The Rotman Lens Antenna System for mobile Line-of-Sight RF Links - A brief technical overview

Robert Fitting – Bit2Signal Communications Engineering

To implement data links that require higher data rates over greater distance, a directional antenna is required due to their greater gain. For a mobile platform such as a vehicle, ship, or aircraft, establishing and maintaining an RF data link requires an antenna system than can be steered, potentially in any direction, to keep the beam properly pointed at the opposite terminal. Multiple antenna technologies exist such as gimbaled antennas and phased arrays, these can be complex and expensive. This paper develops a brief introduction to a simple and inexpensive antenna technology for creating a steerable beam – the Rotman Lens.

The Rotman Lens is a type of "fixed" beam forming network invented in 1965 and is implemented as a light weight and inexpensive printed circuit board (PCB). See photo 1.

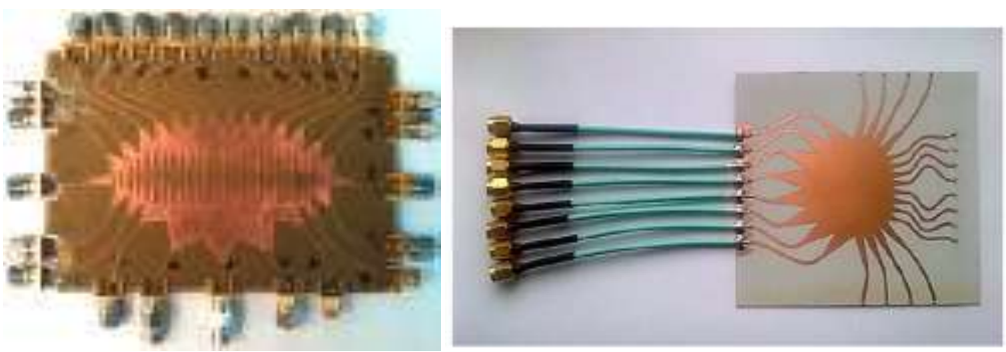


Photo 1. Examples of Rotman Lens Implementations

The beamformer connected with a set of radiators, can be described as a “multi-beam staring array,” typically capable of producing a fan, or swath, of beams. The Rotman lens is constructed with multiple inputs and multiple outputs. The diagram in Figure 1 shows a Rotman lens with 7 feed ports (labeled 1-7 on right) and 15 radiator ports. The beamformer can be applied in either the transmit direction of the receive direction.

As shown in the diagram, the direction of radiation can be adjusted by selection of the feed port.

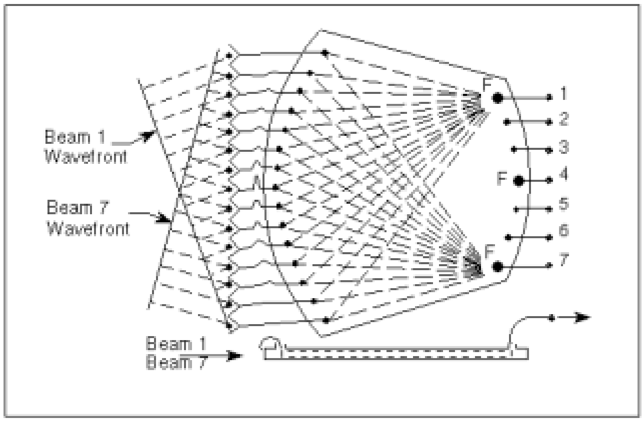


Figure 1. Rotman Lens diagram

Rotman Lens technology is currently being studied by a number of entities. One study is being performed by S*teven Weiss, Steven Keller, and Canh Ly* - Army Research Lab. Their design uses a Rotman Lens connected to an array of patch antennas. In their paper they describe Rotman Lens development software developed for the Army Research Lab by Remcom Corp under a Phase II SBIR. After software simulation, the Rotman Lens was fabricated and measured. The beamformer and patch antenna array is shown in photo 2.

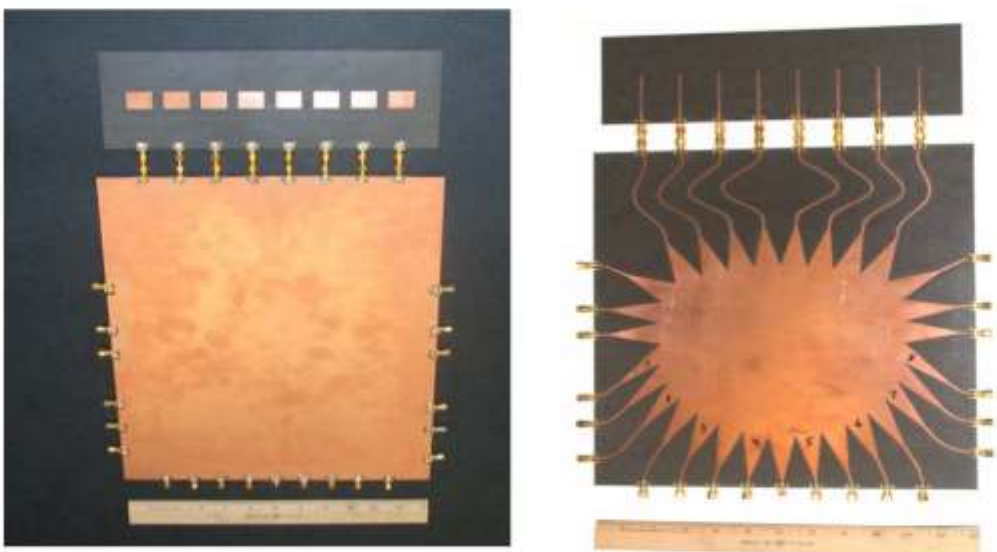


Photo 2. Rotman Lens and Patch Antenna Array

Figure 2 shows the radiation pattern from each feed port.

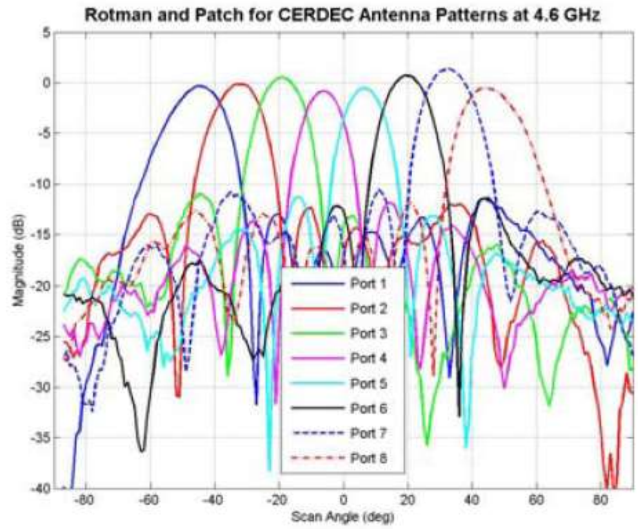
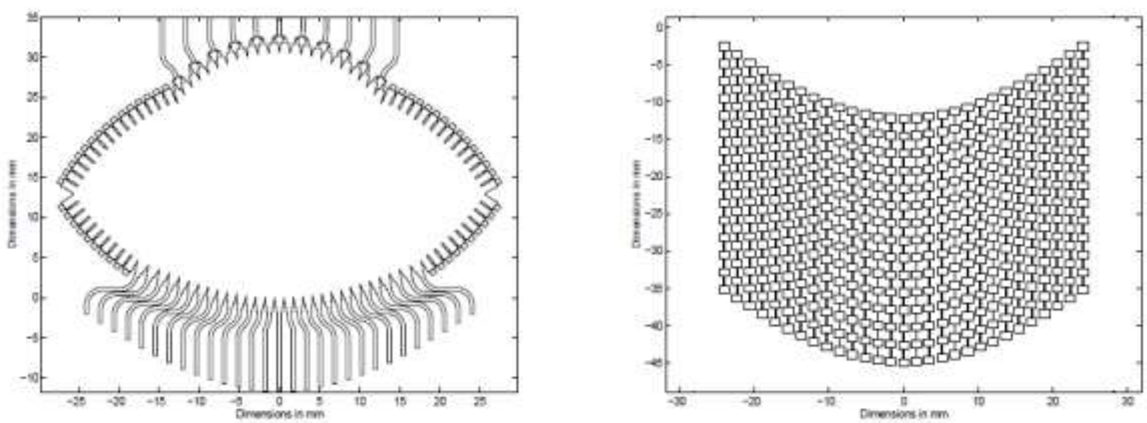


Figure 2. Radiation pattern for Rotman Lens and Patch Antenna

In another study by Hall, Hansen, and Abbott - Univ of Adelaide, an application was evaluated for an Adaptive Cruise control 77 GHz radar. In this study a Rotman lens was designed with 11 feed ports and 29 antenna ports. The antenna array is columns of patch radiators which are fed by a slot under the central patch and matched by an open stub.



(a) Rotman Lens

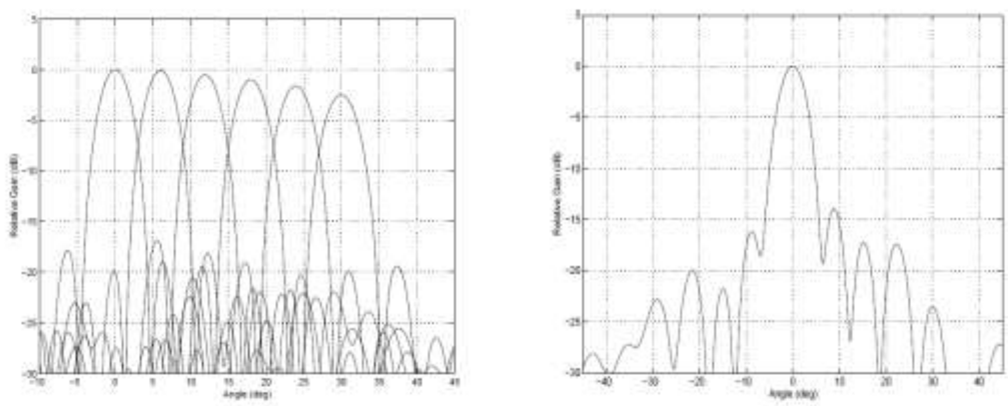
(b) Antenna Array

Figure 3. 77 GHz Radar using Rotman Lens

The performance prediction for the antenna are shown in Figure 4.

Table 1: Predicted Lens Performance

Gain of Mainlobe	> 25 dB
Beam Width	4°
Beam Crossover	-7 dB
Sidelobe	< -15 dB
Total Insertion loss	< 10 dB



(a) Five Staring Beams

(b) Vertical Beam pattern

Figure 4. Performance prediction for Rotman Lens and Antenna Array

The beam pattern created by a Rotman Lens is produced only in one dimension, for example a ring of radiators in the horizontal plane as shown in Figure 5.

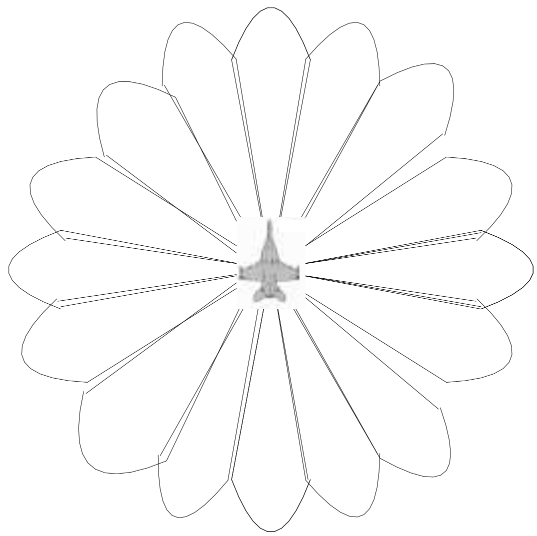


Figure 5. Depiction of one-dimensional ring of beams based on Rotman Lens

While this may be sufficient for air-to-air or ground-to-ground link, other links may require a more three dimensional radiation pattern. To create a beam pattern in more than one dimension, multiple layers of beamformers may be stacked as shown in figure 6.

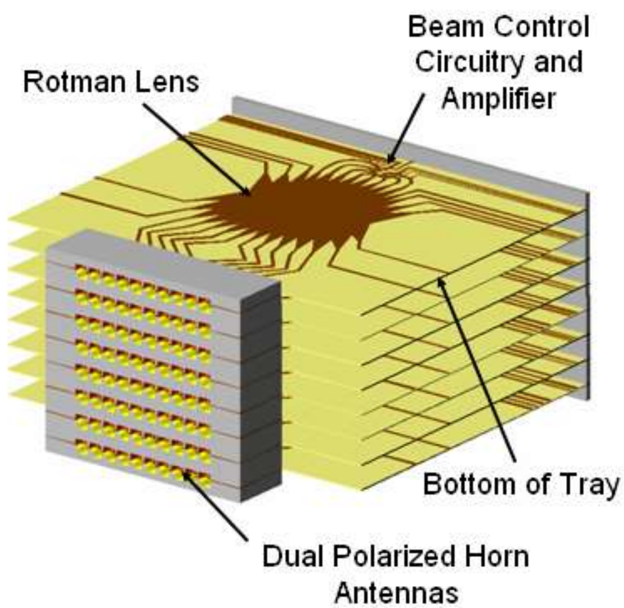


Figure 6. Stacked Rotman Lens for wider coverage

Advantages & Technical Challenges:

Advantages:
The Rotman lens can be manufactured very inexpensively. It is light weight and rugged.
The same holds for patch radiators or feed horn radiators, a low-cost, light weight and rugged antenna system can be constructed from a Rotman Lens.

Challenges:
Beam Steering
A Rotman Lens and antenna array produces a pattern of fixed staring beams. The direction the antenna system is pointed is selected by selecting the applicable feed port. For an electronically scanned system this requires a switching matrix.

Beam Switching
Although an RF switch matrix can be designed and manufactured inexpensively using pin diodes, a consideration is potential signal disruption. Data communications systems using modulations such as PSK or CPM require switching between feed ports to occur in a phase continuous fashion. Any discontinuity will result in loss of data. Switching between ports seamlessly is not impossible but may be a highly difficult challenge.

Beam pointing
Communicating with moving targets requires continuously computing the correct pointing vector. The system must determine which beam the target terminal is currently in and predict which beam the target is moving into in order to coordinate beam switching.
High Frequency Operation:
Construction of the beamformer becomes more difficult at higher frequencies.
At higher frequencies, PCB materials exhibit more loss and higher precision geometric tolerances are required.

For example in the system constructed by the ARL in the 4-5 GHz range, an insertion loss of 10 dB was "measured" while the "predicted" loss of the Univ. of Adelaide systems was < 10 dB @77 GHz.

Conclusion

The Rotman Lens is an intriguing and viable beam steering technology. Although a practical implementation of a Rotman Lens presents some challenges, especially in cases where a wide field of view is required, it provides an inexpensive and rugged approach, making the technology applicable to both stationary and mobile platforms.