# Aluminium feeds for reflector for NadirSAR

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***Abstract*—With the long term aim of developing a NadirSAR quadrotor UAV system specialized for monitoring broad acre grain fields, a large aperture load bearing antenna to use as the main structural element was sort. Here initial design work is presented on a candidate short *f*/D parabolic reflector antenna. An optimized splash plate feed and a dual mode coaxial horn were designed for the 10 to 10.5GHz experimenter's band and were fed by aluminum waveguide. Both feeds gave better than 30% aperture efficiency on a low cost 11.6$\lambda_0$ diameter reflector that had a focal length of *f*/D=0.27.**

***Keywords—parabolic reflector; UAV; Nadir SAR***

## I. Introduction

Multi-rotor UAVs are self-stabilizing flying platforms capable of hovering or low speed flight and consequently are used for both recreational and professional high quality photography and film. Endurance ranges from 10 to 45 minutes. To date, these small UAVs have not been used for radio frequency applications, possibly due to the limited endurance. However, in an educational or science context where restricted flight time is not an operational impediment, these UAVs are attractive for student projects on radio frequency sensing and radar; students are engaged by been able to interact with an actual UAV (organize field trials and conduct flights) and likewise find the opportunity to work on a system to be integrated with the UAV exciting. Broad acre crop growth monitoring by X-band Nadir SAR is an attractive initial application.

X-band Nadir SAR measurements have been flown over various forest types with helicopters at 60 to 100m altitude [1]. Of note is that the forests studied were mono-species and consequently had reasonably homogeneous canopies, simplifying radar result interpretation. The layer of wheat ears across a field is similarly homogeneous, and a quadrotor UAV can be flow at those altitudes. Where flight costs for a helicopter are around €4,000 per hour, a quadrotor UAV will be considerably cheaper and been a small aircraft can fly survey lines or rasters over a field with no damage inflicted by downwash. The aim of such flights would be to detect uneven plant and grain head growth across a field [2].

The motivation for Conformal Load-bearing Antenna Systems (CLAS) was to put the largest possible aperture antenna with the narrowest possible beamwidth in the air to give the highest possible resolution of ground targets for applications such as GMTI. For a large semi-rigid stratospheric airship, such an antenna would be inside the main envelope, span the entire width and be a load bearing component amongst the system of internal cables and ballonets [3]. A competing design was an array of printed antennas with load bearing backing plate which was developed for the underside of a rigidized joined-wing UAV [4]. Both these projects were large budget and for large airframes, but the concept can be applied to small multi-rotors.

There are a profusion of multi-rotor UAV designs in the market having either single or dual-inline motors, but the 2 fundamental load bearing structures are a H or cross/star. For the cross/star planform, the underside of the central hub could support a high gain microstrip array antenna or the tubular arms could be used as slotted waveguide antennas [5]. These proposals fail to exploit the entire diameter inside the motors of a multi-rotor. An aluminum low wind loading mesh parabolic reflector antennas is attractive as a novel load bearing structure due to rigidity and light weight, as well as low cost and availability. In contrast to the truss load bearing H and star/cross structures, a mesh parabolic reflector will be a distributed load bearer which will allow the use of multiple batteries which can be placed close to the motors, Figure 1. The availability of relevant prior experimental work and multi-physics software make possible the simulation of downwash from fixed pitch propellers, of air flow through a full or partial mesh parabola, as well as mechanical loading stresses across exotic structures [6].

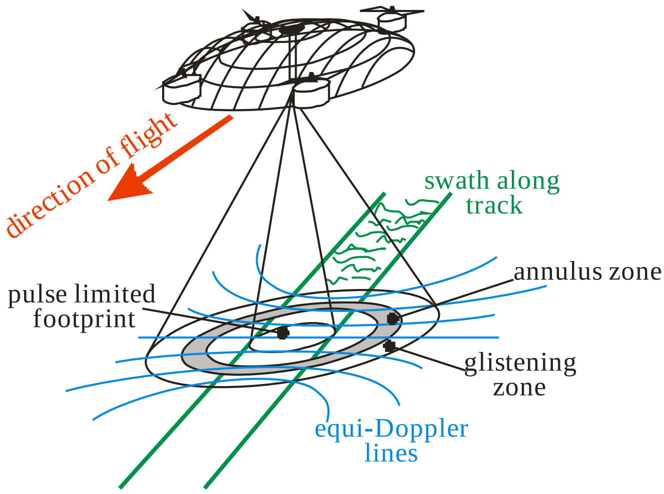


Fig. 1. Structural dish quadrotor concept.

The 3 centimeter amateur radio frequency band from 10.0 to 10.5GHz is allocated across all 3 ITU Regions, as is the 24GHz ISM band. These allocations along with the availability of low cost GaAs RF components enable various ranging radar, synthetic aperture radar and machine vision projects for undergraduate and MSc students. The 3 centimeter amateur radio frequency band is considered first due to the lesser mechanical tolerances. A 340mm diameter stamped steel dish was purchased for €1.30 for initial feed development.

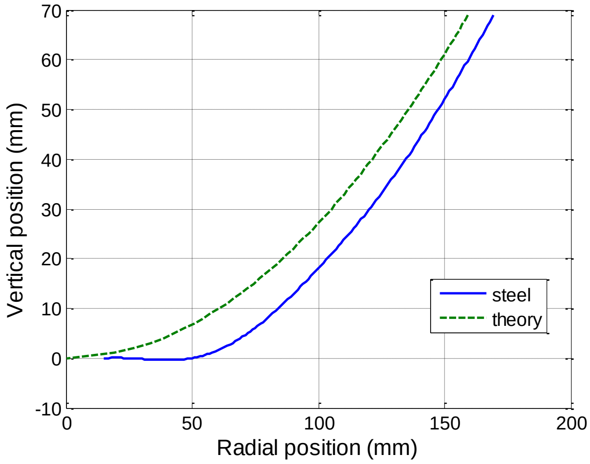


Fig. 2. Profile of the low cost steel reflector antenna compared with theoretical parabola with *f*=92mm.

The shape of the stamped steel reflector was traced and simulated in FEKO™ to determine the focal position as this was not supplied by the manufacturer. The shape was different from an ideal parabola being relatively flat across the central 100mm, Figure 2. In response to a linearly polarized plane wave, the E-field along the axis had a distinct peak at 92mm for 10.25GHz (*f*/D=0.27) and at 84mm for 24GHz (*f*/D=0.25), Figure 3. Thus, this reflector had short focal lengths and the feed ~ reflector system was relatively flat as desired for this application to minimize both drag and lift from forward motion and ambient cross wind.

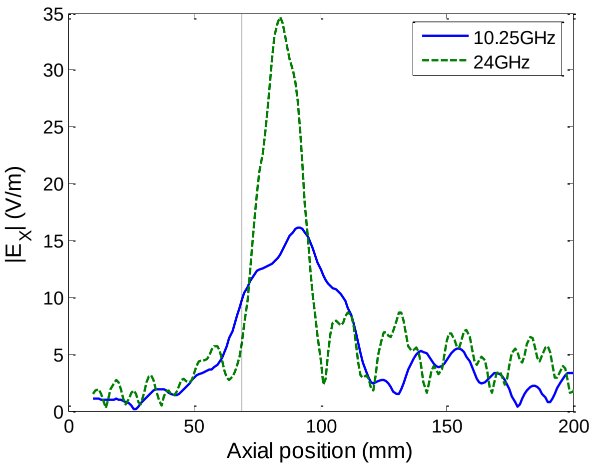


Fig. 3. Electric near field along axis of the low cost steel reflector antenna in response to a linearly polarized plane wave; from FEKO™.

## II. Nadir SAR Configuration

The following section is based on the theory of NadirSAR developed by R.K Raney in [7, 8] and subsequent experimental report [9]. This theory has been refined and published recently in [10].

The designed antenna has 3dB-beamwidth of [5.4, 6, 7] degrees at [0, 45, 90] degree in the beam pattern. The idea behind SAR focusing is to reduce the equivalent antenna footprint by coherently adding all the returns of a scatterer while illuminated by the real antenna footprint. To maximize the precision in the along-track direction, the 0 degree beam pattern will be pointed in the along-track direction.

Taking data from a commercially available UAV (DJI Phantom 3 SE [11]), some specifications are extracted for sample calculations (max speed 16 m/s, max altitude 6000m).

When surveying crops, the swath should not be too large so an operational altitude in the range of 300 m will provide a real antenna footprint of 14.15 m along-track and 18.35 m in the cross-track. The height resolution at Nadir is given by the instantaneous bandwidth of the signal which spans from 10 to 10.5 GHz.

$$\delta h = 0.886\frac{c}{2B} = 0.2658\ m \qquad (1)$$

where $c$ is the speed of light, $B$ the instantaneous bandwidth 500 MHz.

The along track resolution is calculated as follows:

$$\delta R_{AT} = 0.886\frac{cR_0}{2f_c v_S T_i} = 0.2744\ m \qquad (2)$$

where $R_0$ is the height at Nadir point 300 m, $f_c$ the carrier frequency 10.25 GHz, $v_s$ the speed of the craft 16 m/s and $T_i$ the coherent integration time (antenna footprint along-track divided by the speed of the craft).

The only difference in processing between orbital satellite NadirSAR and airborne NadirSAR lie in the phase correction terms arising from the ranging difference during the illumination time.

In terms of pulse generation, the burst length should be lower than the return-trip time between the antenna and the scatterer, yielding 2 µs. The pulse length is thus chosen to be 1.024 µs to obtain a power of two to allow the use of radix-2 Fast-Fourier Transform with an analog-to-digital converter at 1 GHz or 1.28 µs for 100 MHz.

## III. Splash Plate Feed

As the focal length of the stamped steel reflector is relatively short, the feed will not project very far beyond the reflector rim and thus will be protected by it. However, in case of a hard landing which broke the landing gear, it would be advantageous if the feed ~ radar electronics were in a single module which detached from the main structure by popping up. Considering normal operation, a microstrip or semi-rigid RG402 coaxial transmission line to connect the radar electronics to the feed are likely to oscillate due to vibrations. As extruded 6063 aluminum rectangular tube with wall thickness of 1.1mm and inner dimensions of 22.6 x 9.6mm (cutoff frequency of 6.63GHz) was readily available, this was chosen as the transmission line. As an initial attempt at "all-aluminum" construction, a standard circular splash plate was designed for 10.25GHz [12]. The circular disk was 90mm above the floor of the reflector and had a diameter of 29.4mm, while the slots to be cut in the end of the rectangular tube were 14.6 x 2mm. Joining the 2mm thick circular disk to the rectangular tube without braising proved challenging. Removing the sections of the circular disk above the narrow walls of the waveguide did not adversely affect the Directivity, in FEKO™ simulation. Further, it was found that distorting the sections above the broad walls into shortened half ellipses gave improved $S_{11}$ at 10.25GHz, while not adversely affecting the Directivity, Figures 4 to 6. This optimized elliptical splash plate feed was built by folding extensions of the narrow walls over the top of the splash plate, Figure 4. The measured $S_{11}$ was shifted up in frequency compared to the FEKO™ simulations, but still gave $S_{11} \leq$ -10dB across 10 to 10.5GHz. Lengthening the slots by filing was not possible with this construction method, whereas a conventional build in copper or brass with a braised splash plate would easily be filed and would not be a pressure contact joint at risk of damage if knocked. Thus an alternative feed design without pressure joints was sort.

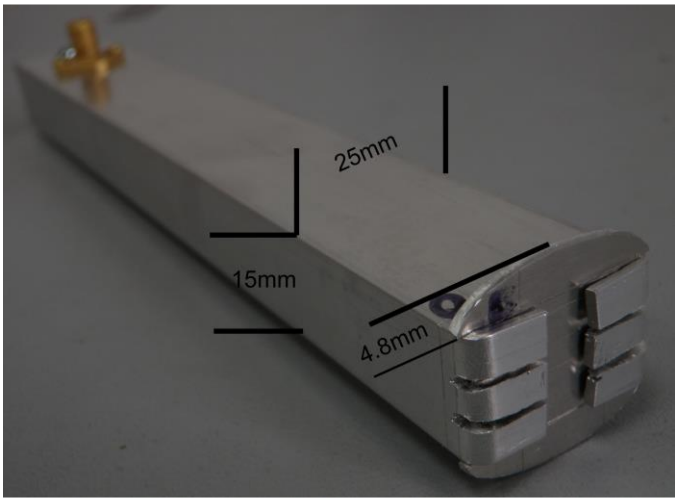


Fig. 4. Photograph of the "all-aluminum" optimized elliptical splash plate feed; note the bent fingers holding the splash plate in place.

Fig. 5. Photograph of the low cost steel dish with the "all-aluminum" optimized elliptical splash plate feed connected by foam block.

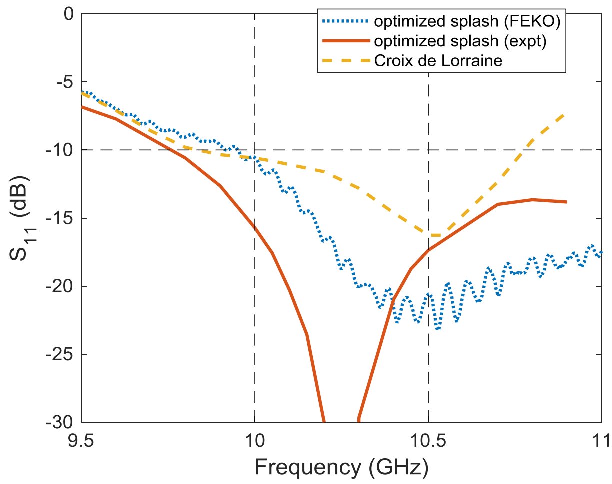


Fig. 6. $S_{11}$ of the "all-aluminum" waveguide feeds to the low cost steel dish.

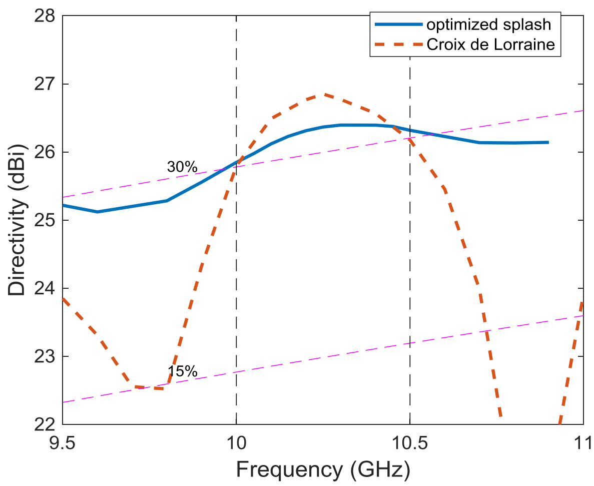

Fig. 7. Directivity of the "all-aluminum" waveguide feeds to the low cost steel dish; from FEKO™.

Across 10 to 10.5GHz, the optimized elliptical splash plate fed low cost steel dish gave better than 30% aperture efficiency in simulation. The broadwalls of the rectangular waveguide feed support TM travelling/standing waves generated by the surface normal ***E***-field of the radiating slots which reduce the directivity of the dish by 1dB [7]. The effect is mostly seen in the E-plane radiation pattern with a pinched main lobe, first sidelobes at 10dB below peak and higher wider angle sidelobes between 70° and 90° which are likely to interact with the UAV landing gear. Consequently, an alternate feed was sort.

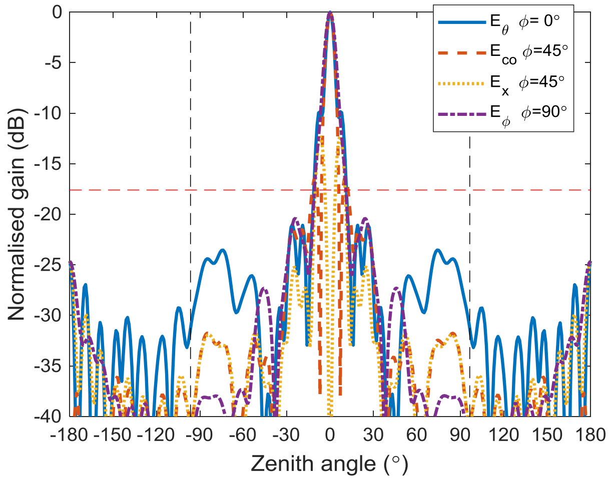


Fig. 8. Radiation patterns of the "all-aluminum" optimized elliptical splash plate fed low cost steel dish at 10.25GHz; from FEKO™.

## IV. Dipole in Cup Feed

A dual mode coaxial horn was formed by combining a coaxial cable fed dipole in a $1\lambda_0$ long $1\lambda_0$ diameter cylindrical horn [13]. A rectangular waveguide fed version was used to feed a $10\lambda_0$ diameter parabolic reflector having $f$/D=0.4 [14]. The small diameter and short $f$/D was close to the $11.6\lambda_0$ diameter of the low cost steel dish at 10.25GHz and the rectangular waveguide feed was attractive due to its rigidity. Readily available 29.5mm diameter 30mm long brandy and whisky bottle lids matched the $1\lambda_0$ x $1\lambda_0$ size requirement for 10.25GHz and were of the preferred metal aluminum.

A parametric study of dipole length and position within a 29.5mm diameter 30mm long cylindrical cup was run in FEKO™ at 10.25GHz. At 4.5mm and 22.5mm from the cup floor, a 13mm dipole was well matched, Figure 9. The former position agreeing with [13]. The on-axis Directivity was about 10dBi irrespective of dipole length or position, except at 18mm where all dipole lengths gave -2.2dBi. This null coincided with the $S_{11}$=0dB ridge for 18mm, Figure 9.

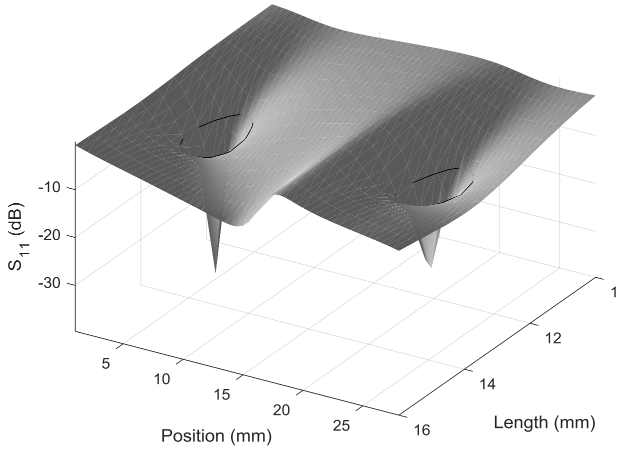


Fig. 9. Effect of dipole length and position on $S_{11}$; from FEKO™, black contour lines mark $S_{11}$=-10dB.

## V. Cup fed by Waveguide

With the design aim of feeding a $1\lambda_0$ x $1\lambda_0$ cup with a rectangular waveguide while avoiding any joints around the primary radiator, topology optimization was tried on a 2mm wide bar Croix de Lorraine shape connecting the short walls of an open waveguide mouth to a 29.5mm x 30mm cup [7]. The resulting structure had adequate $S_{11}$ and gave 0.5dB higher Directivity than the elliptical splash plate across the 3cm band, Figure 6, 7 and 10. The far field radiation pattern was also an improvement over the elliptical splash plate in that the 3dB and 10dB beamwidths of the principal planes equalized and the high wide angle E-plane sidelobes were not excited, Figure 11.

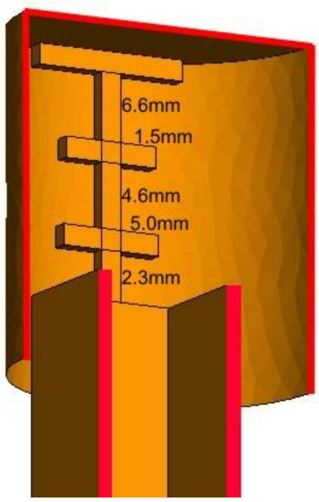


Fig. 10. Cut away diagram of the Croix de Lorraine feed.

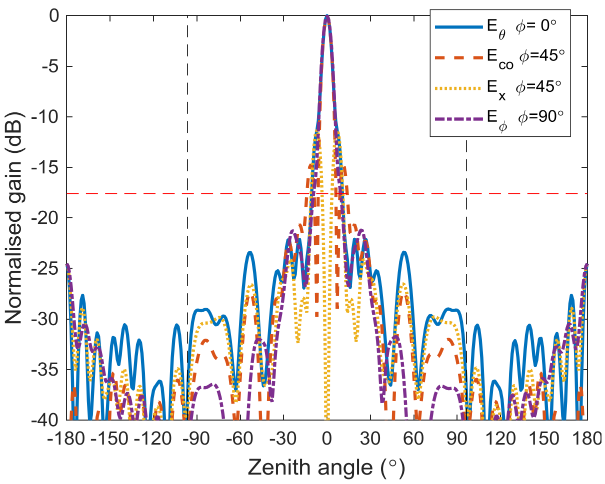


Fig. 11. Radiation patterns of the Croix de Lorraine fed low cost steel dish at 10.25GHz; from FEKO™.

As future work, will investigate rigidizing the Croix de Lorraine feed with nylon bolts.

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