

# Rotman Lens Design for Millimeter-Wave Sensor Application

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**Abstract.** The design of Rotman lens for ESM sensor application in operation band 32-38 GHz is demonstrated in the paper. Initial design made in Remcom's Rotman Lens Designer is confronted with the full-wave analysis in CST Microwave Studio as well as with the results of experimental measurements.

Rotman lens was tested as a broadband replacement of conventional waveguide reflective phasers intended for the sensor.

Parameters of realized prototype are presented and methods of increasing its performance of the structure are outlined.

## Keywords

Rotman lens, millimeter-wave sensor, switched-beam, direction finder.

## 1. Introduction

The use of phased array antenna with shaped or switched beam operation was tested for the ESM sensor in ECM system application in the mm-wavelength band from 32 GHz to 38 GHz. The design with Rotman Lens (RL) replaces common realization with microwave phasers (both waveguide or integrated). The Rotman lens brings simple broadband solution with easy control.

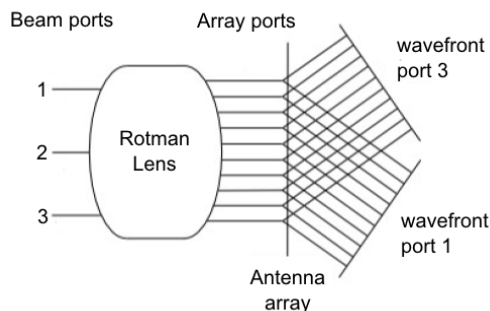


Fig. 1. Rotman lens - basic description.

The RL is a parallel-plate structure having at least three essential parts - array ports, beam ports and RL body itself. It is usually designed for linear antenna arrays.

Array ports are connected to the antenna array with constant time (phase) delay. As the direction of incoming signal (and the corresponding wavefront) change, the maximum energy is routed to one of the beam ports as shown in Fig. 1. In the transmitting mode the direction of radiation corresponds with the beam port fed.

Rotman Lens were presented firstly in 1963 [1], have been improved several times [2, 3] and currently their essential exercise are microwaves [4].

## 2. Initial design

Rotman lens are complex structures, hence having an appropriate design tool is helpful. Remcom's Rotman Lens Designer brings powerful solution for designing the structure. The software package is a tool for the design, synthesis, and analysis of Rotman Lenses and their variants. It is based on geometrical optics combined with the classical Rotman Lens design equations. It is intended for rapid development and analysis of Rotman Lenses given several physical and electrical input parameters. Rotman Lens Designer generates the proper lens contours, transmission line geometry, absorptive port (dummy port) geometry, provides an approximate analysis of performance, and generates geometry files for import other applications for further analysis and fabrication [5].

For intention of our project, following requirements were set:

- Equidistant antenna array with 6.5mm separation.
- 90° sector divided into 8 parts.
- Microstrip 50Ω feeding on Rogers RO 4003 substrate.

The antenna array separation comes from the design of original waveguide horn elements. This dimension was used in spite of the fact, that the separation is insufficient for the upper part of the operation band, where 6.5 mm is  $0.82\lambda$  @ 38 GHz.

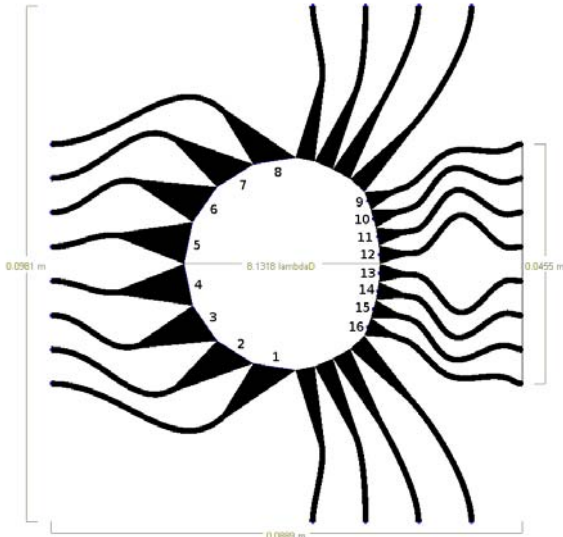


Fig. 2. Rotman lens structure (from Rotman Lens Designer).

The parameters of initial design made in Rotman Lens Designer cover our requirements. Structure (Fig. 2) was exported through the SAT geometry file.

### 3. FDTD Verification

Initial design was simply verified in CST Design Environment (Microwave Studio). Microstrip lines were terminated with the waveguide ports; beam ports 1-8 and array ports 9-16. Dummy ports were terminated by the appropriate boundary conditions.

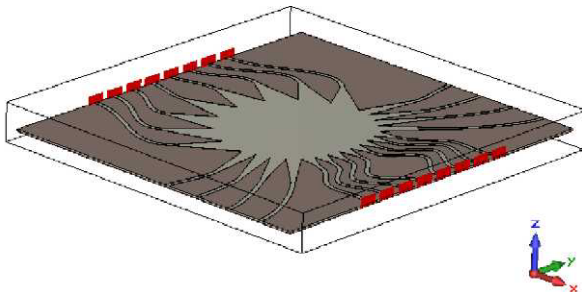


Fig. 3. Rotman lens structure (in CST Design Environment).

The impedance matching in 30-40 GHz band is shown in the following picture. Respecting the structure symmetry only 4+4 lines are printed.

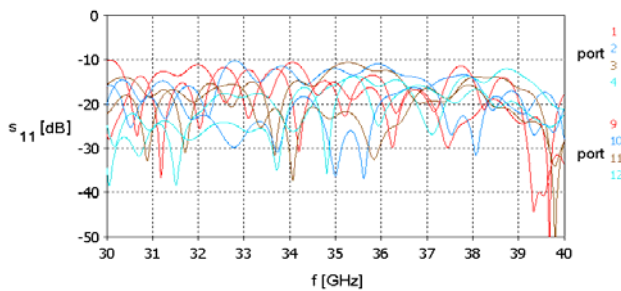


Fig. 4. Impedance matching of Rotman lens ports.

The isolation between adjoining ports is calculated on the following pictures on the side of array ports (Fig. 5) and beam ports (Fig. 6).

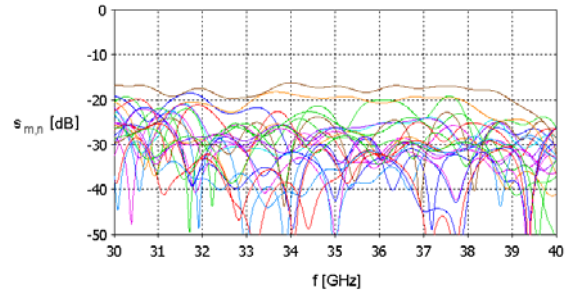


Fig. 5. Isolation between Rotman lens ports - Array ports.

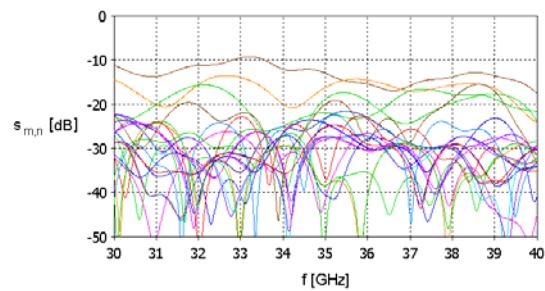


Fig. 6. Isolation between Rotman lens ports - Beam ports.

The isolation is on a sufficient level except the outer ports (1 to 8 resp. 9 to 16 - brown color; 2 to 7 resp. 8 to 15 orange color).

Radiation properties were tested in the transmitting mode. Simple wire monopoles designed at the center frequency 35 GHz were placed at the array port termination. Its impedance matching is shown in Fig. 7.

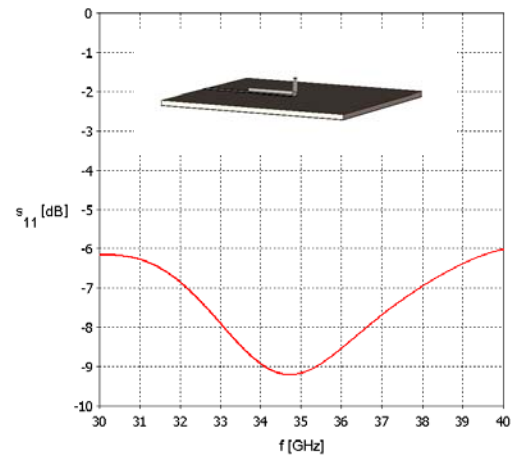
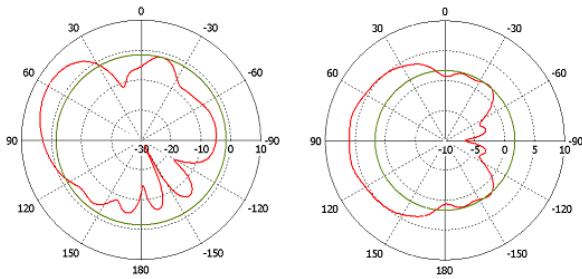
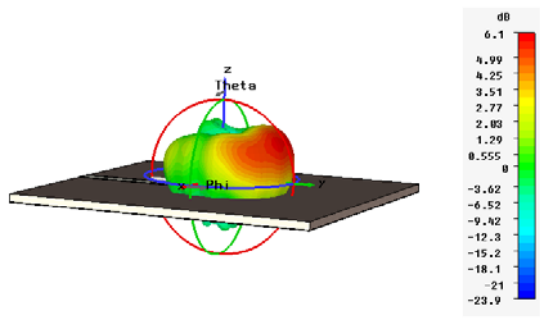


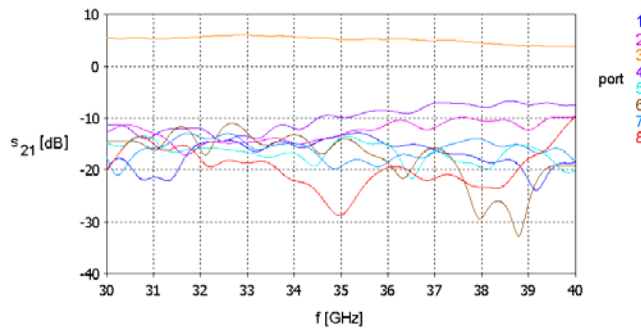
Fig. 7. Antenna element for Rotman lens in 32-38 GHz - structure and impedance matching.

The radiation differs from an omnidirectional due to the existence of the feeding line and the ground plane, which ends just at the monopole position. The main beam has 30° elevation (Fig. 8).



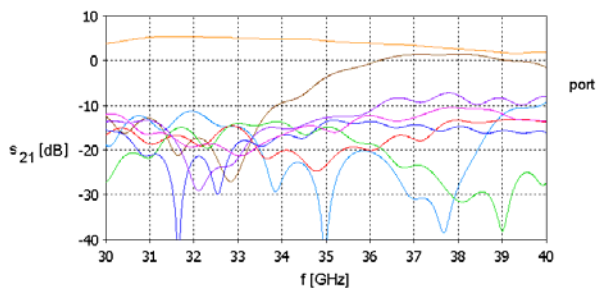
**Fig. 8.** Antenna element for Rotman lens in 32-38 GHz - radiation patterns.

In the receiving mode, transmission between array port and particular beam ports can be evaluated. For example, array ports are fed with the same level and  $83^\circ$  phase difference which corresponds with the signal incoming from  $25^\circ$ . The results of simulation are in Fig. 9.



**Fig. 9.** Beam port's signal levels (signal from  $25^\circ$ ).

The highest power comes to the port 3, while other ports have lower level. These properties are broadband.



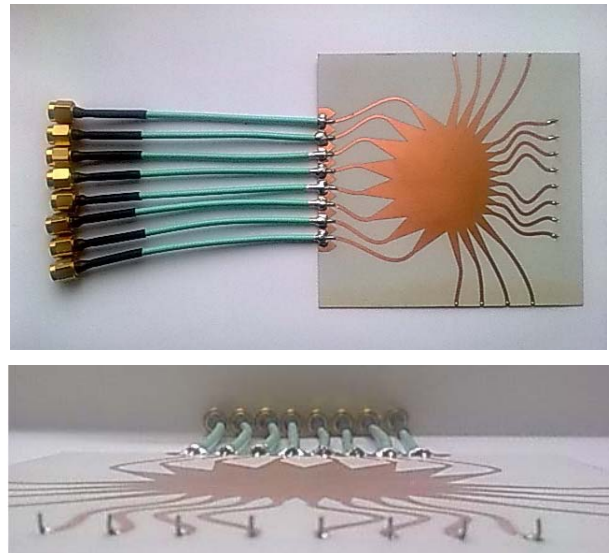
**Fig. 10.** Beam port's signal levels (signal from  $xx^\circ$ ).

Fig. 10 shows similar situation, but the phase difference is set to feed particularly the port 7. The parasitic transmission to the port 1 is caused by the

presence of the grating-lobe, which is created due to the large element separation (6.5 mm). This takes effect especially in the upper part of the operation band.

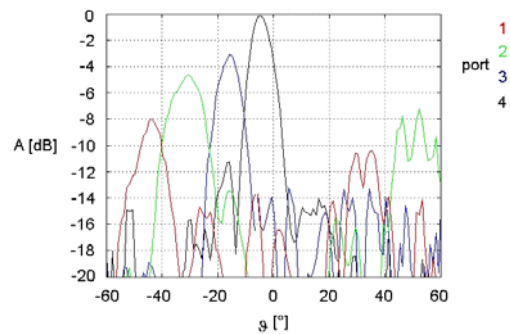
## 4. Realization and measurement

The structure of Rotman lens was realized on Roger's 4003C substrate ( $\epsilon_r = 3.55$ ;  $\tan(\delta) = 0.0035$ ;  $h = 0.508$  mm). The size is approximately  $100 \times 90$  mm.



**Fig. 11.** Realization of Rotman lens for 32-38 GHz band.

Radiation patterns measured in an anechoic chamber while feeding the beam ports 1-4 are in Fig. 11. The main lobe directions are in the correspondence with the numerical model as well as the beam-width.



**Fig. 11.** Radiation patterns of Rotman lens at 35 GHz, ports 1-4.

The presence of grating-lobes in the case of the first and the second (outer) beam can be seen. For their suppression, the antenna elements should be placed more closely. For making the beam-width (and also their level) constant, RL with more array ports should be used. Also antenna elements with a wider radiation pattern should be used.

Further effort should be dedicated for a using an absorptive housing of the RL body, which can increase the main beam directivity.

## 5. Conclusions

Experimental measurements on realized Rotman lens have verified the parameters obtained in Remcom's Rotman Lens Designer. The software is a powerful tool for designing the structure.

Simple configuration with eight antenna and beam ports brings the required possibility to estimate the direction of arrival. Due to the number of ports, beams have unequal width and level. For its matching, RL needs to have more antenna ports. For increasing the performance in directivity, the RL body has to be shielded or surrounded by the absorptive material.

Like in all antenna array application, the element spacing has to satisfy the grating-lobe criterion. Then the structure has a broadband operation.

## Acknowledgements

Research described in the paper has used the free version of Remcom's Rotman Lens Designer. Authors would like acknowledge the trial period extension.

## References

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