe and increases the main lobe which confirms the hypothesis. The substrate used for reflector is the same as the antenna and its thickness has a very little impact on radiation pattern. The shape of the metal is symmetric to the slots and has the same 30° angle of position; however, their dimensions are 20% larger than the actual slots. In this analysis, only the simulation results of back reflector is considered and further modification and fabrication will be carried out as a part of the future research. Fig. 6 shows a comparative illustration of the simulated and measured radiation pattern of the proposed antenna at 35, 37 and 39 GHz. It is evident that the side and back lobes of the radiation pattern is considerably lower than the main lobe level for all the frequencies. Further reduction in side lobe level will be performed using Chebyshev distribution in the feed network and F/B ratio will be improved by the addition of proper back reflector in a future analysis. It is seen from the radiation pattern that as frequency increases side lobe level also increases. Maximum gain also follows the same trend of side lobe level as it increases with frequency which is shown in Fig. 7. In Fig. 8, the inter-element distance is fixed which is half of the wavelength and where wavelength corresponds to 36 GHz frequency. It can be seen from the figure that the side lobe level increases with the ratio of inter-element distance and wavelength. As frequency increases, inter-element spacing becomes comparable to higher frequency wavelength and therefore grating lobe becomes more and more prominent.

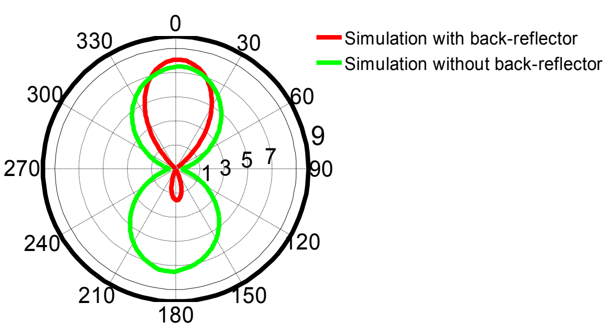
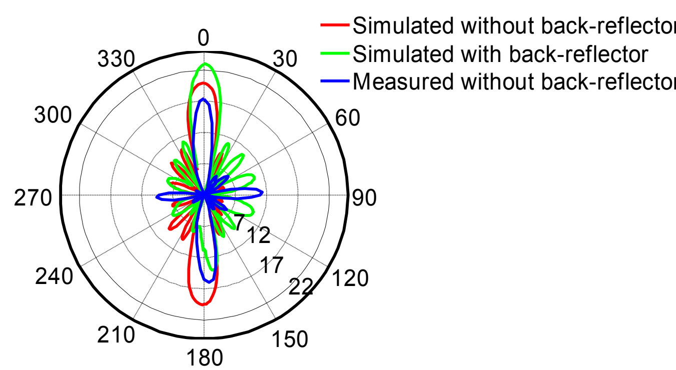
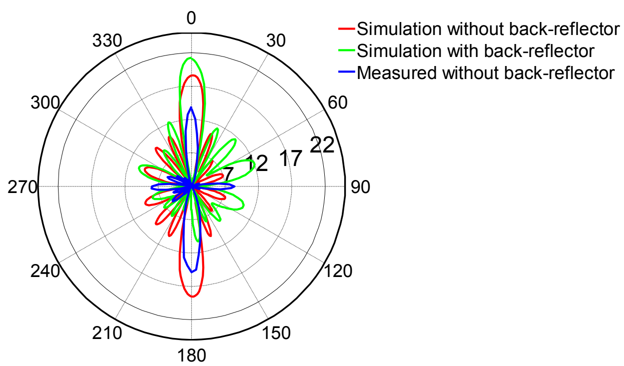


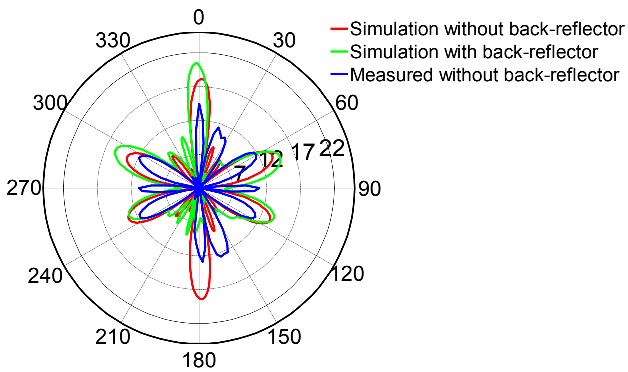
Fig. 5. Radiation pattern of a single element slot antenna array at 35 GHz with and without back-reflector.



(a)



(b)



(c)

Fig. 6. Radiation patterns of CST simulated and measured slot antenna with and without reflector for (a) 35, (b) 37 and (c) 39 GHz

IV. CONCLUSION

This paper focuses on the design and performance analysis of a 4×4 slot antenna array for a Ka-band radiometer. Back radiation of slot antenna is improved by introducing a complementary patch array as back-reflector. This antenna offers a 13 dBi gain

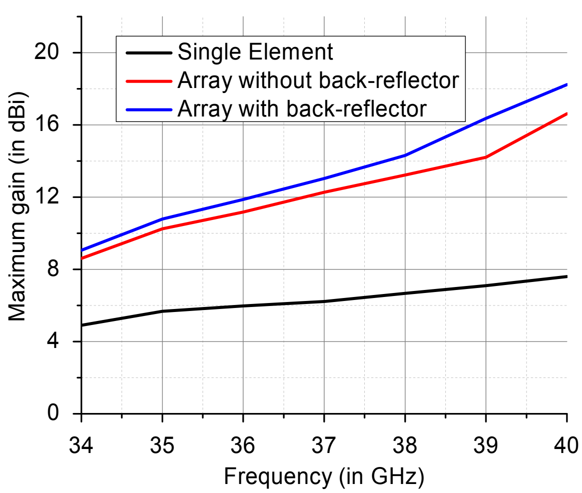


Fig. 7. Maximum gain versus frequency graph

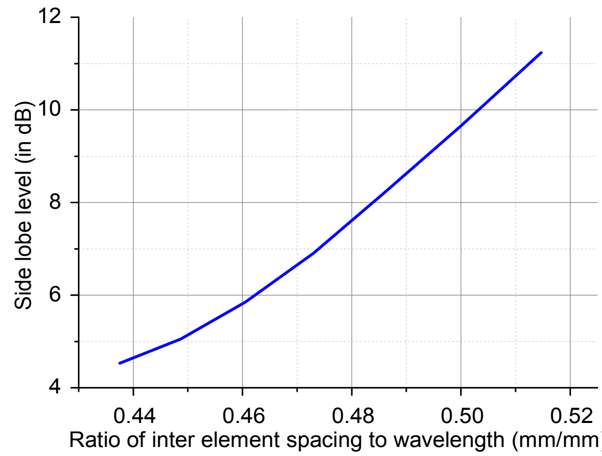


Fig. 8. Side lobe level versus inter-element distance divided by wavelength graph

(in centre of bandwidth) due to adoption of array structure. A 4-stage power divider is used for constructing the corporate feed line in order to feed the array elements. The antenna array is optimized to achieve the required bandwidth, radiation pattern and gain. Array antenna is fabricated and tested in order to experimentally validate the theoretical design and then back-reflector was added to supress back lobe radiation. In future, the fabricated antenna will be used for measuring soil moisture in Ka-band with L- and Ku-bands as an added feature to improve data resolution in the same physical aperture.

V. REFERENCES

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