PHOTONIC BEAMFORMING
FOR PHASED-ARRAY RADAR

F.E. van Vliet

TNO-FEL, P.O.Box 96864, 2509JG, The Hague, The Netherlands

Tel: +31.70.374.07.40, Fax: +31.70.374.06.54, Email: vanvliet@fel.tno.nl

INTRODUCTION

Future radar systems will increasingly be applying electronically steered arrays. The re-use of apertures for different applications, including communication and electronic support applications, is a key issue. The scarcity in antenna locations poses further advantages to antenna co-location or antenna sharing. The sharing of antenna apertures by different systems implies that the antenna, including the front-end and beamformer, has to cover the full bandwidth of the systems it has to serve. This requirement is in agreement with a further increase in bandwidth of the individual systems, in order to improve performance. A relative bandwidth per system between one and two octaves is targeted.

This system approach brings a number of problems. One of the important problems is the bandwidth of the active antenna. This bandwidth issue plays for both the antenna element, the transmit/receive module components and for the beamformer. The alternatives for beamforming are RF beamforming, IF beamforming, digital beamforming, optical beamforming and hybrid beamforming. Of these alternatives, optical beamforming offers potentially the highest bandwidth, and may hence solve the squinting problem, normally present in large wideband antennas. Figure 1, shown below, illustrates how serious the squinting problem can be by relating the mispointing angle with the beamwidth. For this reason, optical beamforming has been subject of study over the last years at TNO-FEL. This paper summarises the Dutch results and achievements in the field of optical beamforming for electronically steered arrays.

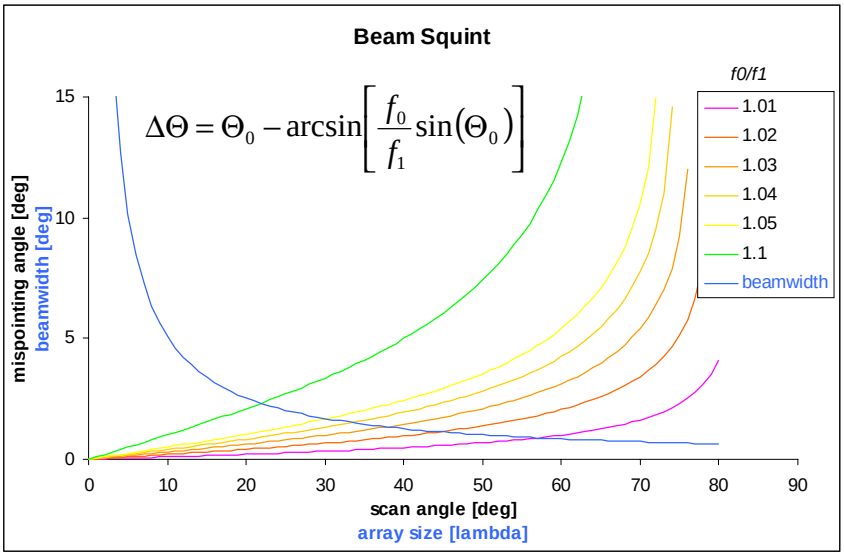


Figure 1. Theoretical beam squint as a function of array size.

NON-COHERENT OPTICAL TTD BEAMFORMING

The wideband potential of optical beamforming is most clear from the possibility of making wideband switched true-time delays (TTD). Due to the fact that the RF signal has a negligible relative bandwidth as compared to the optical carrier, the bandwidth limitations will be based on the electronic interfaces. Several TTD beamformers and beamforming architectures have been demonstrated. Technologies that were demonstrated include discrete delay lines in the form of fibres as well as integrated delay lines on SiO2 and InP. For the switches, both electro-optic as well as thermo-optic switches have been applied. Each of these technologies has advantages for particular time delays needed or for specific switching time requirements.

In co-operation with ASTRON, TNO-FEL has developed a four-channel optical true-time delay beamformer. This beamformer is based purely on telecommunications components with directly modulated lasers, and is suitable for systems where the switching speed between different beams is in the order of milliseconds. The demonstrated performance of the beamformer is a dynamic range of 101 dB Hz^(2.3) over an octave bandwidth (2 to 4 GHz).

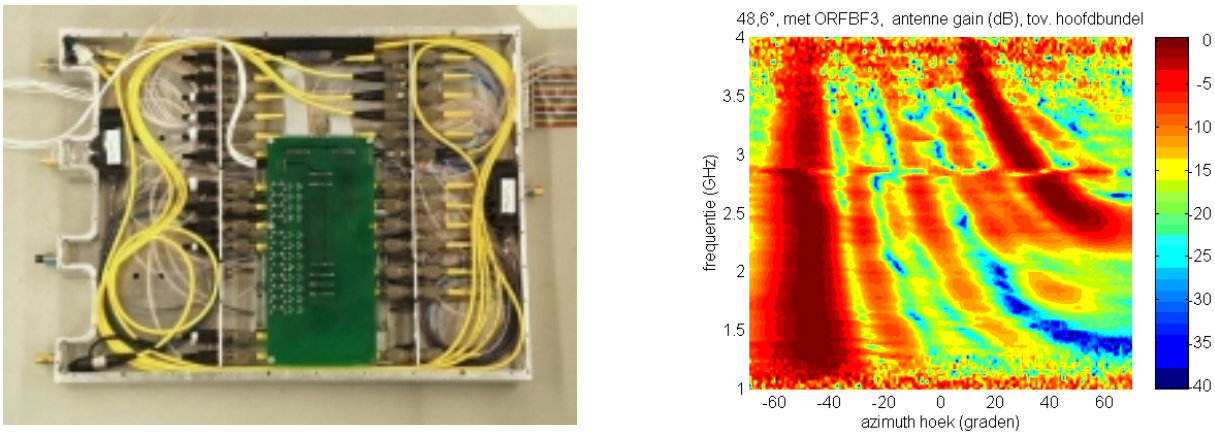


Figure 2. Photo of 4-channel optical beamformer (left) with the antenna pattern results (right). The beamformer was characterised together with ASTRON.

Furthermore, we have recently designed a fiber-optic Butler matrix. The insertion loss is identical to the insertion loss for a single-beam beamformer, the extra beams are obtained by using the additional outputs of the optical splitters. The beamformer offers four outputs corresponding to individual beams and is shown in Figure 3. The beamformer realises 0, 10, 22.5 and 45 degrees beam patterns. It will be demonstrated at a subsystem level in the near future.

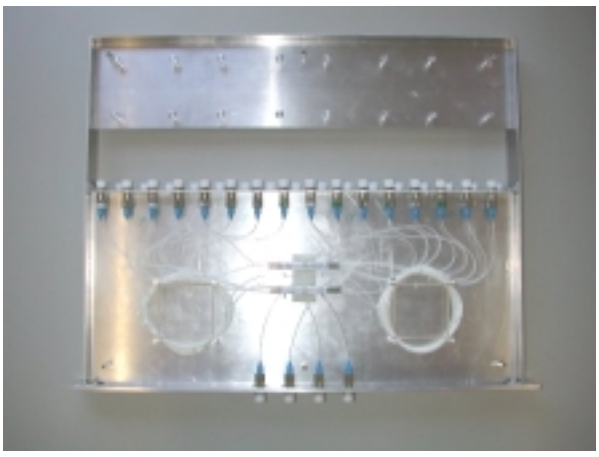
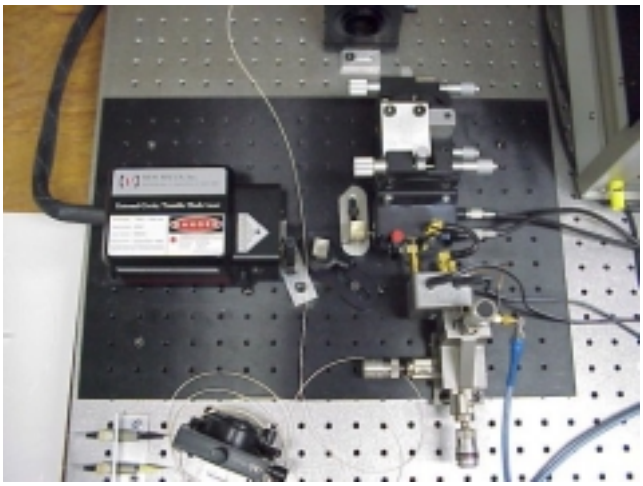


Figure 3. Photograph of the 4-beam Rotman lens beamformer

COHERENT OPTICAL BEAMFORMING USING AN OPLL SOURCE AND OEIC TECHNOLOGY

Coherent beamforming can inherently offer more dynamic range to optical links than non-coherent beamformers. Disadvantages for coherent beamformers include the need for a coherent optical source, the need for polarisation-maintaining components and an increased sensitivity to vibration and thermal variations.

To overcome these limitations, an optically coherent source has been developed, operating at 2.5 GHz. This source, based on the optical phase-locked loop (OPLL) principle, incorporates two semiconductor lasers and microwave electronics that locks the two sources together with the help of a reference source. The difference between the two laser signals then copies the accuracy of the reference source into the optical domain. The OPLL exhibited a locking range of 700 MHz and a locking time of several hours.



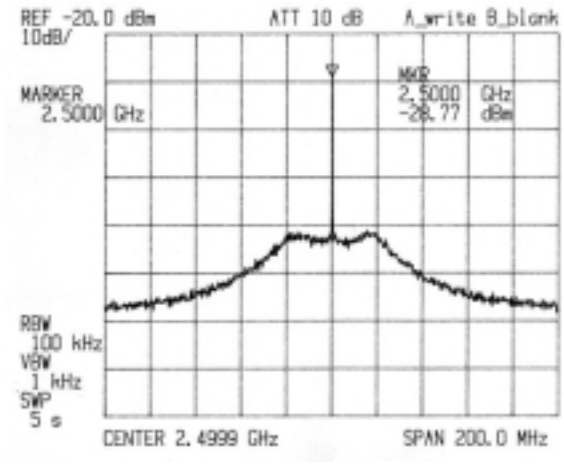


Figure 4. Test set-up of the OPLL and the spectrum measured.

In co-operation with the Delft University of Technology an integrated coherent beamformer on InP has been designed and tested. The OEIC incorporates 16 channel phase and amplitude control and requires the OPLL to be functional. Measurement results show that more than 360 degrees phase control can be obtained and up to almost 20 dB attenuation. A four-channel beamformer was developed as a derivative.

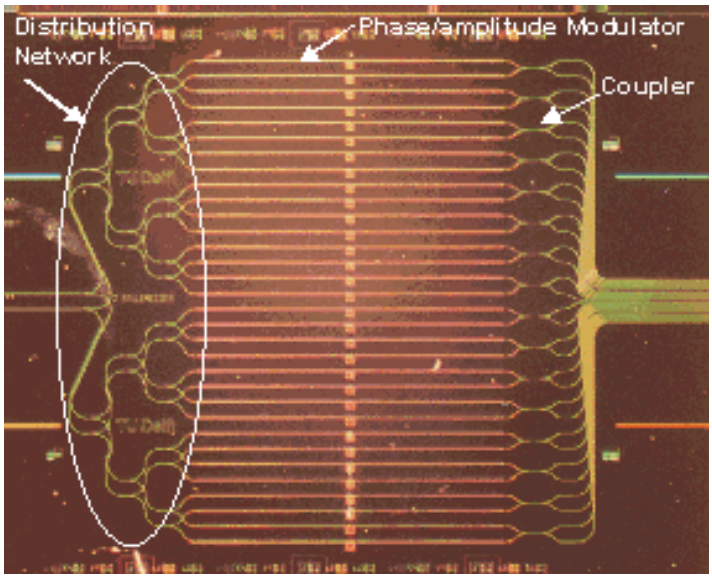


Figure 4. Photograph of the 16-channel InP beamforming OEIC

CONCLUSION

In conclusion, recent developments have resulted in optical beamformers that can provide very wideband beamforming solutions capable of providing more than 100 dB Hz^(2/3) dynamic range. The beamformers presented show state-of-the-art performance. They can be based on telecommunication components for non-coherent beamforming. The results achieved indicate that optical technology is ready to be applied in wideband electronically steered arrays. Depending on the application, non-coherent beamforming is currently the preferred method, due to the insensitivity to the set-up to vibration and environmental conditions.