A VHF Microstrip Antenna With Wide-Bandwidth and Dual-Polarization for Sea Ice Thickness Measurement

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***Abstract*—A VHF microstrip patch antenna was developed to achieve a bandwidth of 45 MHz (30%) from 127 to 172 MHz with dual-linear-polarization capability. This microstrip antenna, having a size of $117\ \mathrm{cm} \times 117\ \mathrm{cm} \times 27\ \mathrm{cm}$, used low-dielectric-constant foam substrates and dual-stacked patches with capacitive probe feeds to achieve the required wide bandwidth. Four such capacitive feeds were used to achieve dual polarizations with less than -20 dB of cross-polarization level. Twenty-four shorting pins were uniquely used here on the lower patch to achieve 40 dB of isolation between the two polarization ports. This antenna has a measured gain of 8.5 dB at 137 MHz and 10.3 dB at 162 MHz. One advantage observed here at the low frequencies of VHF is that more electrical structures can be easily integrated into the microstrip antenna to improve its performance.**

***Index Terms*—Dual-polarization, VHF microstrip antenna, wideband.**

I. INTRODUCTION

IN ORDER TO address a key science goal of understanding the global sea ice thickness and snow characteristics, NASA/Jet Propulsion Laboratory (JPL) is investigating a spaceborne synthetic aperture radar (SAR) to operate simultaneously at two widely separated frequency bands: VHF and *Ku*-band. VHF is for the sea ice thickness (0.5–8 m), while the *Ku*-band is for the snow detection (snow pack structure and water content). Both the spatial and frequency domain interferometry techniques will be utilized in this radar system [1]. The spatial interferometry is for separating different boundary surfaces from the volume scattering, while the frequency interferometry is for determining the positions of surface boundaries. Prior to the implementation of the spaceborne system, a field experiment with an aircraft radar is needed to validate this proposed radar system. This paper addresses only the VHF antenna developments for the aircraft sea-ice radar. The antenna is to be mounted on the outside of a Twin-Otter aircraft to perform the radar functions as illustrated in Fig. 1, where the antenna is mounted in an aerodynamically-sound radome fairing.

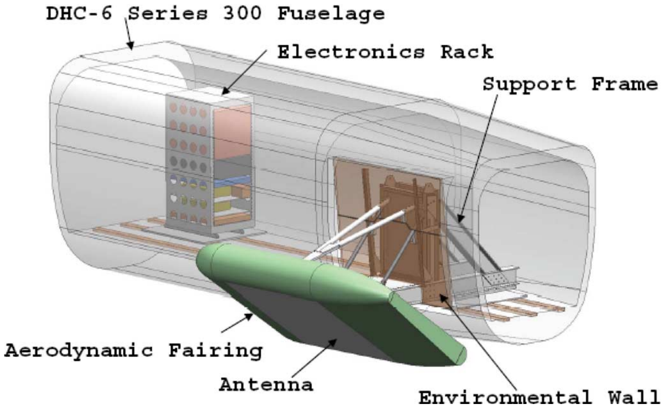

Fig. 1. Artist drawing of antenna in fairing mounted outside of the fuselage. Microstrip antenna is facing down and sideways.

For the sea ice thickness measurement, the aircraft radar system requires a compact low-gain VHF antenna that has a wide bandwidth (30%) to provide frequency coverage from 127 to 172 MHz with dual-linear-polarization. The wide bandwidth is to cover two frequency bands in order to apply the frequency interferometry technique. These two frequency bands are centered at 137 and 162 MHz with each having a bandwidth of 20 MHz. The dual-linear-polarization is required to detect two different characteristics (vertical and horizontal components) of the sea ice returns from the two orthogonal polarizations. At least 20 dB of isolation between the two polarizations is required by the given radar system to clearly distinguish the returned signals of the two different characteristics of the sea ice.

The antenna selected is a dual-stacked-patch for low-mass and compact size considerations. Other possible candidate antenna types are horn and crossed-dipoles. A horn, even with very small flares, would be significantly larger and heavier than the patch design at the VHF frequency. A crossed-dipole radiator with unidirectional radiation would require a ground plane separated 0.25 wavelength from the dipoles. This 0.25 wavelength is about 50 cm at the frequency of 150 MHz, which is almost twice the profile height of the patch antenna and, thus, would be more challenging to properly mount aerodynamically outside the aircraft. To achieve the wide bandwidth, the dual-stacked patches [2] with relatively thicker substrates and low-dielectric-constant foam material were used. Capacitive feed probes [3] were used on the lower patch to assist the achievement of wide bandwidth by canceling the excessive inductance occurring in a relatively thick substrate. An aperture-slot-coupling technique [4], instead

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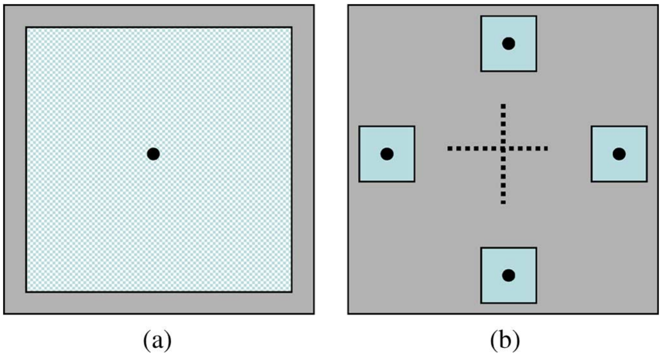

(a) (b)

Fig. 2. (a) Top view of both patches; (b) top view with top patch removed and showing four capacitive feed probes and shorting pins.

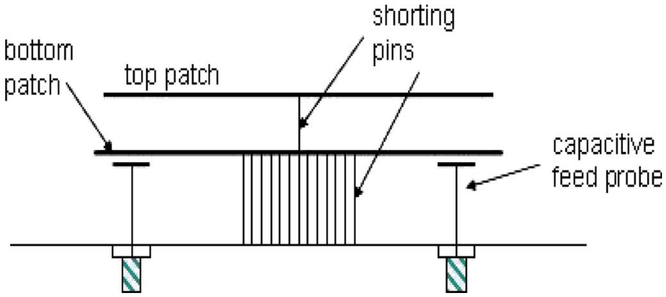


Fig. 3. Side view of the stacked patches.


(a) (b)

Fig. 4. (a) Photo of the whole antenna with top patch shown; (b) photo showing the bottom patch with the top patch removed.

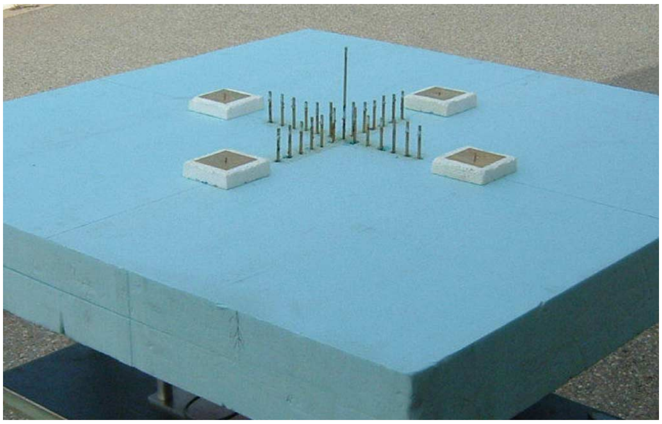


Fig. 5. Photo showing all shorting pins and all capacitive feed probes with both top and bottom radiating patches removed.

of the capacitive feed probe method, can certainly be employed here to achieve wide bandwidth. However, this technique would require an additional layer of substrate material for the coupling microstrip lines, which would significantly increase the antenna thickness and weight at the VHF frequency. Four, instead of two, capacitive feed probes [5] were employed to suppress higher-order modes that occurred in the relatively thick substrate in order to yield the required -20 dB cross-pol levels. Each pair of oppositely located feed probes was excited with 0° and 180° phases to achieve such higher order mode suppression. However, it was found that when using such four feed probes with thick substrates, there exists a large amount of coupling (≈ -5 dB) between the two oppositely-located feed probes. This large coupling, not only worsens the input return loss, but also wastes a large amount of input power and, hence, makes the antenna less efficient. To reduce the amount of coupling, many shorting pins were placed between the bottom ground plane and the lower patch. By introducing these shorting pins, the direct wave coupling between the two opposing feed probes is blocked off. The waves underneath the patch (stronger magnitude at the center) have to go around the shorting pins to reach the radiating edge on the other side and, hence, reduce the amount of central waves travel into the opposite feed probe. Because of this reason, it was also found that the more the shorting pins the less the coupling. However, as the number of shorting pins increases, the antenna bandwidth starts to decrease. This is because we are reducing the space and degree of freedom for the waves to travel underneath the patch. After a tradeoff study, a total of 24 shorting pins (12 for each polarization) were determined to be optimum for this application. One key advantage of developing a patch antenna at the low frequency of VHF is that many components or devices, such as the shorting pins and feed probes, can be easily inserted into the antenna. This would be very difficult to do, for example, at the frequency of *X*-band or *Ka*-band. Another advantage of designing an antenna at the low frequency of VHF is that the mathematical design generally agrees with the measurement result quite well without any iterative process. This is because, at this low frequency band, mechanical tolerance is larger and hence the prediction becomes more accurate. The MoM based computer software, Ensemble, was initially used to perform the antenna analysis and design.

II. ANTENNA DESIGN

The dual-stacked-patch configuration is shown in Figs. 2 and 3, where the capacitive probe feeds excite the bottom patch directly and the top patch is parasitically excited. The top square patch has a dimension of 69.3 cm and the bottom patch is a 76.2 cm square. There are four capacitive feed probes with each having a square-disc capacitor of 6.35 cm in dimension and spaced 1.4 cm from the bottom radiator patch. Each probe is located 25.4 cm from the antenna center to achieve good input impedance match. The capacitive patch is used to provide proper capacitance for canceling the excessive inductance introduced in the relatively thick substrate [3]. As shown in the breadboard unit in Fig. 4, low-dielectric-constant $(\varepsilon_{\mathrm{r}} \approx 1.05)$ foam material is used throughout the antenna as a supporting structure for the patches. The bottom patch is separated 16.5 cm from the finite-size (117 cm-square) ground plane, while the top patch is separated 10.2 cm from the bottom patch. Thus the complete antenna has a volume of $117\ \mathrm{cm} \times 117\ \mathrm{cm} \times 26.7\ \mathrm{cm}$. A shorting

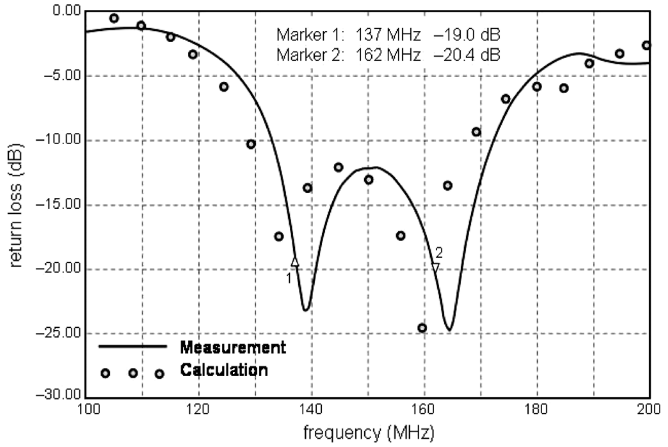


Fig. 6. Measured and calculated antenna input return loss.

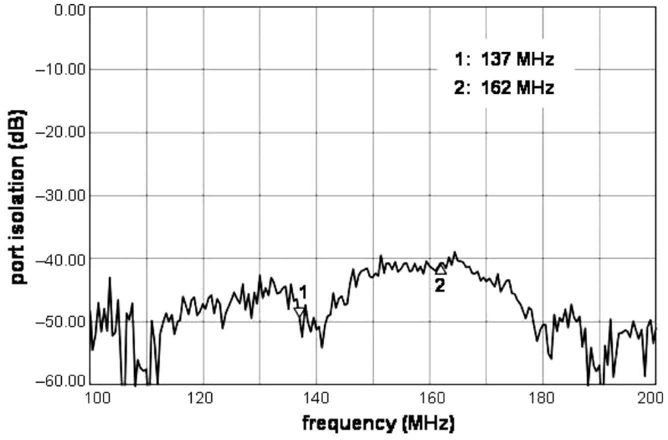


Fig. 7. Measured isolation across the band between the two polarization ports.

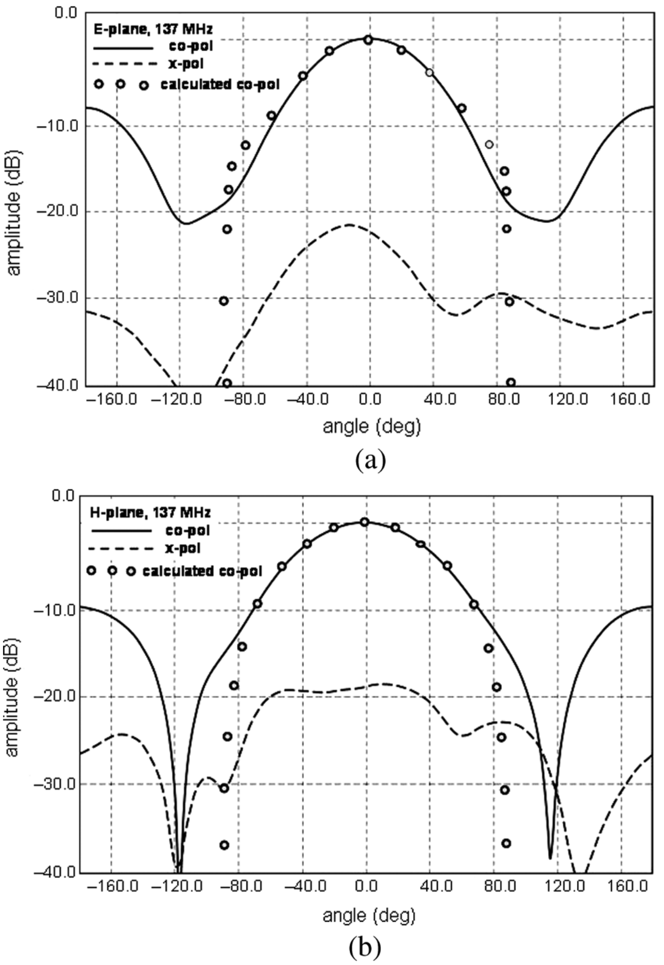
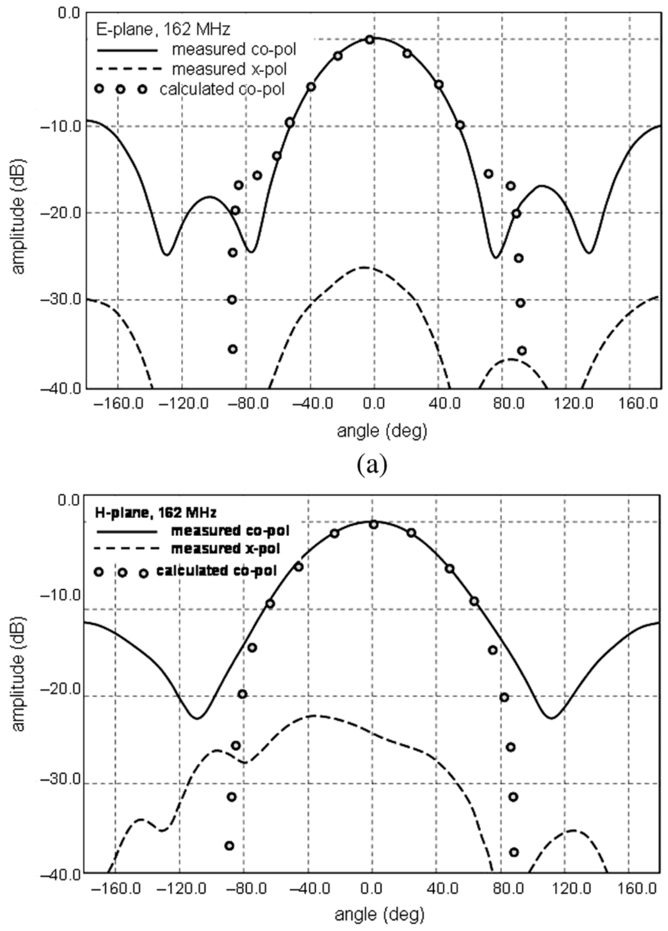


Fig. 8. Measured and calculated (a) E-plane and (b) H-plane patterns at 137 MHz.

pin is soldered to both radiating patches and the ground plane at center of the antenna to suppress undesirable higher-order modes. An additional set of 24 shorting pins, as shown in Figs. 3 and 5, is used to reduce coupling between each two oppositely located feed probes. These shorting pins are used only between the bottom patch and the ground plane. All shorting pins are made of copper rods with diameter of 0.3 cm. To excite the four feed probes, two hybrid power dividers are used with each exciting two oppositely located probes. Each hybrid power divider has two equal power outputs but 180° phase differential, which is used to cancel higher-order modes and, thus, lower the cross-pol radiation. It should be noted here that the weight of the shorting pins, the capacitive probes, and the hybrid power dividers is insignificant when compared to the overall antenna weight of 12 kg (not including the radome).

III. TEST RESULTS

The measured and calculated input return losses of each feed probe are given in Fig. 6 where the measured result clearly indicates a double-resonance with a -9.6 dB $(\mathrm{VSWR} = 2:1)$ bandwidth of 42 MHz. Although it did not quite meet the required 45 MHz bandwidth, it is considered acceptable to the radar system. The measured isolation between the two polarization ports is shown in Fig. 7, which indicates the achievement of 40 dB of isolation across the entire bandwidth. The measured and calculated E-plane and H-plane patterns of the antenna at the frequencies of 137 MHz are shown in Fig. 8, while those at 162 MHz are shown in Fig. 9. The measured patterns show acceptable cross-pol levels of lower than -20 dB. The predicted patterns, using the Ensemble software, were calculated with an infinite-size ground plane, which can only yield data within the angular region of $\pm 90°$ and is accurate only within $\pm 75°$. Although the Ensemble has the capability of implementing a finite ground plane option, the faster infinite ground plane approach was carried out at the time to take a quick look of the main beam forward pattern performance. Nevertheless, finite ground plane calculation has been performed by a dedicated method of moments (MoM) code to predict both forward and backward pattern performance with aircraft structure scattering effect included as to be described for Figs. 11 and 12. The measured and calculated co-pol patterns agree very well within the angular region of $\pm 75°$. Since the measurement of the antenna is performed on an electrically very small ground plane (117 cm square and about a half wavelength), the measured cross-pol level of -20 dB is much higher than the calculated level (on infinite ground plane) of lower than -40 dB due to strong edge diffraction. The measured antenna gain is 8.5 dB at 137 MHz and 10.3 dB at 162 MHz. From the measured radiation patterns, it can be noticed that the backlobe level of the antenna is quite



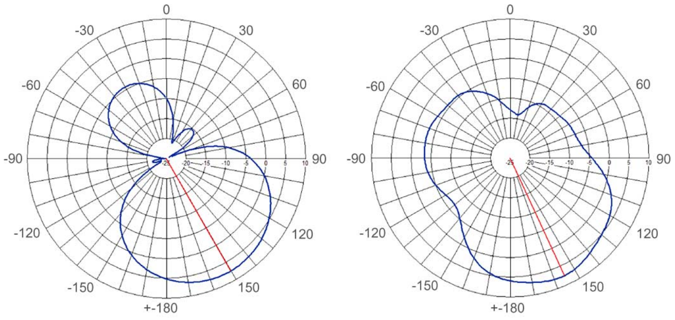
(a)

(b)

Fig. 9. Measured and calculated (a) E-plane and (b) H-plane patterns at 162 MHz.

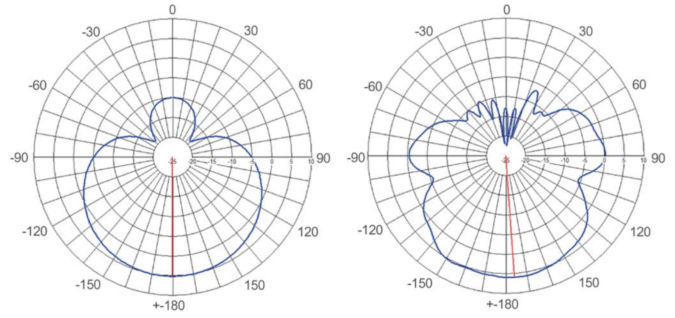
(a) (b)

Fig. 10. (a) Twin-Otter aircraft with antenna and (b) the computer simulation model.



(a) (b)

Fig. 11. Simulated 2-D pattern of (a) the antenna by itself and (b) when the antenna is mounted on the aircraft as shown in Fig. 10. Pattern cut in orthogonal plane to the axis of fuselage.



(a) (b)

Fig. 12. Simulated 2-D pattern of (a) the antenna by itself and (b) when the antenna is mounted on the aircraft as shown in Fig. 10. Pattern cut in plane containing the axis of fuselage.

high (≈ -10 dB), which could cause large amounts of multipath scatterings from the outside structures of the aircraft. Since the antenna design software, Ensemble, does not have the capability of calculating the multipath scattering effect due to three-dimensional objects located outside the antenna, a dedicated electromagnetic scattering code using the MoM was applied here to simulate the multipath scattering effect of the antenna when it is mounted onto a Twin Otter aircraft as illustrated in Fig. 10. Figs. 11 and 12 give two typical calculated radiation patterns of the antenna when it is by itself and when it is mounted onto the aircraft. The aircraft does affect the antenna pattern in some ways, such as a slight distortion of the main beam. The multipath scattered fields also fill up most nulls of the free-space patterns. However, these pattern effects were not considered significant to the radar system.

IV. CONCLUSION

A dual-polarized wideband microstrip antenna has been successfully developed at the very low VHF frequency of 150 MHz having a bandwidth of 30%. It employed the technique of dual-stacked-patch augmented with four capacitive feed probes and multiple shorting pins. -20 dB of cross-pol and 40 dB of polarization isolation were achieved.

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Dr. Petros was inducted into NASA’s Space Technology Hall of Fame in 2001.