Multi-Port Amplifier fed Linear Array

P. James

Airbus Defence and Space (UK) Ltd, Portsmouth, Hampshire, PO3 5PU, UK

Abstract — The object of this paper is to describe the possibility of feeding a linear array with a pair of MPAs, so that a variable amplitude taper can be applied to the array. This may be achieved by switching edge elements off completely or giving them relatively low amplitude, whilst at the same time using all the amplifiers at or near their maximum. Hence the array may be used most efficiently. The aim of this paper is to show that a pair of 8x8 MPAs may feed a linear array. It will also present some predictions of the radiation patterns.

I. INTRODUCTION

An MPA is used to amplify signals with typically 8 input and 8 output ports, although designs with other numbers are possible, fig 1, [1]. It comprises of a power divider or INET, amplifiers and a power combiner ONET, [2, 3]. Now an 8 x8 MPA feeding directly into an 8 element linear array sounds very attractive but the internal amplifier power range can be very large with some combinations of input signals. For any combination of input signals the MPA operates most effectively with uncorrelated rather than correlated signals. However an 8 x8 MPA can have 1, 2 or 4 correlated signals applied and the internal amplifiers do not see a variation at all. From this situation a pair 8x8 MPAs feeding an 8 element linear array with the 4 outputs of each MPA feeding centre and edge elements - other outputs having matched loads- will allow the amplifiers to operate at a maximum for an array of 8, 4 or 2 elements in operation. This allows the array to change its beam width and sidelobe levels.

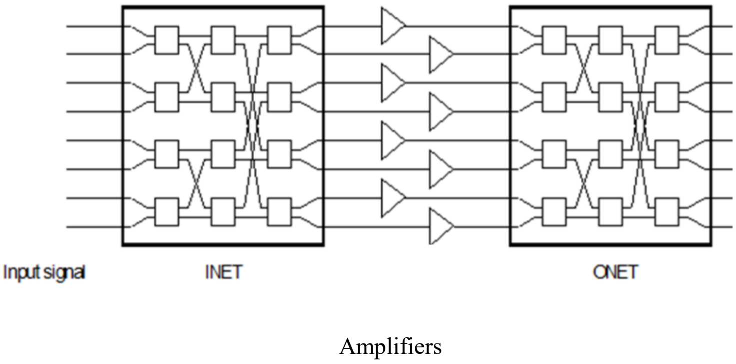

Fig. 1 The MPA showing the amplifiers and matrix networks

II. MODEL OVERVIEW

An 8 x 8 MPA can amplify up to 8 input signals. It achieves this by splitting the incoming signals 8 ways within an INET, amplifying these quadrature and 180° phase signals and recombining them within an ONET, [4, 5 & 6]. The MPA model comprises of an INET and ONET which are assumed to be the same. Amplifiers are located within each path.

Operation of the MPA can be understood more clearly if the INET and ONET matrices are expressed as **A** and the amplifiers by the diagonal matrix **S** and phase and amplitude errors defined as the diagonal matrix **E**. An 8 x 8 INET or ONET is composed of 12 hybrid couplers where each hybrid transfer function is defined by **h**:

$$h := \begin{pmatrix} 1 & e^{-\pi \frac{i}{2}} \\ e^{-\pi \frac{i}{2}} & 1 \end{pmatrix} \cdot \frac{1}{\sqrt{2}}$$

The ideal INET or ONET matrix is composed of a set of 12 of these 2 x 2 **h** matrices given as:

$$A := \begin{bmatrix} 1 & e^{\frac{-\pi\cdot i}{2}} & e^{\frac{-\pi\cdot i}{2}} & e^{\pi\cdot i} & e^{\frac{-\pi\cdot i}{2}} & e^{\pi\cdot i} & e^{\pi\cdot i} & e^{\frac{\pi\cdot i}{2}} \\ e^{\frac{-\pi\cdot i}{2}} & e^{\pi\cdot i} & 1 & e^{\frac{-\pi\cdot i}{2}} & e^{\pi\cdot i} & e^{\frac{\pi\cdot i}{2}} & e^{\frac{-\pi\cdot i}{2}} & e^{\pi\cdot i} \\ e^{\frac{-\pi\cdot i}{2}} & e^{\pi\cdot i} & e^{\pi\cdot i} & e^{\frac{\pi\cdot i}{2}} & 1 & e^{\frac{-\pi\cdot i}{2}} & e^{\frac{-\pi\cdot i}{2}} & e^{\pi\cdot i} \\ e^{\pi\cdot i} & e^{\frac{\pi\cdot i}{2}} & e^{\frac{-\pi\cdot i}{2}} & e^{\pi\cdot i} & e^{\frac{-\pi\cdot i}{2}} & e^{\pi\cdot i} & 1 & e^{\frac{-\pi\cdot i}{2}} \\ e^{\frac{-\pi\cdot i}{2}} & 1 & e^{\pi\cdot i} & e^{\frac{-\pi\cdot i}{2}} & e^{\pi\cdot i} & e^{\frac{-\pi\cdot i}{2}} & e^{\frac{\pi\cdot i}{2}} & e^{\pi\cdot i} \\ e^{\pi\cdot i} & e^{\frac{-\pi\cdot i}{2}} & e^{\frac{-\pi\cdot i}{2}} & 1 & e^{\frac{\pi\cdot i}{2}} & e^{\pi\cdot i} & e^{\pi\cdot i} & e^{\frac{-\pi\cdot i}{2}} \\ e^{\pi\cdot i} & e^{\frac{-\pi\cdot i}{2}} & e^{\frac{\pi\cdot i}{2}} & e^{\pi\cdot i} & e^{\frac{-\pi\cdot i}{2}} & 1 & e^{\pi\cdot i} & e^{\frac{-\pi\cdot i}{2}} \\ e^{\frac{\pi\cdot i}{2}} & e^{\pi\cdot i} & e^{\pi\cdot i} & e^{\frac{-\pi\cdot i}{2}} & e^{\pi\cdot i} & e^{\frac{-\pi\cdot i}{2}} & e^{\frac{-\pi\cdot i}{2}} & 1 \end{bmatrix} \qquad (2)$$

The amplifier matrix is defined as:

$$S := \begin{bmatrix} s1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & s2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & s3 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & s4 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & s5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & s6 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & s7 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & s8 \end{bmatrix}$$

(3)

Where the amplification is provided by the amplifiers s1,s2,s3,s4,s5,s6,s7,s8. These are nominally equal and set at unity. If a single signal Vin is injected into the MPA it may be represented by:

Vin = (1 0 0 0 0 0 0 0) (1)

Then the output signals can be expressed in matrix form as:

$$\mathbf{Vout = A\ S\ A\ Vin^T} \qquad (2)$$

The output amplified signal is given by

Vout= (0 0 0 0 0 0 0 S) (3)

The internally amplified signals may be predicted as:

$$\mathbf{Vmid = S\ A\ Vin^T} \qquad (4)$$

Now all the components of **Vmid** should be equal if the MPA is balanced. So if we wish to feed a linear array with an MPA the input signal vector must be of the form:

Vin= (1 i 0 0 0 0 i 1)

Thence **Vmid** = (1 –i -1 –i –i -1 –i 1) x 0.707

Vout = **A S A Vin**^{T}

Vout^T = (i 0 0 -1 -1 0 0 i)

The output signal phases can be equalized by suitable lengths of transmission line. Therefore the four output signals from MPA no. 1 and MPA no. 2 are fed into an 8 element linear array with all other unused input and output ports being correctly terminated, fig 2. The active output ports of the two MPAs form the vector of array elements **a,** with amplitudes a_n, and phases α_n.

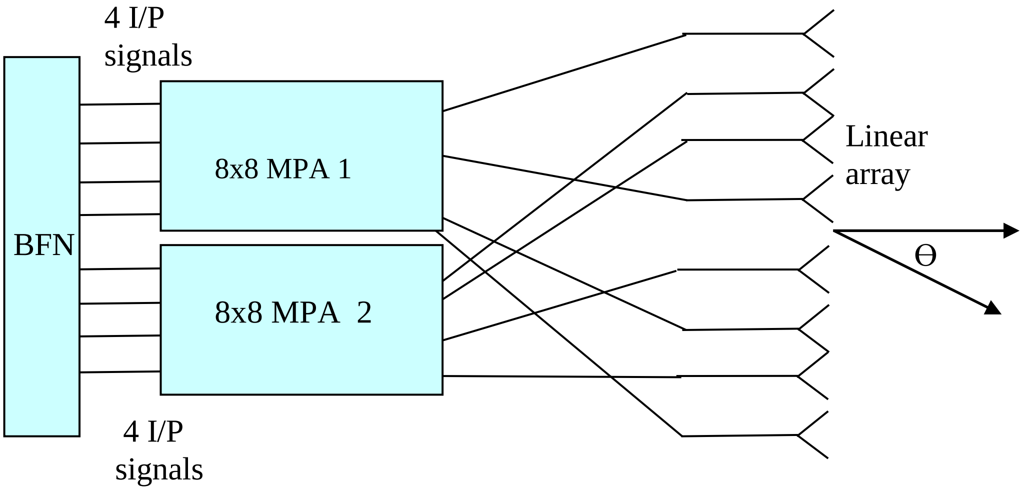

Figure 2 MPA fed 8 element linear array fed from a Beam Forming Network (BFN)

The vector **a** of array elements is then used to calculate the far-field radiation pattern [6]:

$$E(\Theta) = \sum_{n=0}^{n=7} a_n \ e^{(-ikdn \sin \Theta - i\alpha_n)}$$

Where d is the array element spacing, typically set at 0.7 of a wavelength. ϴ is angle, see fig 2, α is applied phase shift.

An alternative MPA feed arrangement is one in which the two MPAs feed into a linear array composed of 16 element radiators. In this arrangement the power output from the 2 sets of eight amplifiers are fed into 16 element radiators, that is, the power per amplifier is fed into each antenna element. This may be seen as a more efficient antenna and feed arrangement.

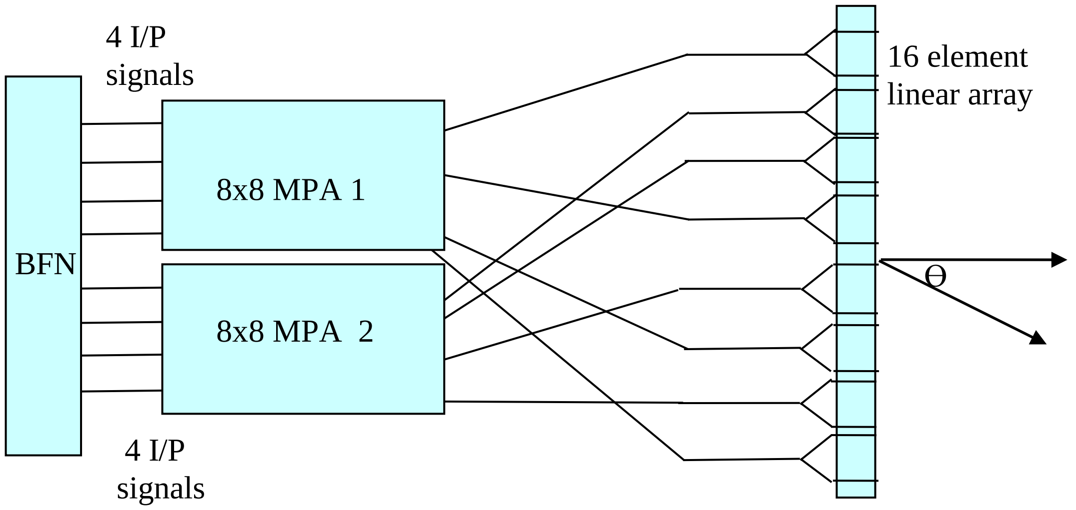

Figure 3 MPA fed 16 element linear array fed from a Beam Forming Network (BFN)

IIII. MODELLING METHOD

An array fed by two MPAs may be operated with all 8 element radiators emitting with constant amplitude signal. Alternatively it may be operated with 2 less input signals feeding into the MPAs and feeding 6 element radiators and to generate a wider beamwidth but still utilize all the amplifiers. This can progress to feed 4 or 2 and generate ever wider beamwidths but still utilize all the amplifiers. The 16 element linear array fed MPA modelling is very similar.

Alternatively, an amplitude taper [6, 7] may be applied to control the sidelobes and increase the beamwidth. So long as the amplitude taper is symmetric it will cause no variation in the powers of the amplifiers. Some beam squint is possible although this will disturb the inner MPA amplitude distribution to some extent and a trade-off between squint angle and amplifier amplitude ripple may be necessary. Of course if the phase shifters are placed after the MPAs then any squint may be possible subject to the occurrence of grating lobes in the far-field pattern.

V. PREDICTIONS

A model was assembled using matlab © and successfully simulated to generate antenna radiation patterns. For the case of all 8 element radiators emitting with constant amplitude the resulting radiation pattern is shown in fig 4. When only 6 input ports of the two MPAs are used it forms a 6 element array, yet uses all the amplifiers of the MPA is shown in fig 5. When only 4 input ports of the two MPAs are used it forms a 4 element array, yet uses all the amplifiers of the MPA, the radiation pattern is shown in fig 6. Following on from this when only 2 input ports are used it forms a 4 element array and the radiation pattern is shown in fig 7.

An amplitude taper, fig 8, has been applied to the array in order to reduce the sidelobe structure, [7], to below -20 dB, the pattern is shown in fig 9. In this case there is no amplitude ripple within the amplifiers of the MPA. If a phase taper is applied to an 8 element array with amplitude taper it will give a beam squint of 5º as shown in fig 10. There is however a power distribution within the MPA on the amplifiers of about 2 dB, fig 11. This is significantly lower than the amplitude taper applied to the linear array however. If the antenna is squinted to a further angle then a greater amplifier power variation is experienced as shown in fig 12. Of course phase shifters could be located between the MPAs and the linear array to give conventional phase steering with no amplifier amplitude variation.

Applying a Fourier Transform beam shaping technique, [7], produces a wide beamwidth of 29 degrees with a low sidelobe structure of -21 dB as shown in fig 13. The corresponding amplitude taper for this shaped beam is shown in fig

14. A concern is that if an amplifier should cease working there would be degradation to the antenna pattern. This would result in a 1/16th or 0.3 dB loss of power with the resulting radiation pattern is shown in fig 15.

A 16-element linear array fed by two MPAs as shown in fig 3 forms a narrow beam radiation pattern with a uniform amplitude distribution in fig 16. A 16-element linear array fed by two MPAs with an amplitude distribution that creates a radiation pattern with -24 dB sidelobes is shown in fig 17. The corresponding amplitude distribution is shown in fig 18, although the amplitude distribution within the two MPAs is zero. A broader beam formed from a 16 element array with some sidelobe control is shown in fig 19 with a 12 deg and -15 dB sidelobe level with its aperture distribution shown in fig 20. A beam with 10 degrees and -17.5 dB sidelobe level is shown in fig 21.

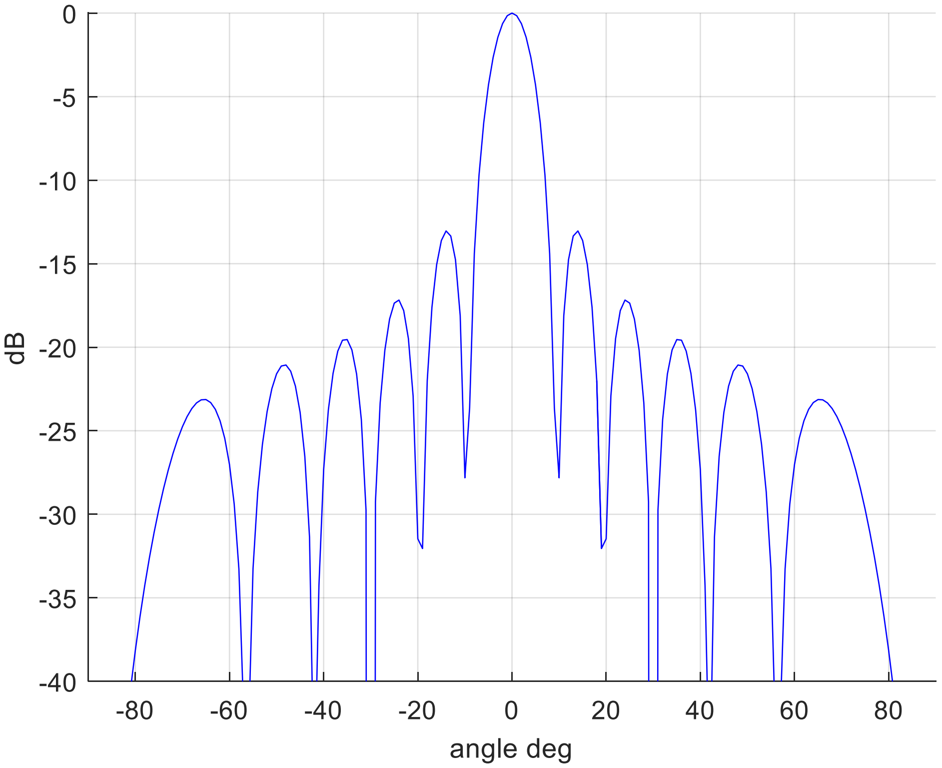

Fig 4 Antenna pattern generated from an 8 element linear array

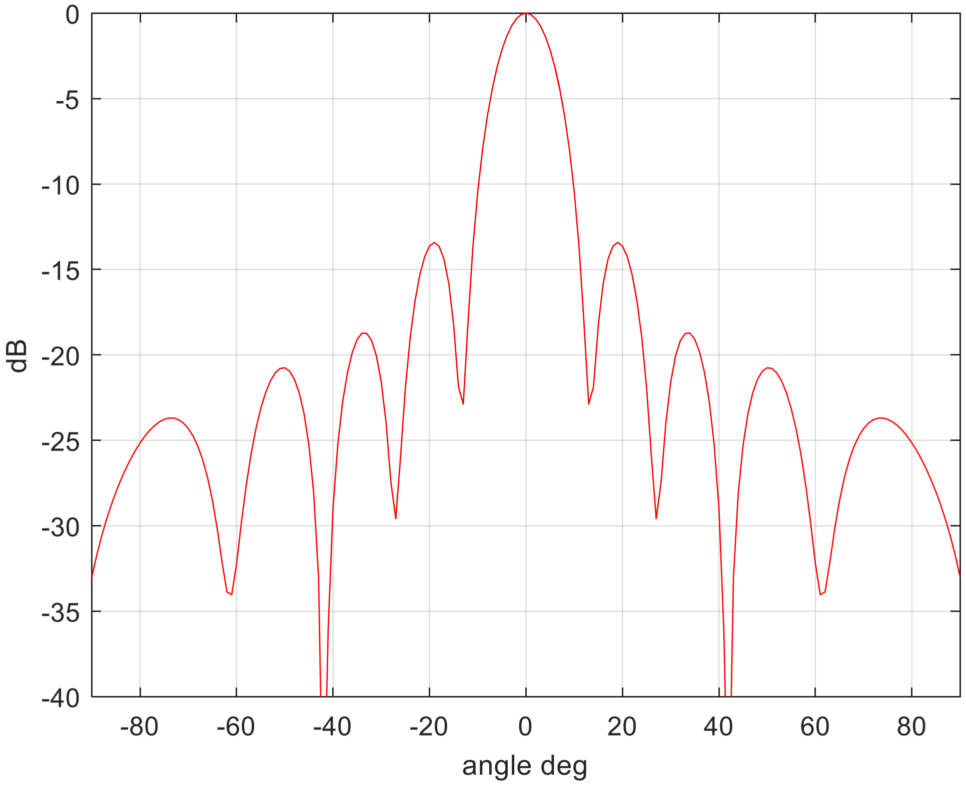

Fig 5 Antenna pattern generated from a 6 element array

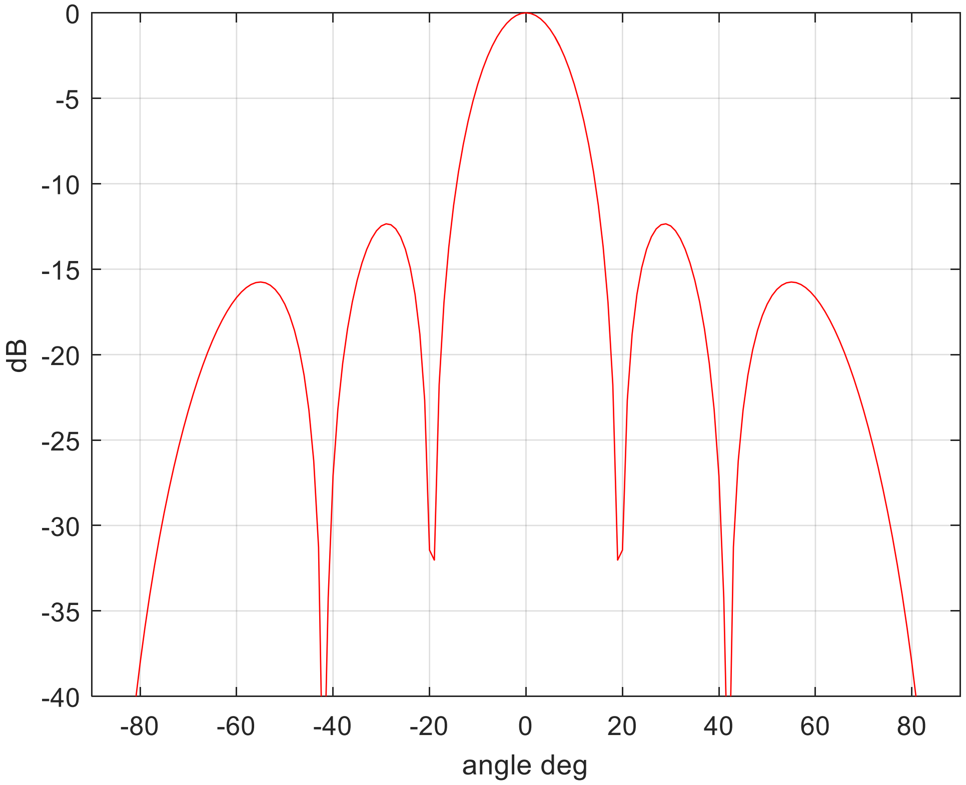

Fig 6 Antenna pattern generated from a 4 element array

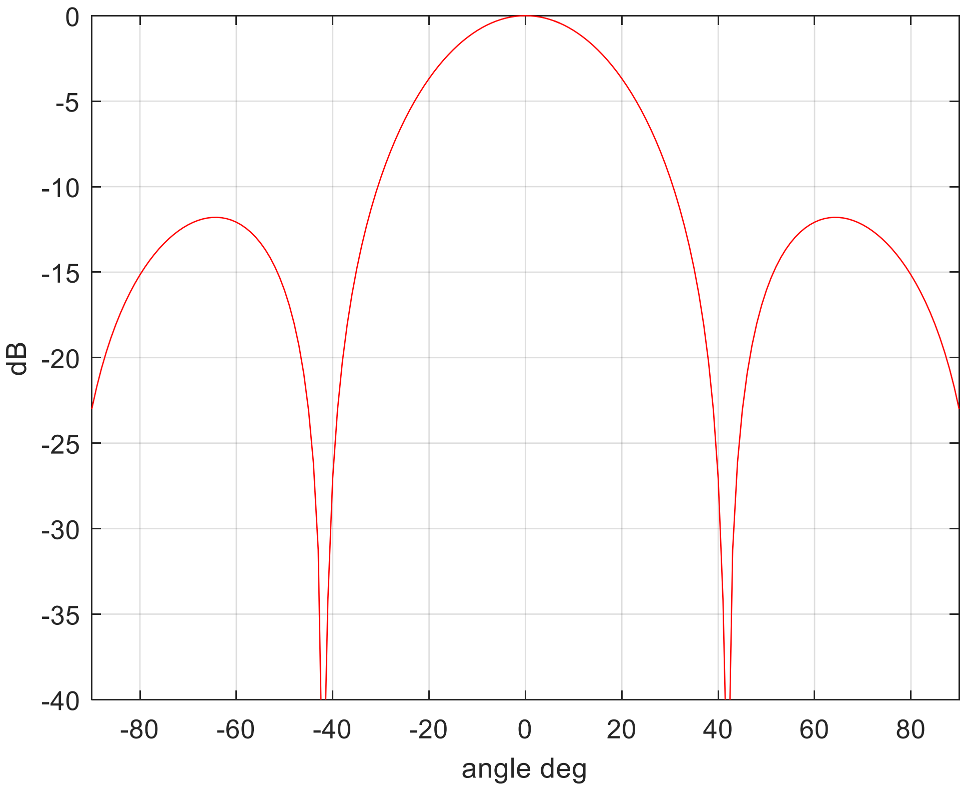

Fig 7 Antenna pattern generated from a 2 element array

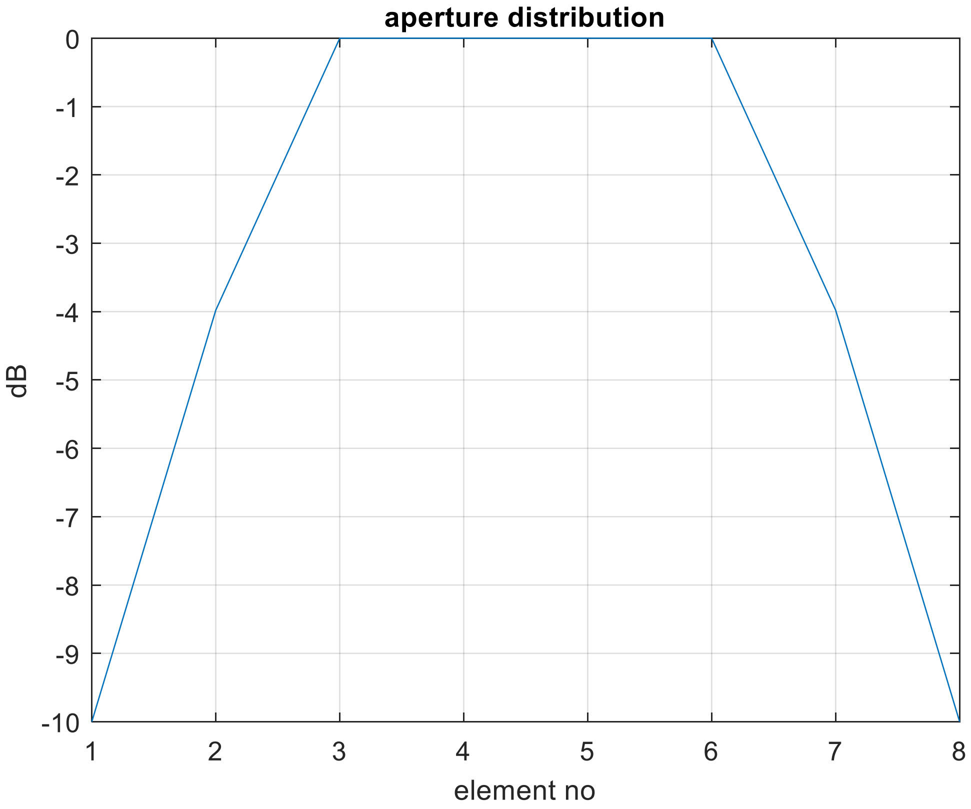

Fig 8 An 8 element array with amplitude taper for fig 9

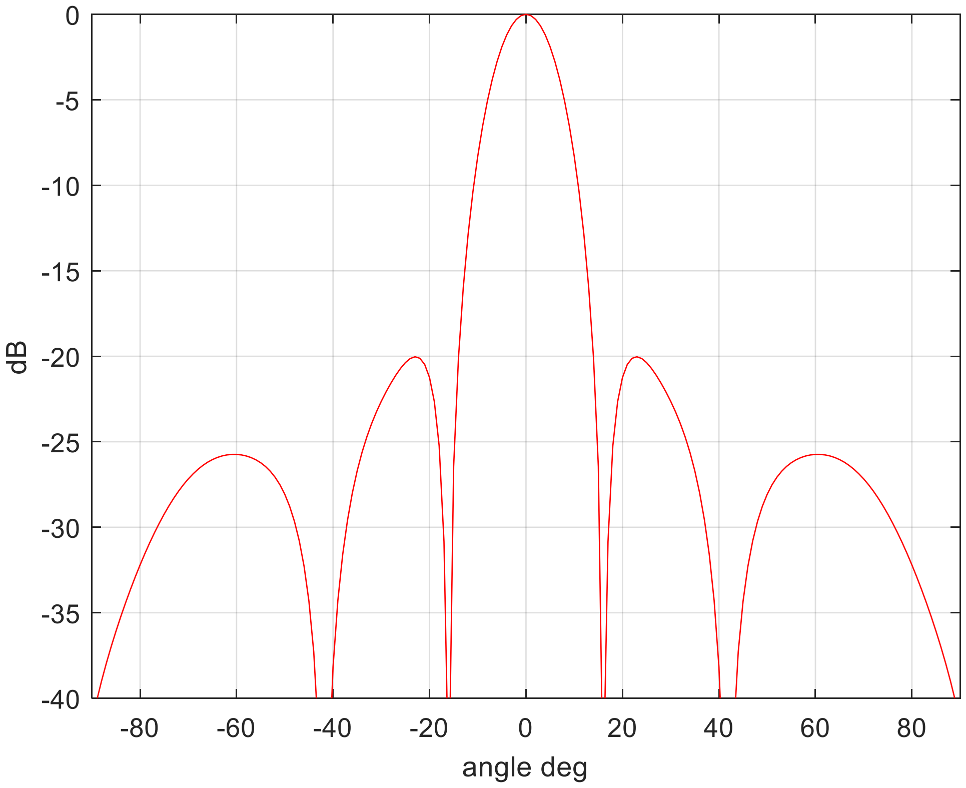

Fig 9 Antenna pattern generated from an 8 element array with amplitude taper

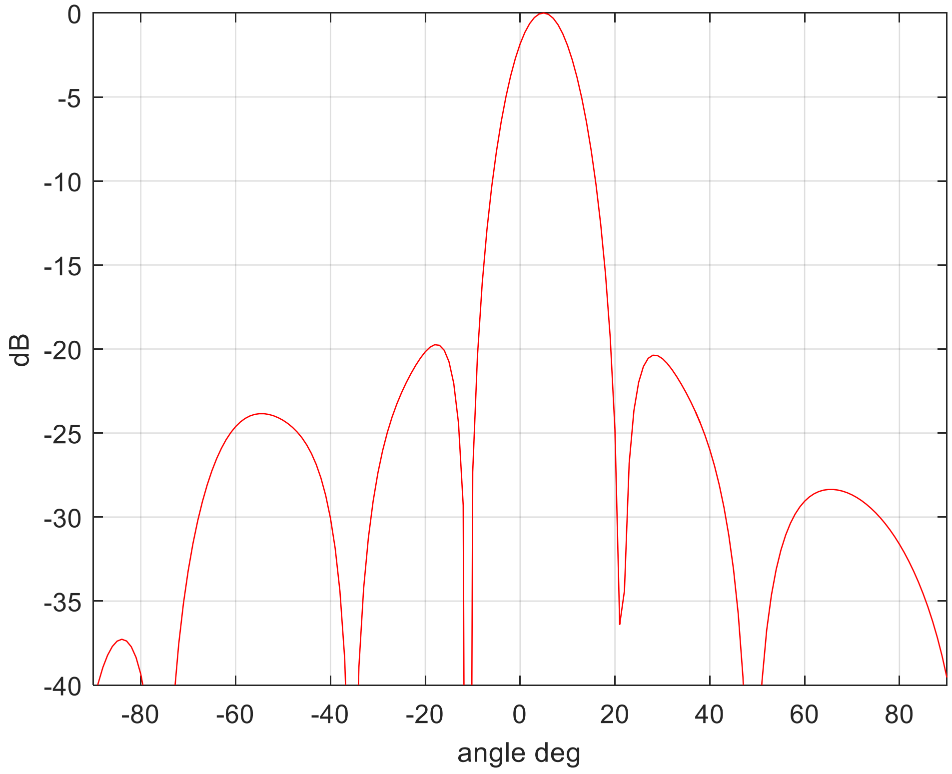

Fig 10 Pattern generated from an 8 element array with an amplitude taper and squint

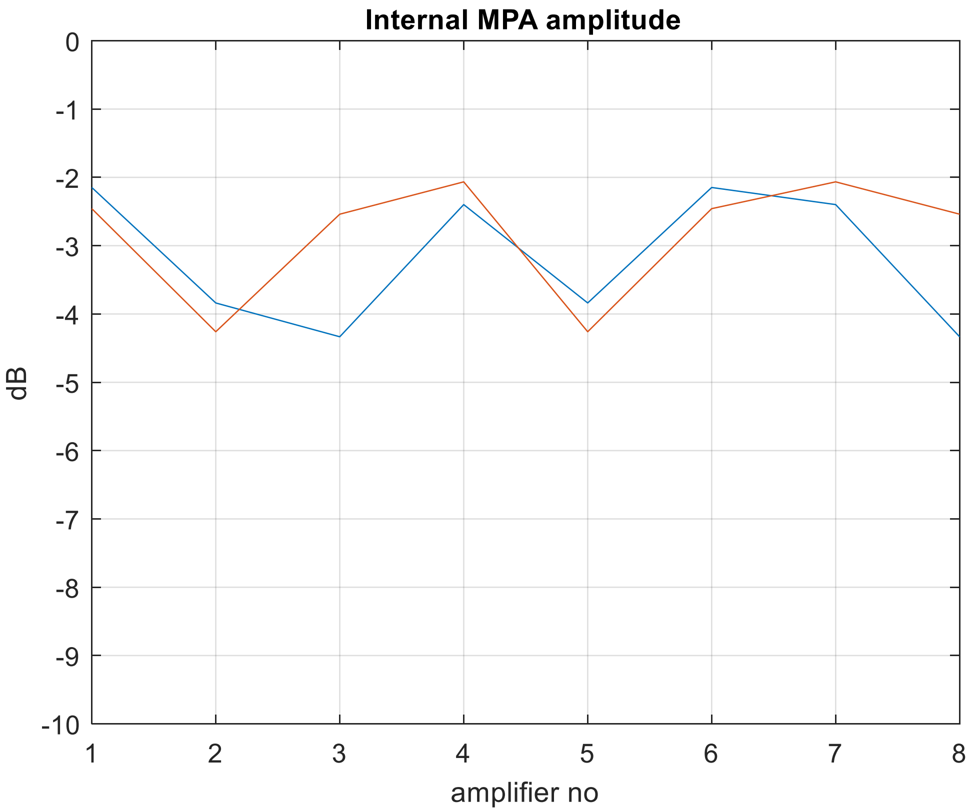

Fig 11 Amplifier power distribution for 8 element array with an amplitude taper and squint

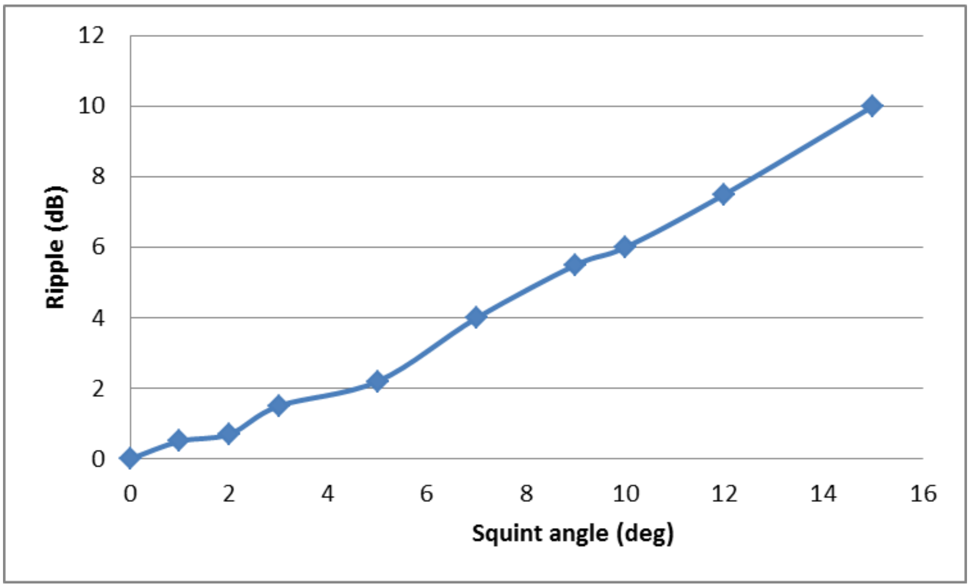

Fig 12 MPA amplitude ripple vs. beam squint angle

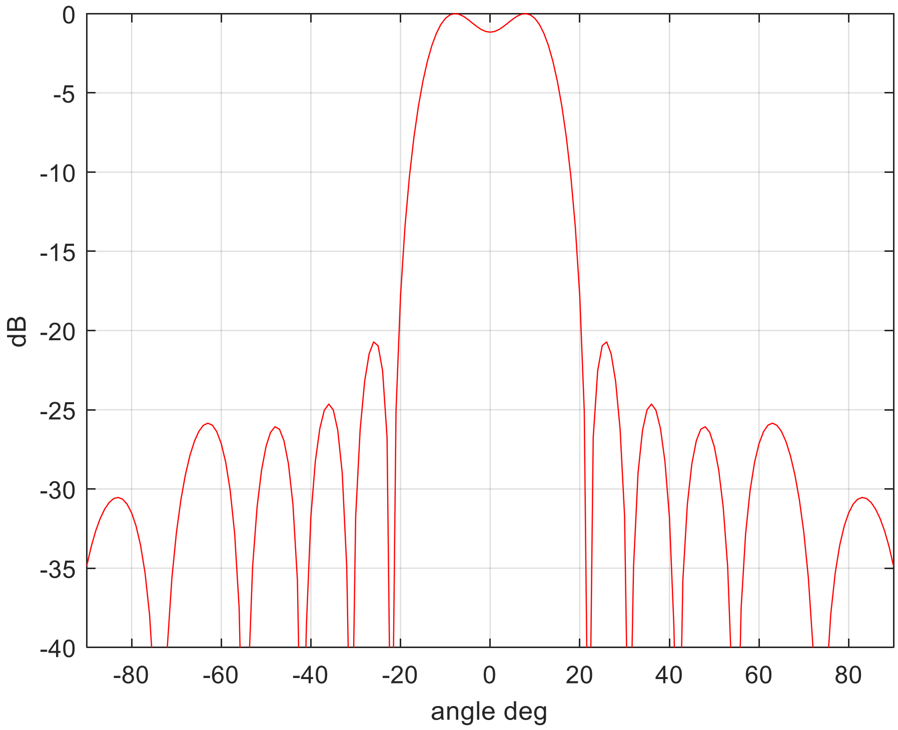

Fig 13 Shaped pattern generated from an 8 element array with an amplitude distribution to produce a half power beam width of 29 degrees and a sidelobe level of -21 dB.

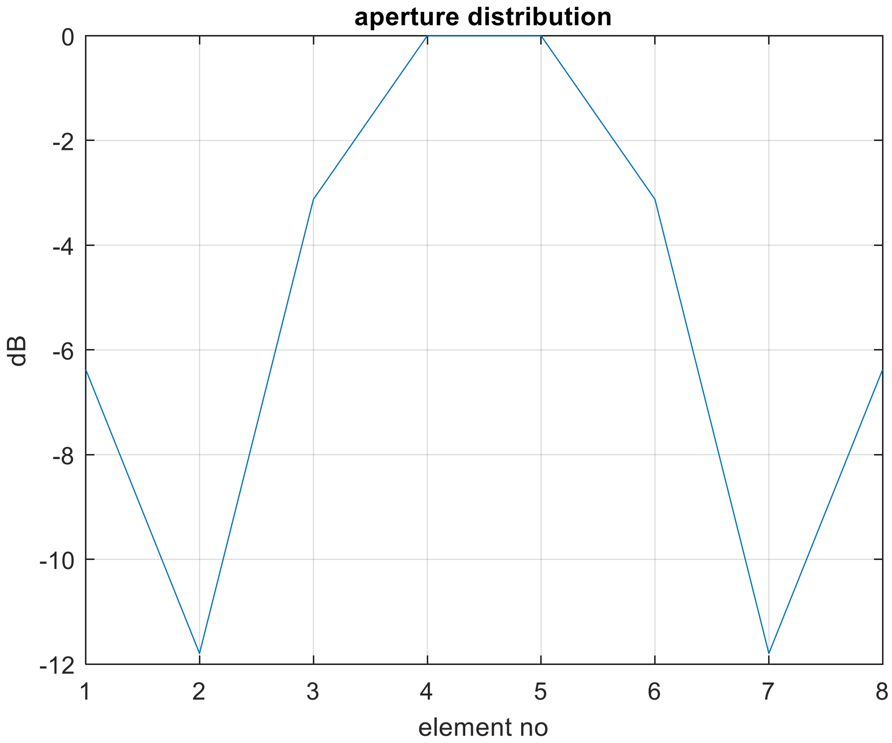

Fig 14 The corresponding amplitude distribution for the shaped beam with half power beam with of 29 degrees

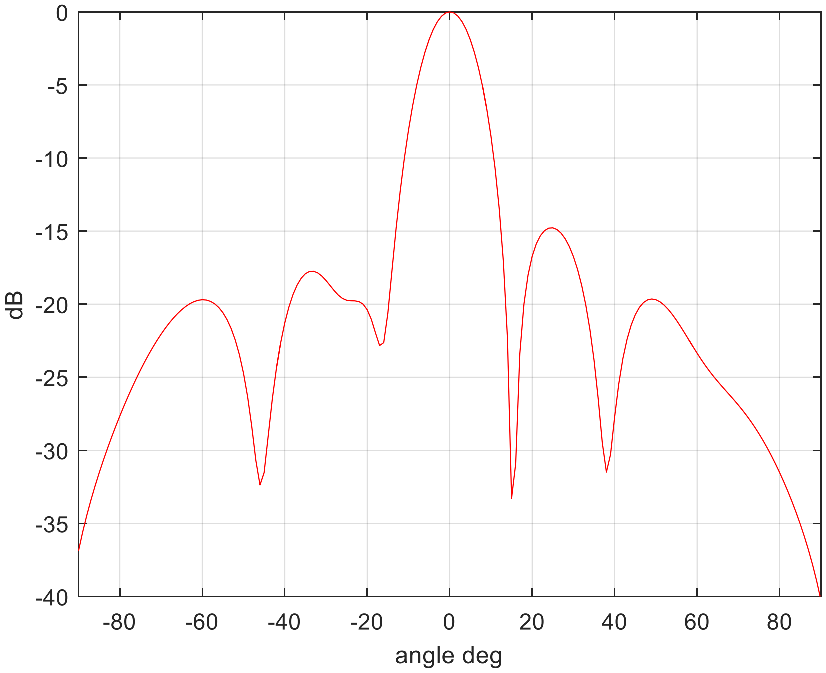

Fig 15 A radiation pattern produced from an 8 element array with an amplitude distribution (cf. fig 9) and one failed amplifier.

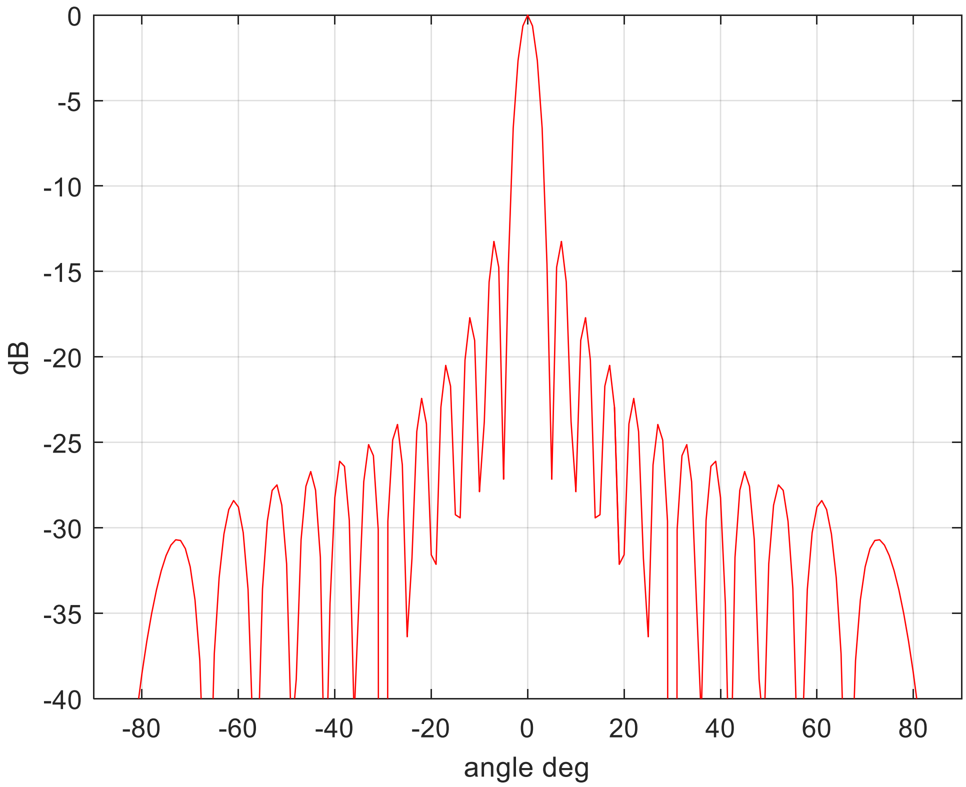

Fig 16 Antenna pattern generated from a 16 element array with no amplitude distribution

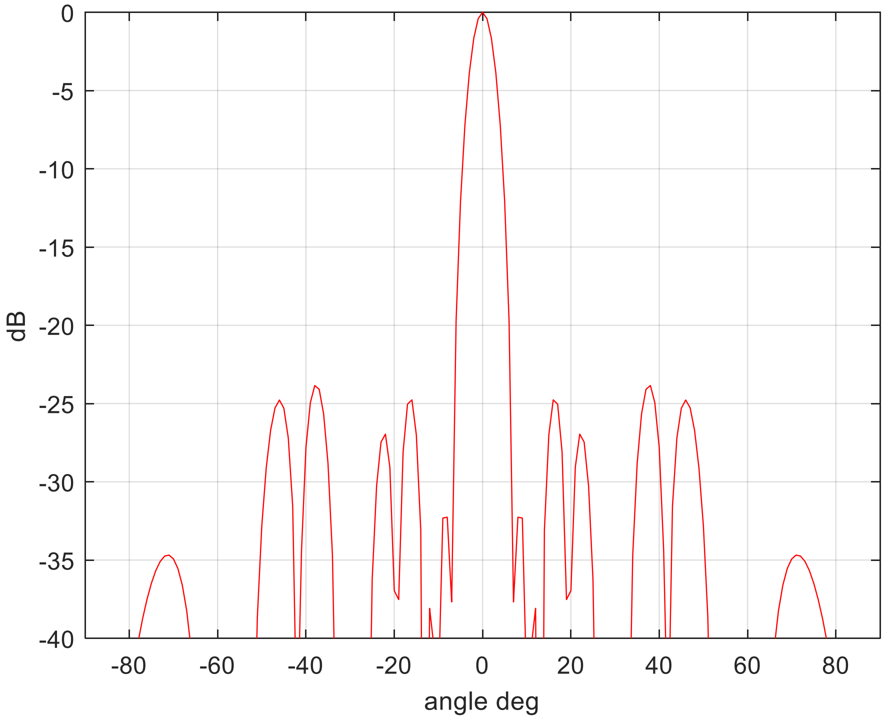

Fig 17 Antenna pattern generated from a 16 element array with amplitude taper to give -24 dB sidelobe level.

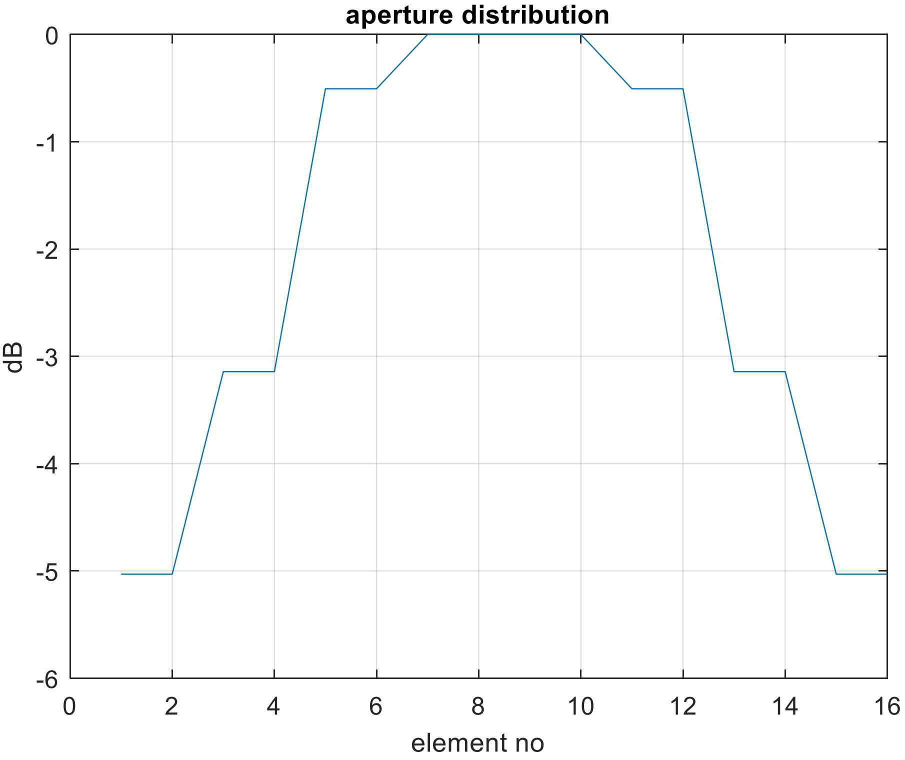

Fig 18 The 16 element array antenna distribution corresponding to a pattern with a -24 dB sidelobe level.

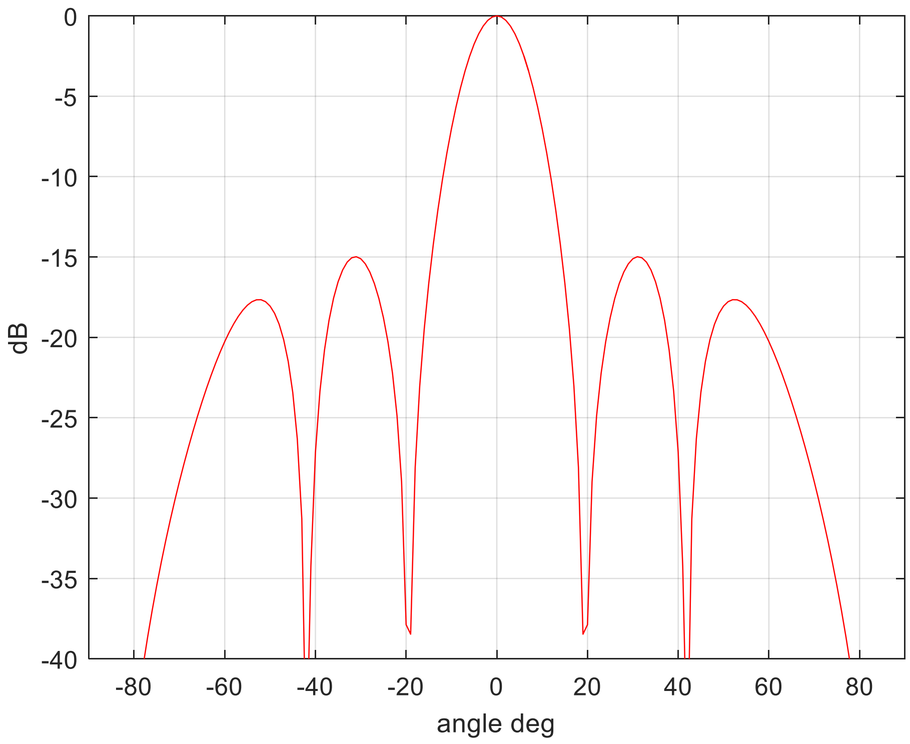

Fig 19 Antenna pattern generated from a 16 element array with an amplitude distribution designed to give a broad beam half power beamwidth of 12 deg and -15 dB sidelobe level.

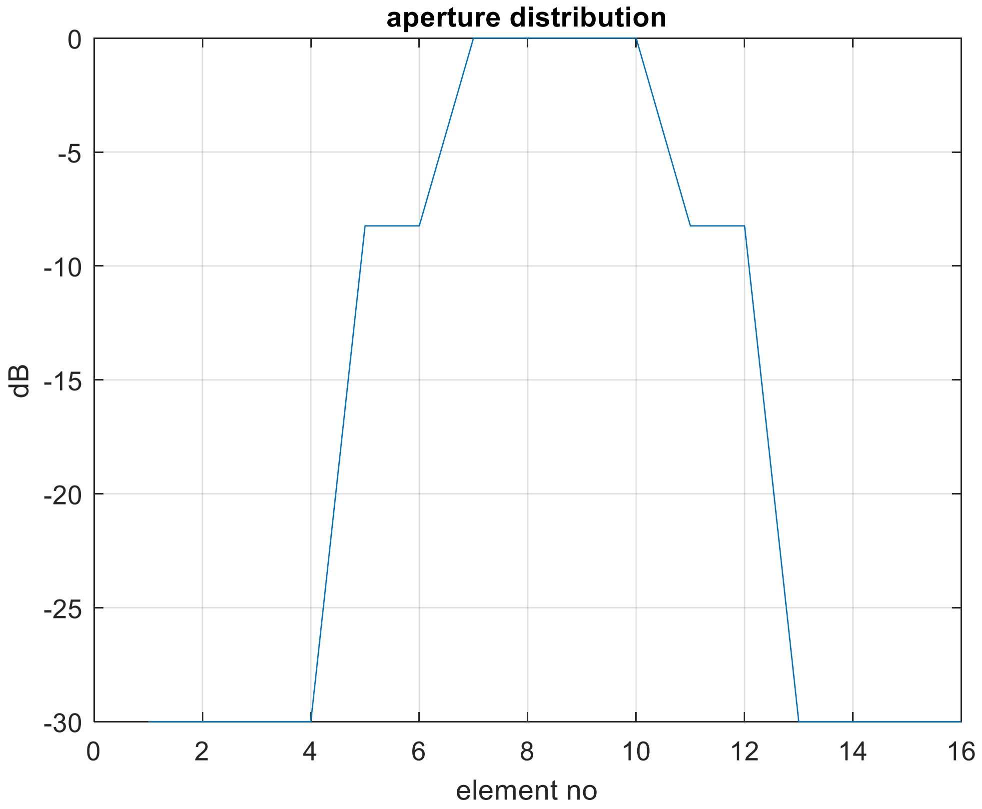

Fig 20 The aperture distribution for the above antenna radition pattern

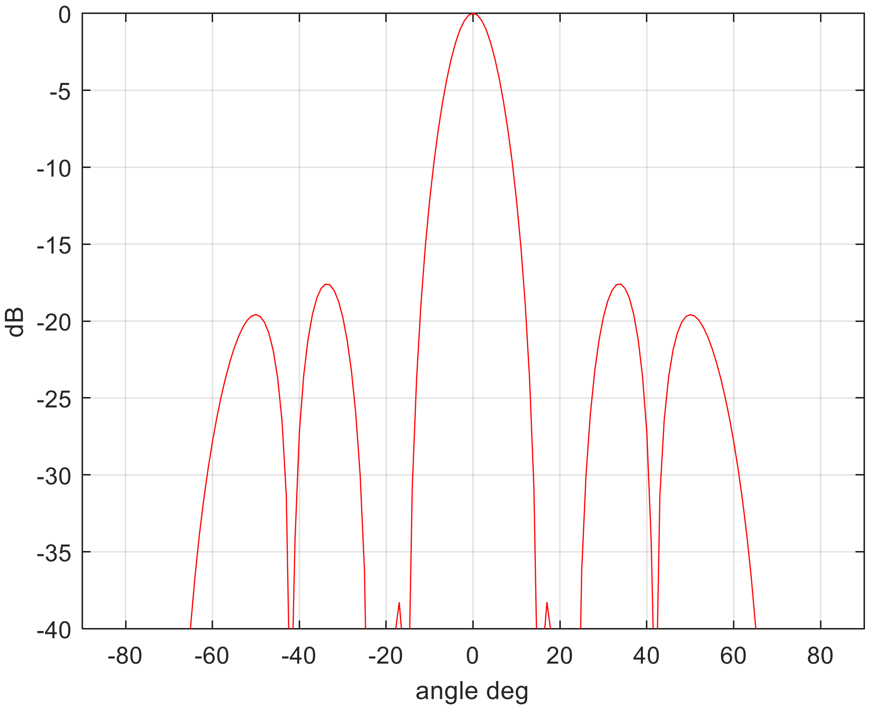

Fig 21 Antenna pattern generated from a 16 element array with an amplitude distribution designed to give a broad beam half power beamwidth of 10 degrees and -17.5 dB sidelobe

VI. CONCLUSION

This paper has described the theoretical design of a pair of 8x8 MPAs that feed an 8 element linear array with the 4 outputs of each MPA. They feed the centre and edge element radiators and will allow the amplifiers to operate at a maximum power for an array with 8, 4 or even as low as 2 elements in operation. It also enables an amplitude taper to be applied to the array. This allows the array to change its beam width and sidelobe levels without the corresponding loss of power of the amplifiers within a conventional linear array. Examples of radiation patterns formed with different array tapers have been presented. It has also demonstrated that a failure of an amplifier has minimal changes to the antenna sidelobe structure. It has showed that some beam scanning is possible with a degree of amplitude variation within the amplifiers of the MPAs. This configuration could be extended to a 16 element linear array with similar characteristics.

VI. REFERENCES

[1] The Butler Matrix Transponder', Comsat Tech. Rev., vol. 4. no.2, pp. 319-345, Fall 1974. W. A. Sandrin

[2] Design of a Multiport Amplifier Beam Forming Network for a Mobile Communications Antenna, J. Lowdell, S. V. Potter, P.James, G. Cobb, M.Walden & R. Hopper. EuCap Nice, Nov 2006.

[3] RF Modelling of a Multiport Amplifier for a Mobile Communications Satellite, P. James, S.V. Potter, G. R. Cobb & M. Walden, ARMMS, 2007.

[4] Detailed Design of a Generic Ka-band Multi Port Amplifier 4, P.James, D. Daryanani O. Clarke & M. Connolly, 2012, 2nd ESA Workshop on Advanced Flexible Telecom Payloads.

[5]Modelling of Multiport Amplifiers for Space Applications, P.James, Keysight, University of Manchester, June 2016

[6] The Evolutionary Optimsation of Shaped and Minimum Sidelobe Radiation Patterns for Synthetic Aperture Radars. P. James, GALESIA 95, Sheffield, UK.
[7] Antenna Theory: Analysis and Design, Wiley, C. A. Balanis