5th International Conference on Electrical and Computer Engineering
ICECE 2008, 20-22 December 2008, Dhaka, Bangladesh

Dual Beam Phased Array Antenna with Wide Scan Angle For Repeater Applications

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Abstract: A dual polarized, dual beam phased array antenna with wide scan angle capabilities was designed and manufactured for repeater application. Two fixed feeding networks were designed and manufactured for the dual beams. With the feed networks, one broadside main beam and one tilted main beam were generated. The antenna achieved good isolation of -35.5dB between the two main beams (broadside and tilted beam) within the frequency band of interest (2.5-2.7 GHz). The return loss for the broadside feed network port was found to be below –7.5dB and return loss for the tilted beam feed network port was less than -15dB. The side lobe levels for the broadside beam and the tilted beam were -12dB and -8dB down, respectively. The cross-polar level for the broadside beam was lower than -20dB at the center frequency both in the elevation plane and in the azimuth plane. Also, for the tilted beam the cross-polar level in elevation plane was measured to be as low as -20dB at the centre frequency

***Index Terms* — Repeater, dual beam antenna, scan angle, port isolation.**

I. INTRODUCTION

Today's cellular communication systems are primarily designed to provide cost effective wide-area coverage for users with moderate bandwidth demands (voice and low data rate). The very high data rates envisioned for next generation wireless systems in reasonably large areas do not appear to be feasible with conventional cellular architecture. The reasons being the proposed spectrum higher than the 2GHz band and more vulnerable radio propagation in higher bands in non-line-of-sight conditions. Another restriction is the lack of bandwidth needed to provide Mbps transmission over the cellular networks. The brute force solution to these concerns is to increase the density of base stations and the operators need to build a dense ''forest'' of base stations to provide wireless broadband over the coverage area. But the increase in base station numbers will result in considerably higher deployment and operation costs, and would be feasible if the number of subscribers is also increased. Also costs for additional infrastructure, and hence cost for additional services to be delivered over the cellular networks cannot be radically higher in comparison to the existing systems such as Wireless LAN at an airport or hotel, or simply a wired high speed connection at office or at home. It is obvious from the above discussion that some fundamental enhancement or upgrading is required for the ambitious data throughput and coverage requirements of future systems, and the integration of multi-hop capability by means of using fixed repeaters or relays into the conventional wireless networks may be one of the cost-effective ways of upgrading existing networks [1-3]. Furthermore, significant researches are performed on future relay assisted MIMO systems and repeater based cellular distributed antenna networks [4-6]. Thus, repeaters or relays may play a significant role in future generation of wireless systems.

In this paper, a dual beam phased array antenna is considered for repeater or relay application. The proposed repeater antenna has two fixed main beams with orthogonal polarization. One of the main beams is a broadside beam directed towards the base station and the other beam is scanned about 40^o-50^o from broadside and is directed towards the user premises. In order to achieve the required scan range of the second beam, a linear phased array with progressive phase shift concept is considered. The operating frequency for the antenna was selected within the band of 2.5-2.7 GHz. The proposed antenna concept for this application is shown in Figure 1.

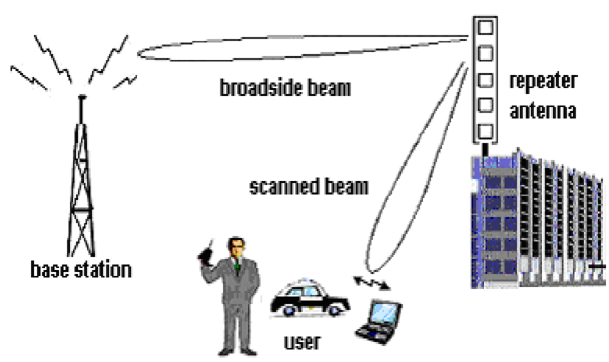

Fig. 1 Dual beam phased array concept for repeater application

II. DESCRIPTION OF THE ANTENNA

A small sized (58cm in length) low cost array antenna is considered for a proof of concept of repeater applications. The antenna was chosen to be a linear array with 8 elements to incorporate a simple feeding network with uniform power division. As the feed networks are composed of power dividers and T-junctions, it is easy to design feed networks having output port numbers equaling a power of 2. The element spacing to avoid grating lobe was chosen to be 0.5 wavelengths.

An improved microstrip inverted stacked patch geometry as presented in [7] was chosen as the single element for this array. After selecting the element type, element spacing and number of elements, the linear array with the feed networks was simulated in ADS. The objective of this simulation was to find the tilt angle for the scanned beam so as to obtain maximum isolation between the feeding ports for the two beams of the array antenna. While simulating the feed networks, ideal power dividers and phase shifters were assumed. The amount of phase shift added between the antenna elements was swept over a range of frequencies to produce different tilt angles, and the isolation between the two polarization ports was analyzed. The ADS simulation results for this case are shown in Figure 2, and the isolation curves track the scanned radiation pattern level at the broadside main direction as expected. The simulation results show that three scan angles, such as 15^o, 30^o and 48.5^o from broadside give highest isolation between the two feed ports. Among these three tilt angles; 48.5^o tilt angle seemed most appropriate for the repeater application and thus was chosen for the scanned beam of the proposed antenna.

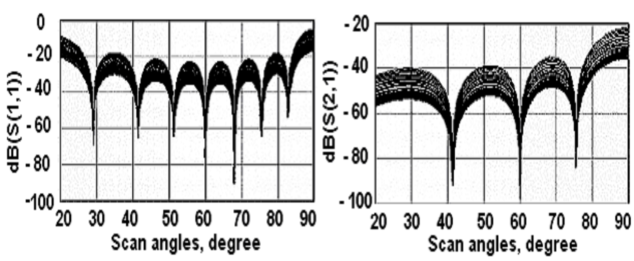

Fig. 2 Simulation results for return loss and isolation at beam ports as a function of scan angle from array axis with frequency as a parameter

The complete linear array was built on (58×10) cm^2 substrates both for the lower and the upper patches. TLC-30 substrate with thickness of 1.5mm was used for the lower patch array, and for the upper patch array FR4 substrate with a thickness of 0.8mm was chosen. The centre to centre distance between the elements was set to be 5.75cm (0.5λ). The array of upper patches was placed 12.1mm above the array of the lower patches with the help of plastic spacers. The manufactured complete array antenna is shown in Figure 3, and only eight out of ten elements were fed from the feed networks with the remaining edge elements terminated in matched loads.

III. DESIGN OF TWO FEED NETWORKS

Two feeding networks were designed, one for the broadside beam and the other one for the 48.5^o tilted beam. Simple T-junctions were used as power dividers while transmission lines were used as fixed phase delays. For the broadside beam, the phase difference between adjacent antenna elements is zero degree, and for the 48.5^o tilted beam the phase progration between the antenna elements was calculated as [8]: $\beta = kd\cos\theta$ where $k = \frac{2\pi}{\lambda}$, $d = \frac{\lambda}{2}$ and $\theta = \left(90^0 - 48.5^0\right)$. The phase shift as calculated by the above expression was found to be -135^o (or 225^o). Thus, the feeding network was designed to have -135^o phase shift between adjacent antenna elements. The two manufactured feed networks and the complete array antenna are shown in Figure3.

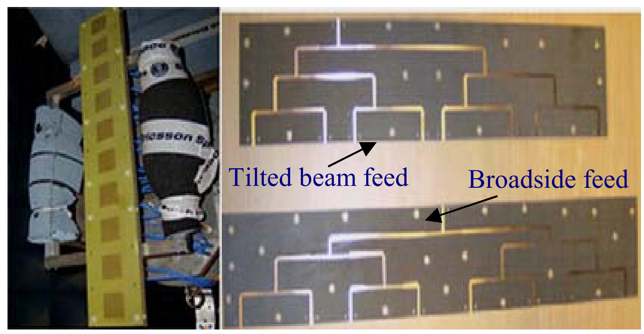

Fig. 3 Complete array antenna at test range and the two feed networks

IV. S- PARAMETER RESULTS

The tilted beam feed network was connected to the horizontal polarization and the broadside feed network was connected to the vertical polarization port of the antenna during measurements. Figure 5(a) and Figure 5(b) present the measured phase progression for the feed networks separately. It was found that the phase progressions for the tilted beam feed network was close to the requirement of -135^o and the broadside network was close the required 0^o phase progression. Figure 6 presents the measured mutual coupling between antenna elements and it is seen that the mutual coupling between two adjacent elements is less than -11dB, and the mutual coupling between the second adjacent elements is less than –20.5dB within the band of interest. The isolation between the orthogonal ports of two adjacent antenna elements was higher than 25dB. Figure 7(a) shows a block diagram of the complete antenna arrangement, and Figure 7(b) shows measured return loss of the complete array and isolation between the two beam ports.

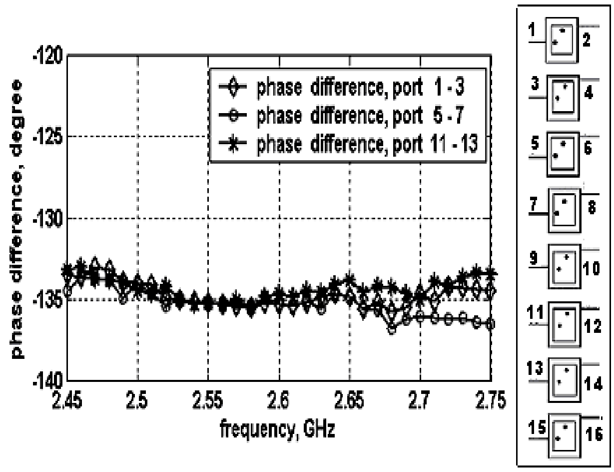

Fig. 5(a) Measured phase progression between adjacent antenna elements of the tilted beam feed network, the results of the remaining ports being similar and are not shown

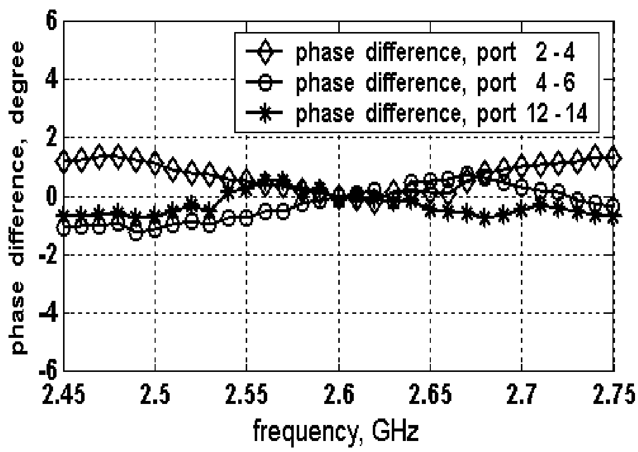

Fig. 5(b) Measured phase progression between adjacent antenna elements of the broadside beam feed network, the results of the remaining ports being similar and are not shown

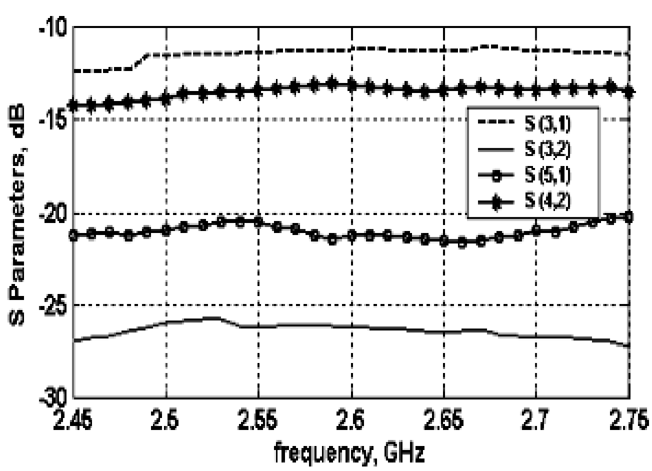

Fig. 6 Measured mutual coupling between antenna elements in the array

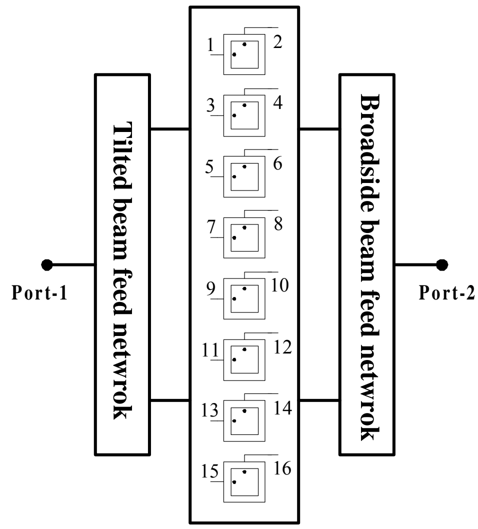

Fig. 7(a) Antenna and feed network arrangement during return loss and beam port isolation measurements

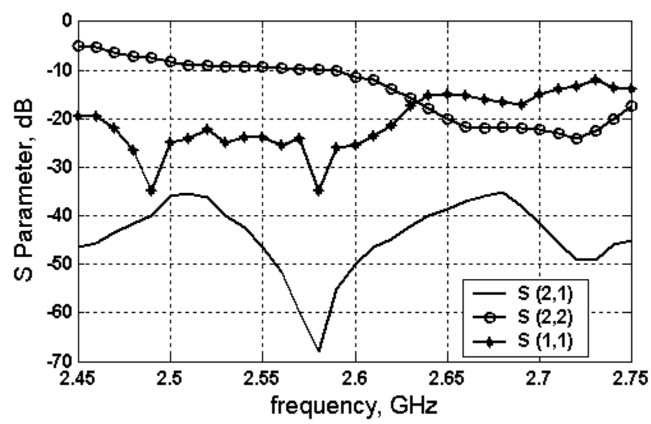

Fig. 7(b) Measured return loss and port isolation for the complete array; feed 1 connected to the horizontally polarized beam and feed 2 to the vertically polarized beam

V. RADIATION PATTERN MEASUREMENTS

Both elevation and azimuth plane radiation patterns were measured for broadside beam while only elevation plane pattern was measured for the tilted beam. Due to the fixture and turntable arrangements, the azimuth pattern of the tilted beam was not possible to measure through the main beam peak. However, the azimuth pattern would be very similar for the two beams. Both co- and cross-polar levels for the two beams are plotted in Figure 8. As observed, the side lobe levels for the broadside beam in the elevation plane is about -12dB down as expected for a uniform amplitude distribution and for the tilted beam, it is -8dB down. For the tilted beam case, the reason for the relatively higher level of side lobes is due to the element factor. The element pattern at a -48.5^{o} tilt angle is almost -3.5dB lower compared to the broadside direction. In the tilted beam case, the high side lobe level at +48° is roughly the mirror of the main beam (fig. 8(c)). This is due to reflections at the antenna elements and limited isolation at the T-junctions in the feed network.

The cross-polar level for the broadside beam is lower than -20dB at the center frequency of 2.6GHz both in the elevation and the azimuth plane. However, the cross-polar level increases to -13dB at the band edges. The main reasons of high cross-polar level are random probe feed positioning errors in the array as well as small element distance (0.5λ), and high mutual coupling between adjacent array elements. For the tilted beam, the cross-polar level in elevation plane is found to be lower than -18dB at all frequencies within the band of interest.

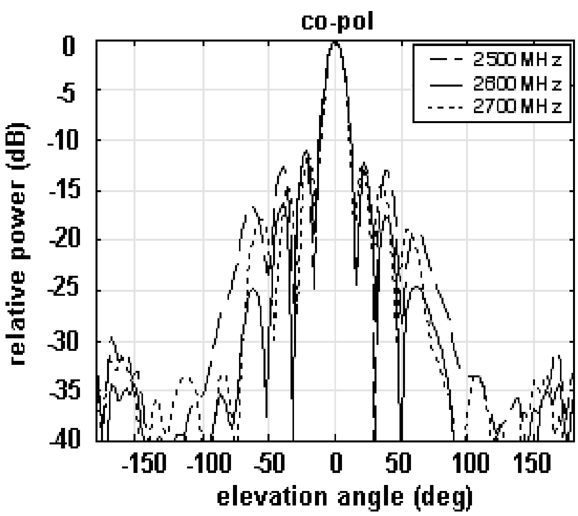

Fig.8(a) Measured elevation plane co-polar radiation pattern for broadside beam

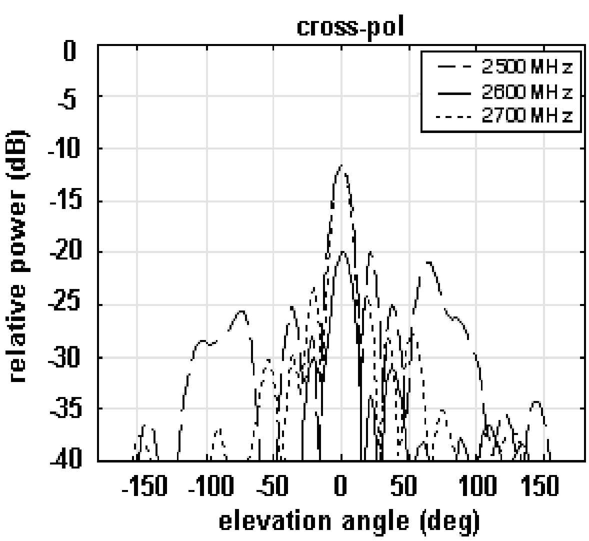

Fig. 8(b) Measured elevation plane cross-polar radiation pattern for broadside beam

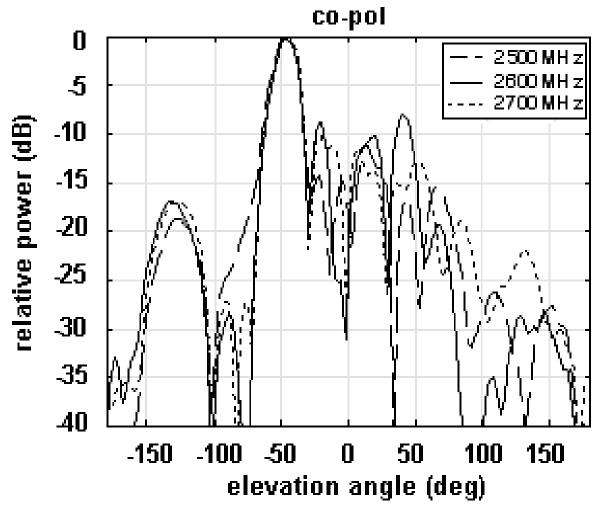

Fig. 8(c) Measured elevation plane co-polar radiation pattern for tilted beam

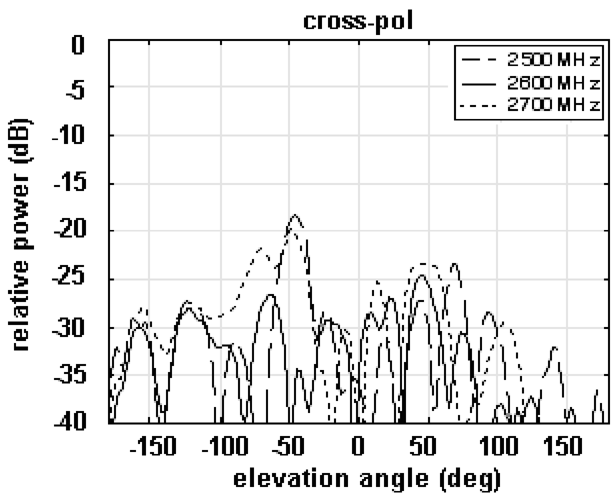

Fig. 8(d) Measured elevation plane cross-polar radiation pattern for tilted beam

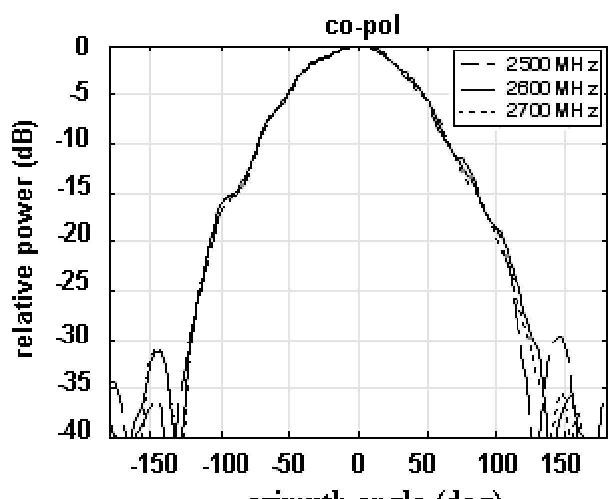

Fig. 8(e) Measured azimuth plane co-polar radiation pattern for broadside beam

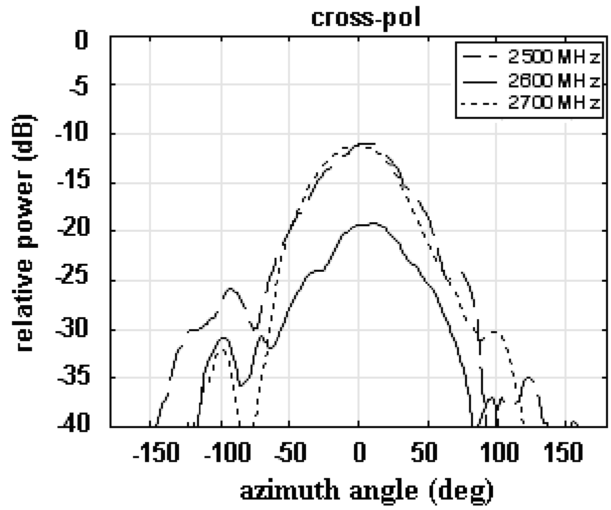

Fig.8(f) Measured azimuth plane cross-polar radiation pattern for broadside beam

VI. MEASURED DIRECTIVITY & GAIN

The directivity for both beams was calculated to be 14.5-15.2 dBi by integrating the patterns within the band of interest. The directivity of a linear array is rather constant as a function of the scan angle. The realized gain of the antenna was 11.8-13.1 dBi and 12.7-13.5 dBi for the broadside and tilted beam cases, respectively. There is a loss of about 1.5dB, which includes losses in feed network, connecting cables, reflection loss, signal power loss in cross-polarization, and misalignment during the measurements. The reduced gain for the broadside beam at the low frequency is mainly due to high reflection losses (fig. 7(b)). A return loss of -8dB gives a reflection loss of 0.75dB, which explains the lower realized gain at 2.5 GHz in the case of the broadside beam. The measured results are summarized in Table 1.

Table 1 Measured directivity, gain and 3-dB beam width

f (GHz)	Beam width (deg) (Broadside, elevation)	Beam width (deg) (Broadside, azimuth)	Beam width (deg) (Tilted-beam, elevation)	Gain (dBi) (Broadside)	Gain (dBi) (Tilted-beam)	Directivity (dBi) (Broadside)	Directivity (dBi) (Tilted beam)
2.5	13.8	78.2	17.9	11.8	13.5	14.5	15.2
2.6	13.5	78.0	16.7	13.1	13.4	15.1	14.9
2.7	12.3	77.6	17.6	13.0	12.7	15.0	14.8

VII. CONCLUSION

Design of a dual beam phased array antenna with wide scan angle has been demonstrated. The manufactured antenna performances agree with the theoretical and simulated results. The manufactured antenna with added power amplifiers can easily be used for future investigations and field measurements in repeater applications.

ACKNOWLEDGEMENT

The authors wish to thank Saab Space, Sweden, for the use of the indoor antenna test range.

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