The Inverted E: A Doubly-Shorted F Antenna for Near-Field Sensing Applications

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Abstract

We describe the Inverted E antenna: a novel design of doubly-shorted patch that offers improved bandwidth and aspect ratio performance over a standard Inverted F design, and is smaller than a standard patch. These performance enhancements make the design ideal for use in near-field sensing arrays, and are achieved by adding a second, slightly-offset short on the opposite side from the first. The second short forces the radiating edge to remain constant with changing frequency, rather than moving as with an inverted F. The entire edge space between the two shorts then radiates, which allows a reduction in the size of the patch. This also has the effect of suppressing resonant behaviour, which increases the operating bandwidth of the antenna. The Inverted E is consistently sensitive across all polarisations, with an aspect ratio less than 2 dB in the near field, making it useful as a measurement antenna for sources of unknown polarisation. Prototype antennas were manufactured at Sylatech Ltd. In this paper we present simulation and experimental data for these prototypes, which show them to have a centre frequency of 9.2 GHz, a bandwidth of 300 MHz and a close approximation to circular polarization. The prototypes are now being integrated into compact high element count arrays, for which all the Inverted E's novel features are well-suited.

1 Introduction

The standard microstrip antenna is commonly used as the basis for the elements in phased array antennas, where its compact, two-dimensional design allows arrays to be easily and cheaply manufactured on PCBs. As FPGA technology allows for fast capture and real-time processing of array data, post-focussed synthetic aperture arrays are set to become more prominent in antenna design over the next decade. Improvements to array element design are therefore likely to be a major feature of antenna research and development in the immediate future.

The dimensions of a standard patch patch antenna are set by its frequency of operation: its side length is half the wavelength of its operating frequency, as given in Equation 1 [1], where λ_d is the wavelength in the antenna's dielectric and λ_0 is wavelength in free space. This can make patch antennas too large for many applications where the size of either the elements or the total array is constrained, such as in near-field imaging applications, where too large an array can put parts of the imaging target out of some antenna elements' field of view.

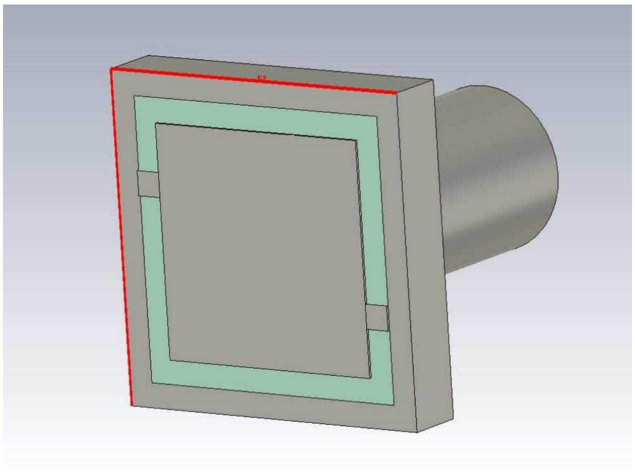

Figure 1: CAD drawing of the Inverted E Antenna

$$L = 0.49\lambda_d = \frac{0.49\lambda_0}{\sqrt{\epsilon_r}} \tag{1}$$

One design for shrinking the size of a patch antenna while maintaining many of its benefits is the Planar Inverted F Antenna (PIFA) [2]. This shrinks the antenna to half its side length by shorting the far end of the antenna to the groundplane – the relationship to a half-wave patch is similar to that between half-wave dipole and quarter-wave monopole designs. In a PIFA, the field near the short are forced to zero, so while the PIFA's current-voltage distribution remains the same as the half-wave patch, the antenna gain is reduced along with the electrical size of the radiating area.

2 Development

The Inverted E was designed to be optimised for near-field imaging of sources of unknown radiative characteristics, such as biological tissues. As the sources may be of undetermined polarisation, a linearly-polarised antenna could produce problems. Hence, a design was constructed with slanted radiation by offsetting the shorts between the radiating patch and the ground plane/housing of the antenna. It was also critical that the antenna could be manufactured in-house at Sylatech, and would easily integrate into an array. The current antenna consists of 3 parts, an aluminium housing, the PCB patch, and an SMA connector. The housing aluminium can be extended to any size, with areas for the patch components removed to quickly make an array of any size. The antenna design is also easily modifiable to be etched on a PCB, allowing cost-effective manufacture of PCB arrays using this design.

The complete manufacturing of the Inverted E involves only 4 steps: milling the aluminium, creating the patch PCB detail on milling machines, using adhesive to stick the PCB to the housing, and soldering the SMA pin to the radiating patch. By creating an aluminium housing that is incorporated in the prototype version of this design, custom and irregular array shapes can be quickly prototyped by moving around a single PCB component into each slot created for the PCB in the arrays. This allows a minimal number of components to be manufactured for the first off array prototype.

Arlon CuClad 217 was used as the dielectric in the prototype antennas; this has a relative permittivity $\epsilon_r = 2.17$. At 9.2 GHz this gives a wavelength of 22.1 mm. The patches are square, with side lengths 10 mm, giving the prototype antennas a side length of 0.45λ. The rationale for this design was to create an antenna which is small and easily placed alongside other antennas in arrays, so reducing the rectangular aspect ratio of the PIFA without the associated deterioration of bandwidth performance is a performance gain for this application.

There are two clear advantages of this design over a standard PIFA, both of which are of great importance to our application. Firstly,

The design also produces good isolation when surrounded by other antennas of the same type. For our current imaging application, up to 24 of these antennae will be placed within a 15x15cm housing, and so isolation is critical to the signal integrity.

2.1 Simulation

The antenna design was modelled using CST Microwave Studio; results can be seen in Figure 1, where the field is seen to be strongest around each of the offset shorts, with a clear constant ground running between

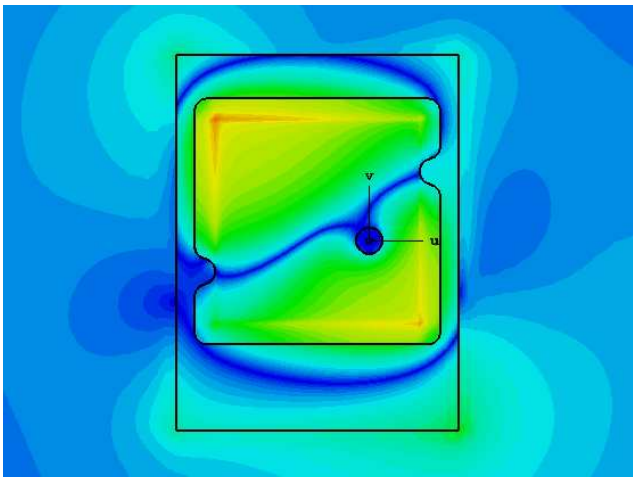

Figure 2: CST simulation of the Inverted E during radiation

the two shorts, through the feed and radiating each side, with maxima around the opposing corners, thus inducing the slanted radiation along both orthoganal edges, giving the low aspect ratio desired for imaging of amorphous targets. Simulations gave the antenna gain as 6.32 dB, with a 3 dB beamwidth of 92.7^0 in the $\phi = 0$ plane and 92.5^0 in the $\phi = 90$ plane. S11 was simulated as being below -10 dB between 8.8105 GHz – 9.1845 GHz: a 374 MHz beamwidth.

3 Test Methodology

The Far-field testing was conducted in an anechoic chamber based at the University of York, as shown in Figure 3. An ETS-Lindgren 3117 double-ridged waveguide was used as the measurement antenna, at a distance of 2.5 metres from the antennas under test. AUTs were mounted on a turntable within the chamber, held 10 cm above the turntable on polypropylene mounts. Beam pattern tests were performed using an Agilent 8510c vector network analyzer, running at a power of 10 dBm.

Cross-talk tests were performed in the same anechoic chamber, with two Inverted Es mounted on the turntable, separated by 24 mm centre-centre. The 8510c was again used, running at 10 dBm as before.

As the antenna is to be used for a near-field imaging operation, producing 3D patterns of the radiation output was deemed crucial to ensure the antenna would work for the desired operation. Near-field testing was conducted using an X-Y scanner constructed at Sylatech Ltd, consisting of two stepper motors, an aluminium frame, an Agilent E4407B Spectrum Analyser and a HP 8350B sweep oscillator, plus AN74 used as the absorbing foam. The Inverted E antenna was used as the stationary source, whilst an X-band loop was used as the receive antenna. The antenna under test

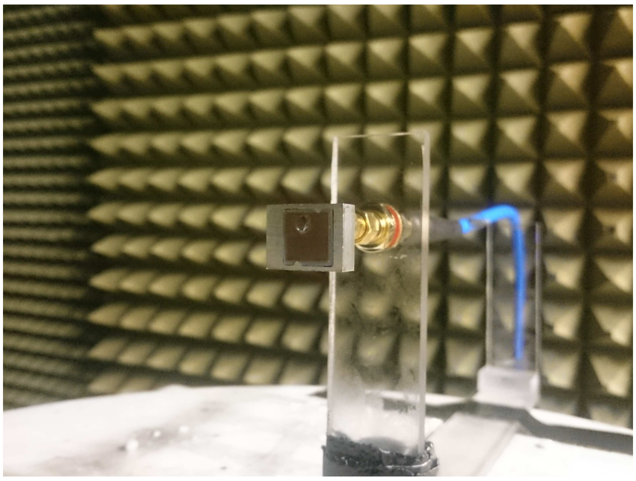

Figure 3: An Inverted E antenna during beam pattern testing in the York anechoic chamber

Figure 4: An Inverted E antenna during beam pattern testing in Sylatech X-Y scanner

Table 1: Far-field antenna characteristics

Beamwidth (f = 9.2 GHz)		
	Simulation	Measurement
θ	95^0	104.0^0
ϕ	96^0	84.4^0
Directivity (9.2 GHz)		
	6.6	6.7 dB
Bandwidth (S11 $\leq$ -10 dB)		
f_l	8.81	9.06 GHz
f_h	9.18	9.30 GHz

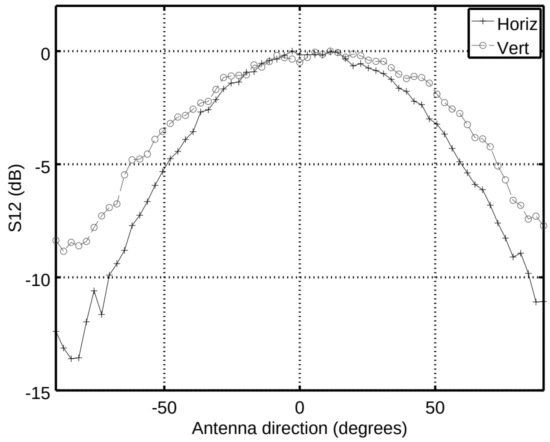

Figure 5: Beam pattern in Horiz & Vert polarisation

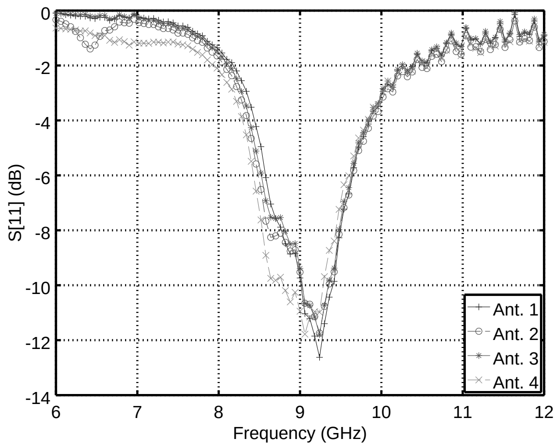

Figure 6: S11 from Anechoic Chamber

was separated by 10 centimetres from the measurement antenna, which was a loop with a gain of $\leq$ 2 dB. A 200x200 step scan was run, with a step size of 0.3 mm over a 60 cm test bed.

4 Results

4.1 Far Field Results

Results from the measurements in the anechoic chamber are shown in Table 1, and in Figures 5 to 7. The directivity, at 6.7 dBi, agrees with simulation and is in line with what would be expected from patch antennas of this size. The aspect ratio of < 2 dB allows the antennas to receive signals of all polarizations, which is a useful characteristic in the intended imaging application. Also useful for imaging is the low crosstalk, which is never above -26 dB for 24 mm centre-centre separation – which equates to 9 mm between the prototype antennas' housings. This allows the antennas to be packed close together in arrays while maintaining the signal to noise ratio required by imaging.

$$Gain = \frac{32400}{BW_{\theta} BW_{\phi}} \tag{2}$$

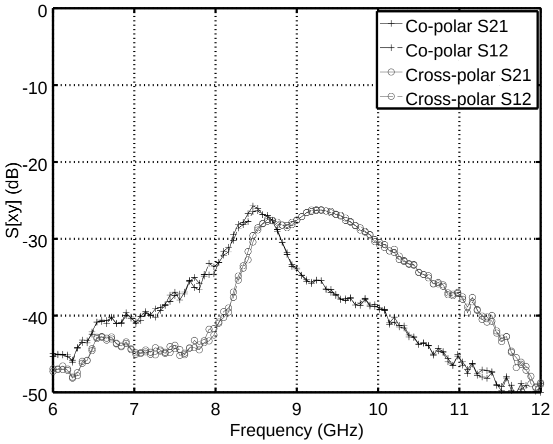

Figure 7: Crosstalk, measured at 24 mm separation in Anechoic Chamber

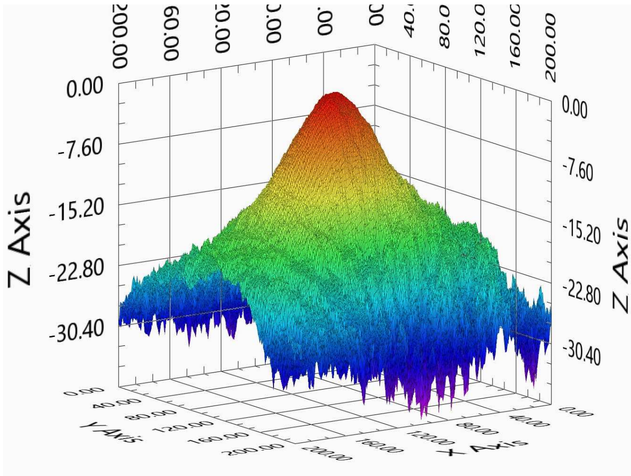

Figure 8: x-plane beam plot from X-Y scanner

Table 2: Near-field antenna directivity

Directivity (f = 9.2 GHz)	
θ	26.5^0
ϕ	18.6^0

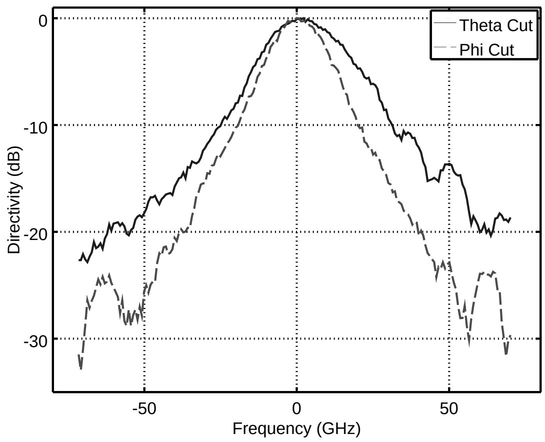

Figure 9: θ and ϕ near-field directivity of the Inverted E, measured on the X-Y scanner

4.2 2D Scanner Results

The results from the XY scanner measurements are given in Table 2. Directivity is plotted in Figure 9. Figure 8 shows a representation of the 3D data gathered from the scanner.

These measurements were taken at 10 cm distance, which is within the antennas' Fresnel zone. The directivity measured here is over three times that of both the far-field measurements and the simulations. No loading effects would be expected at 10 cm, and the 3D plots from the scanner (e.g. in Figure 8 offer no clues as to this discrepancy, as they show a normal-looking beam pattern. This discrepancy must be regarded as significant, and is discussed in the next section.

5 Discussion

Testing of the Inverted E prototypes has demonstrated that they are similarly directive to other antennas of this size, and additionally have low values for crosstalk and for aspect ratio – both of which make them suitable for near-field array imaging. The fractional bandwidth is 3-4% which is sufficient for its intended application, while the antenna length has been kept to 10 mm; a PIFA may be made wideband, but only if it lengthened to a point that would be infeasible for use in an array. For applications where element count matters, achieving a sufficient bandwidth while minimising the side length is an important performance consideration.

A discrepancy remains, however, between the results taken in the anechoic chamber and in the 2D scanner. The anechoic measurements were taken in an established facility and also agree with simulation, whereas the XY scanner was new at the time of measurement, the anechoiic results should be preferred, subject to further investigation. It would be interesting to use the scanner to measure at closer ranges to detect the limits of the antennas' reactive near-field zone; however, the measurements at closer ranges suffered from excessive reflections, so this is currently infeasible.

The results show that there is a clear radiation main lobe forming in front of the antenna, and that the radiation is not linearly polarised relative to the orientation of the antenna itself – aspect ratio was consistently measured as < 2 dB. The radiation pattern contains no high sidelobes – another beneficial characteristic in an antenna designed primarily for imaging applications.

6 Conclusions

The Inverted E is an advance on the microstrip patch and Inverted F antennas, adding a second short to stabilise the location of the radiating edge, and offsetting the location of the second short in order to reduce aspect ratio. This latter property has been measured at < 2 dB at the prototype antennas' operating frequency of 9.2 GHz. Prototypes have a bandwidth of around 250 MHz, and crosstalk as been measured at <26 dB at a separation of 0.8λ.

In the future, it would be interesting to use an Inverted E as the measurement antenna on an receive on the X-Y scanner, to determine the minimum signal and resolution detectable by the antenna. Varying output power and antenna shape would produce a variety of pattern parameters, and the clarity at which it can determine these would lead to a better idea of how the array will perform as a whole.

A key area for improvement would be to carry out high accuracy scans of the full 360 theta and phi cuts, to allow mathematical calculation of the gain of the antenna. It would also be beneficial to repeat the X-Y tests, using multiple antennas as the source to determine the isolation and interference patterns that are produced by an array of Inverted E elements.

References

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[2] Kin-Lu Fang, Shyh-Tirng; Yeh, Shih-Huang; Wong. Planar Inverted-F Antenna, 2004.

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