Phase Shifters Design for Scan Range Extension of Rotman Lens Beamforming Based Antenna Arrays

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***Abstract*—The design of the phase management unit needed for extending the scan range of a 24 GHz array antenna system based on Rotman lens beamforming is presented. The developed phase management unit consists of both static and switchable reflective type phase shifters, whose particular arrangement, in combination with a Rotman lens, allows increasing the maximum steering beam angle by 100%. Finally, the proposed concept is validated through simulation including the complete beamforming network and antenna array system.**

Keywords—*Rotman lens, phased array, beamforming network*.

I. INTRODUCTION

With the continuous development of high performance communication and radar systems toward millimeter-waves, Rotman lens [1] is gaining importance as beamforming network thanks to its broadband and efficient functionality and its cost-effective implementation. However, the design of a large scan angle phased array based on Rotman lenses can be prohibitive due to component dimensions and increasing phase error. Many attempts were made for enhancing the performance of the lens (see e.g. [2]-[3]), based on new technological solutions or by optimizing the design procedure. This paper focus on the concept introduced in [4], where an innovative method for doubling the scan range capability of the Rotman lens beamforming network was proposed and numerically validated. In particular, the scan range extension method is based on the introduction of a phase management unit, initially built by using ideal phase shifters [4]. This work will the develop a planar, compact and accurate phase shifter system for realizing the proposed concept.

II. EXTENDED SCAN RANGE CONCEPT

This research is based on the concept described in [4], where a method for doubling the scan range of an automotive Short Range Radar (SRR) based on Rotman lens beamforming network was proposed. The extension of the scan range was achieved by placing a special phase management stage between the antenna array and a 24 GHz Rotman lens, characterized by 16 beam ports, 16 array ports and a maximum scan angles of ±30°. By applying this novel concept, the beam steering capability of the beamforming system can be increased up to ±60°. The two essential functions of the phase management stage are called Complete Beams Shifting (CBS) and Beams Mirroring (BM). The CBS is the transfer of all beams to positive (or negative) scan angles, due to the insertion of an appropriate phase distribution after the Rotman lens. In other words, referring to the SRR systems designed in [4], by applying this functionality the cascade of Rotman lens and CBS stage would shift all beam from the conventional ±30° scanning angles to the range 0° to 60°. On the other hand, the BM consists on the application of an additional switchable 0°/180° phase shift at every second antenna array input: the combination of this phase reversal added to the CBS effect is the mirroring of the beam scanning angles toward the negative range. By considering again the example discussed above, the array beams which are pointing in the 0° to 60° range will be moved to the 0° to -60° scanning angles. In Fig. 1 the application of the phase management unit functions to the SRR Rotman lens based beamforming antenna array is depicted.

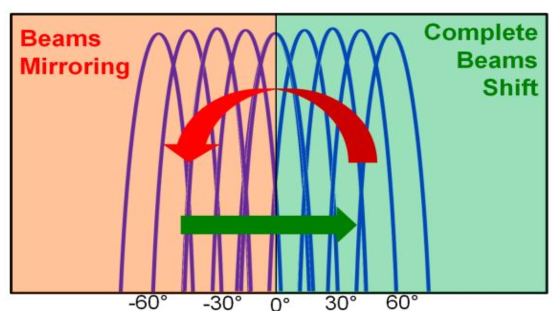

Fig. 1. Combination of "Complete Beam Shifting" and "Beam Mirroring" for scanning range extension of Rotman lenses.

III. PHASE SHIFTER DESIGN

The core element of the extended scan range method is the phase management stage, which is placed between the array and the Rotman lens, as illustrated in Fig. 2. Specifically, 16 phase shifters have to be fabricated for generating the required n•90° (with n=1, 2...16 array ports) phase distribution necessary for the CBS procedure. Furthermore, 8 elements of the phase control stage must be able to provide a phase inversion for producing the BM effect. By design considerations, the reflective type phase shifter (RTPS) has been chosen as development technique.

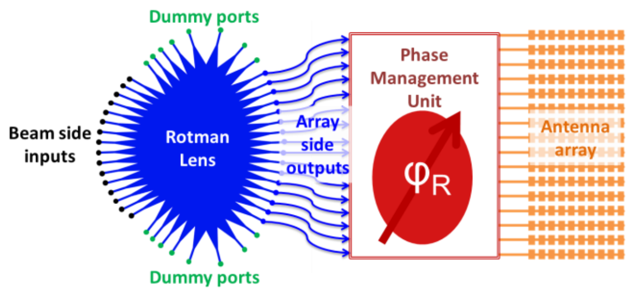

Fig. 2. Extended scan range concept block diagram

As shown in Fig. 3, where the simulated basic phase management cell is shown, a hybrid ring coupler topology has been selected for both fixed (*RTPS A*) and switchable phase shifters (*RTPS B*). In fact, in the case *RTPS B*, the phase inversion is obtained by using PIN diodes mounted in opposite direction for terminating to open/short a pair of reflective loads (thus creating a sign inversion). According to RTPS theory, phase shift is determined by the reflection coefficient of the two loads (ideally pure reactance, realized as stubs).

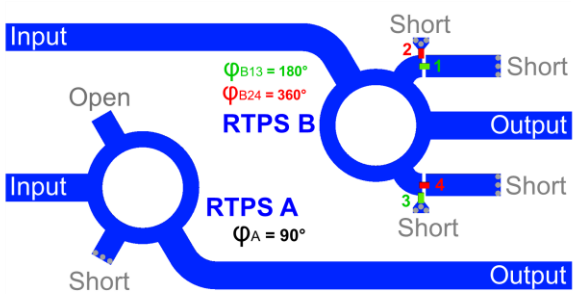

Fig. 3. Empire XPU model of the designed RTPS A for 90° and RTPS B for 180° phase shifting. PIN diodes that are ON/OFF simultaneusly are represented in green/red (respectively to 180° and 360° phase shifting).

Furthermore, for compensating the error deriving from the line length difference during the ON/OFF state of the diodes, a balanced approach has been used in such a way that 2 diodes (i.e. PIN diodes *1* and *3* for 180°, while *2* and *4* give 360°) are simultaneously conducting in the opposite branches, thus equalizing the path length to ground. In fact, at millimeters-wave frequencies, physical dimensions of components must be included in the design along with the equivalent circuit of the PIN diode. Moreover, non-idealities of the diode influence the effective length of the stubs, therefore dimensions must be tuned for having the correct phase difference among all the phase shifters. The same concept is used in *RTPS A* for providing the constant phase shift, by simply using open and short stubs with proper length. Phase shift of 270° and 360°/180°, given by configurations *RTPS C* and *RTPS D* respectively, are the dual versions of *RTPS A* and *RTPS B.*

IV. Simulated Results

The simulated phase management unit S-parameters, shown in Fig. 4, indicate a good return loss over more than 4.5 GHz BW (referring to -10 dB criterion) and low insertion loss of 1.3 dB at the target frequency of 24 GHz (maximum of 1.9 dB at 27 GHz). The phase reversal concept is also providing good results at center frequency, showing a maximum phase error of 2.7° among the 4 RTPS. However, results confirm that the solution is intrinsically narrowband, but adequate for the 24 GHz SRR application. The cause is the loading line length mismatch among the fixed and switchable RTPS.

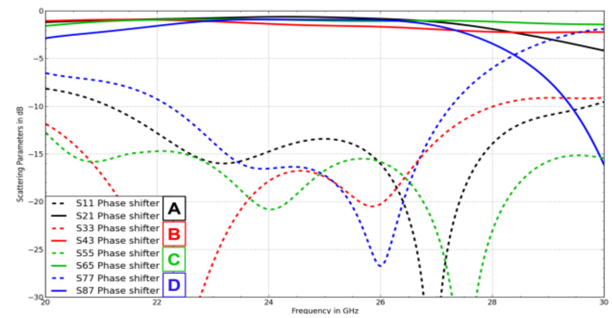

Fig. 4. Simulated S-parameters of the 4 reflective type phase shifters providing 90° (black), 180° (red), 270° (green) and 360°(blue).

Finally, Fig. 5 shows the simulated directivity of the complete extended scan phased array. From the picture it is noticed that maximum is at broadside, with the value of 26.4 dBi, while the lowest value is of 21.3 dBi when the beam is tilted to 60°.

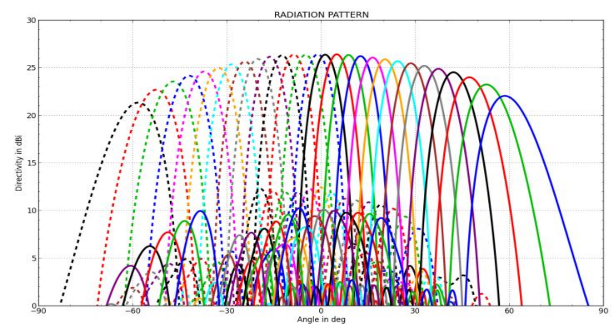

Fig. 5. Simulated directivity of the extended scan range SRR system including the proposed phase management unit.

V. Conclusions

The design of the phase management unit based on RTPS for the application of the extended scan range concept on a 24 GHz SRR automotive radar system has been presented and numerically validated. The proposed phase adjustment unit fulfills the CBS and BM procedures necessary to double the scan range of the Rotman lens beamforming network.

References

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