Cascaded Rotman Lens Fed Circular Array

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A. Chepala and V. Fusco.

A single Rotman Lens fed circular array requires phase shifters to beamsteer whereas a two cascaded Rotman Lens fed circular array can beam form and steer by simply exciting a single Rotman Lens beamport. In this paper, we show how cascaded Rotman lenses feeding a circular array can use this property in order beam steer/shape and perform retrodirectve action. Experimental validation at 9.3GHz is given.

Introduction:
Traditionally Rotman Lenses (RL) are used for beam forming and steering especially when feeding uniform linear arrays (ULA). Each RL beam port excitation steers the beam of the ULA [1-2]. Unlike ULAs circular array CA symmetry provides 360° coverage with uniform beamshape and gain [3-4]. The use of the circular array (CA) in combination with a single RL, fed by fixed angle mode alignment phase shifters placed in series with variable angle phase shifters for beam rotation are required in order to provide a 360° coverage. In this paper, we show how two cascaded RLs (CRL) when used to feed a CA can enable beam steering, beamshaping and retrodirective action without the need for phase shifters.
The paper is organized as follows. First, we describe our proposed CRL fed beamforming/steering approach. Secondly, we show the flexibility of using CRL fed CA in controlling the beam width of the radiated beam by adding switches into the interconnection between the two RLs. Finally, we show the application of using CRL fed CA as a retrodirective array and finally conclude.

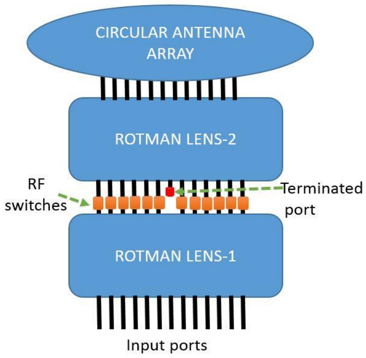

Fig. 1 Cascaded *Rotman Lens Fed Circular Antenna Array.*

Cascaded Rotman Lens Fed Circular Array: A RL is a passive beamforming network generally used with antenna arrays for its ability to generate the desired excitation phases across the output (array) ports of a ULA, that would steer the beam to a pre-set direction corresponding to the applied beam port excitation. Accordingly, for a ULA the beam is steered along the azimuth plane as each RL beam port is excited. The associated phase distribution requirement for beam forming in a CA is different to that of a ULA. For CA excitation the RL is used to simultaneously create multiple linear phase distributions that correspond to the natural modes of the CA, this modal technique was described in [5]. In the CRL arrangement in Fig. 1 the beam ports of RL1 are directly connected to the beam ports of RL2. Beam control excitation is applied at the array ports of RL1 and the CA is attached to the array ports of RL2. Note in the cascaded RL case that no phase shifters are required thereby enabling a real-time response without any processing delays. Next we describe the design and fabrication of the CRL fed CA and its beamforming/shaping characteristics when fed with the RLs.

Fabricated prototype CA fed with CRL: A micro-strip based Rotman lens (RL) was designed and fabricated according to [1-2], Fig 2. While the CA was designed according to the principles in [5].

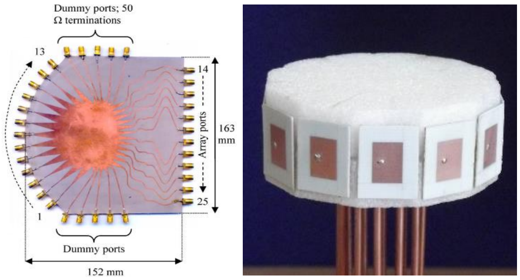

Fig. 2 *Rotman lens and Circular Patch Array (CA).*

The radiating element for the demonstration CA was chosen for ease of fabrication as a microstrip patch. The operating frequency as 9.3 GHz (X-band) and the dielectric *RO40003C* (ε_r = 3.38 and *loss tangent* = 0.0027).The calculated dimensions for the above specifications are patch *length* = 7.52 mm, patch *width* = 10.14 mm, patch *height* = 0.51mm and $\varepsilon_{r\text{-}eff}$ = 3.13. The beam and array port return losses were all below –10 dB at 9.5 GHz. The nearest beam port-to-port isolation is better than –15 dB. A circular array with 12 elements (angular separation between neighboring elements is 30°) was designed with the above patch elements. The separation between the elements is 0.5λ and the diameter of the array is approximately 2λ, i.e. 60 mm at 9.3 GHz. The CA was assembled on Styrofoam, see Fig. 2.
When the proposed CRL network shown in Fig. 1 is used, each port excitation applied at the input to RL1 generates from the CA a beam pointing in a different direction. Note that no mode alignment or variable phase shifters are required as is the case when a single RL is used. Fig. 3 shows the measured steered patterns in the far field obtained by this approach. The far-field patterns are separated by an angle equivalent to the angular separation of individual radiating elements (which is 30° as there are 12 elements on the circular array covering the full 360°). Next, we discuss the additional possibility of beamshape control in this configuration.

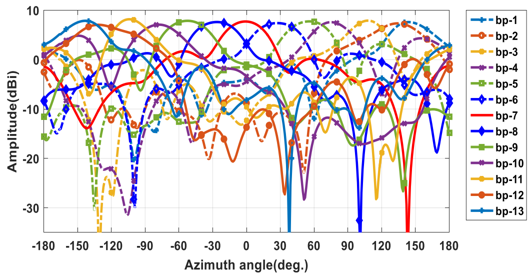

Fig. 3 *Far Field Patterns of Cascaded Double RL fed CA. Here bp designates the selected input port on RL1.*

Beamwidth control by switching: The cascaded RL architecture provides an added benefit of permitting control of the beamwidth of the radiated beam. This is done by using SPST absorptive switches positioned between the interconnections between RL1 and RL2 as shown in Fig. 1. By pairwise switching the interconnections we can control the beamwidth of the radiated far-field patterns as shown in the Fig. 4. In order to facilitate the beam shaping potential of the arrangement as discussed later, beam port 7 of RL2 is terminated with a matched load as shown in Fig. 1. Here, the switches control the effective aperture size, as the aperture size reduces when the elements are switched-off on a symmetrical basis and so the beam-width increases followed by gain reduction as observed in the far-field patterns in Fig. 4 when the center input port of RL1 is fed. Note here that port-7 is terminated with a matched load in order to accommodate symmetrical mode switching. Table 1 compares the proposed CRL fed CA overall attributes to those of previously published single RL fed CA.

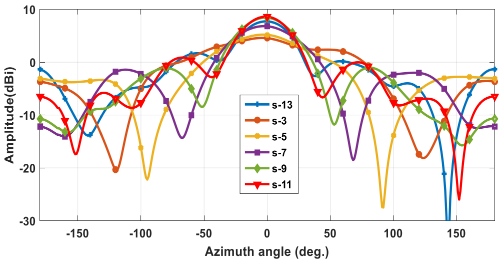

Fig. 4 *Far field patterns of beam controlled Cascaded RL fed CA.*

Next, we discuss the application of CRL fed CA as a retro directive CA.

Table 1: Single and cascaded RL configuration comparison

	Single RL fed CA	Cascaded(Double) RL fed CA
1	Multiple beamport excitation and fixed phase shifters required to beamform.	Single beamport excitation, no fixed phase shifters required to beamform.
2	Beamsteering requires variable phase shifters.	No variable phase shifters needed.
3	Single RL losses.	Double RL losses.
4	For retrodirection bi-directional amplifiers required.	Unidirectional amplifiers required for retrodirection
5	No control over beamwidth.	Beamwidth can be controlled.

Retrodirective array: Retrodirectivity is the property of retransmitting a signal back in the direction of an interrogator without a prior knowledge of its direction of arrival. Retrodirective arrays are used in many applications especially in communication and tracking. ULA retrodirective arrays are most commonly used and have the limitation of their angular coverage. A single RL fed ULA as retrodirective array was presented in [6].

Next, we demonstrate the use of the CRL fed CA for retrodirective action, this is based on [7] and provides validation for the proposed method therein. The angular accuracies and the gain variations of the far-field bi-static RCS patterns of the proposed retro architecture are reported. It should be noted that a single RL fed CA requires symmetrical mode-pair interconnectivity, wherein mirror beam port pairs are inter-connected using identical length transmission lines, Van Atta fashion, [8]. With this approach active modulation or amplification of the signal, being retrodirected is difficult due to the requirement for bi-directional amplifiers/modulators. In case of CRL fed CA we require only selective termination at the input port of RL1 (either short or open circuit termination or terminate with a reflection amplifier or reflection modulator) in order to retrodirect an incoming signal. RL losses can be overcome by the use of a one port reflection amplifier located at the selected input RL1 port.The measured far field retrodirective bi-static patterns are shown in Fig. 5. Here the input ports of RL1 (see Fig.1) are terminated in a short circuit

Fig. 5 shows that retrodirection is occurring. We note that there is pattern distortion due to the operation of the RL at high angle of incidence, which can be related to RL impairment for these angles [2]. This is mainly due to the spill over and reflections from the RL dummy ports. This leads to reduced beam gain, and also increased side lobe level response of the retrodirected far field pattern. The main far field pattern features are summarized in Table 2. These show that gain remains relatively flat (within 1.5 dB) across the full 360^0 of coverage (for a ULA 3dB gain variation over $\pm 40^0$ would be typical). Also beam pointing error BPE is below $\pm 4^0$ out to $\pm 90^0$ and degrades to about $\pm 14^0$ beyond this angle of incidence (AOI). Overall, this architecture proves to present useful retrodirective properties with full 360° angular coverage.

Table 2: Far-field parameters of retrodirective cascaded rotmen lenses fed circular array

AOI(°)	-150	-120	-90	-60	-30	0
BPE(°)	-19	-14	4	-4	-4	1
Gain(dB)	7.1	8.2	7.4	7.5	7.5	7.7
AOI(°)	30	60	90	120	150	180
BPE(°)	2	1	0	9	12	-2
Gain(dB)	7.2	7.8	6.7	7.9	7.8	6.3

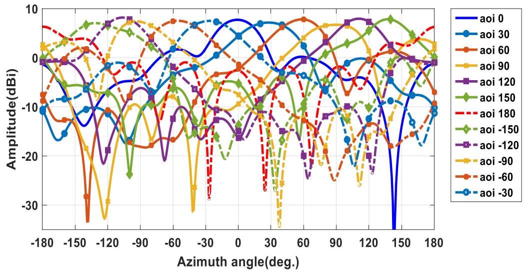

Fig. 5 *Retro-directed far-field patterns of DRL fed CA.*

Conclusion: The operation of a twelve element circular array fed with a cascade of two interconnected Rotman lenses for beam forming/steering and retrodirection without the need for phase shifters over 360^0 was presented. The additional flexibility of beamwidth control was also demonstrated by using switching of the interconnections between the cascaded Rotman lenses. The suggested technique should find application in satellite, radar and communication scenarios.

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