Integrated InP circuits and Si TTD

for analogue optical beamforming applications

F.E. van Vliet, F.L.M. van den Bogaart
TNO Physics and Electronics Laboratory (TNO-FEL)
P.O. Box 96864
2509 JG The Hague
The Netherlands
Email: vanvliet@fel.tno.nl

Introduction

In future microwave systems, there will be an increasing need for wide bandwidths. Electronically steered antennas with bandwidths up to an octave or more are foreseen. The beamforming for these systems is problematic. The systems are generally in need of time-steering instead of phase-steering. Electrical true time-delays (TTD) are difficult to make over large instantaneous bandwidths. The beamforming options are RF beamforming, IF beamforming, digital beamforming, optical beamforming and hybrids of these four techniques. Optical beamforming is the alternative that is most suitable for true time delay beamforming; the relative bandwidth of the microwave signal referred to the optical carrier is almost zero.

In The Netherlands, the R&D regarding microwave photonics for optical beamforming is concentrated at TNO Physics and Electronics Laboratory, at The Netherlands Foundation for Research in Astronomy (ASTRON), and at the Eindhoven University of Technology (EUT) [1-3]. The activities at these centres will be discussed.

Incoherent beamforming: TTD

The wideband potential of optical beamforming is most clear from the possibility of making low-loss wideband switched true-time delays. Several different technologies were employed for switched true-time delays at TNO-FEL, including thermo-optic and electro-optic switches, and delays in fibre technology as well as integrated on wafer-scale Silicon and chip-scale InP.

Figure 1: Example of optical delay lines on Si wafer

In a co-operation between ASTRON and TNO-FEL, a four-channel fibre-optic true-time delay beamformer has been demonstrated. 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 (2-4 GHz).

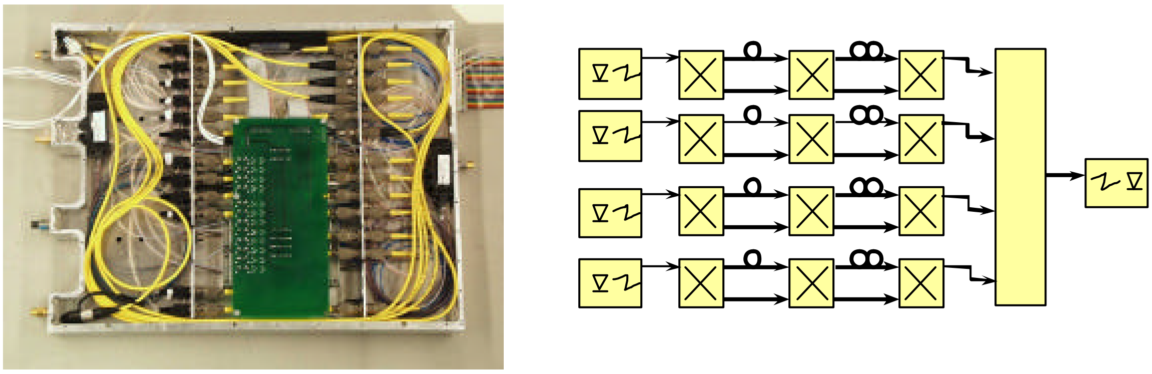

Figure 2: Photograph and schematic of 4-channel optical beamforming,

Furthermore, TNO-FEL has recently demonstrated an optical multibeam beamformer using a fibre implementation of a Rotman lense. A 4x4 beamformer was realised, combining four distributed apertures into four antenna beams. The beamformer will be tested in co-operation with the German FGAN, and finds its applications primarily in airborne applications.

The telecommunication industry widely relies on wavelength division multiplexing. This strategy can also profitably be used for beamforming purposes. The use of several colours of light reduces the amounts of hardware needed, and facilitates easy steering of the antenna beam. A set-up using wavelength division multiplexing is currently under investigation by TNO-FEL and EUT, employing both dispersive and dispersion-free TTD's and allowing for a distribution of the antenna panels coupled.

Coherent Beamforming: OPLL and OEIC's

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 by TNO-FEL, 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 use of cheap and small laser diodes resulted in very strict requirements on the total delay, present in the loop. The results of this setup, including the spectrum of the locked source and the measurement set-up itself will be presented. The OPLL exhibited a locking range of 700 MHz and a locking time of several hours.

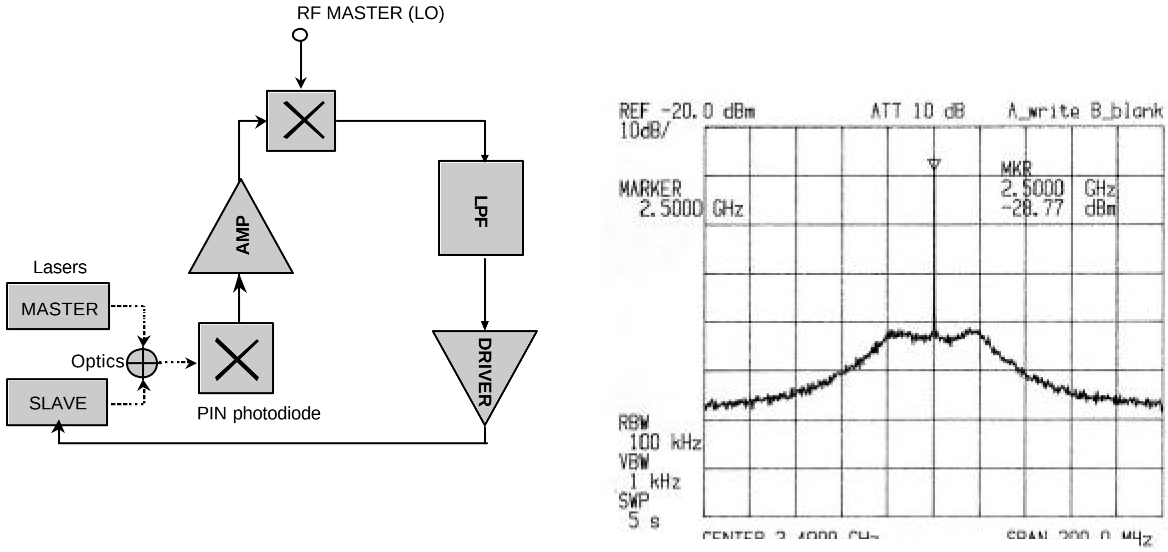

Figure 3: Schematic and measurement results of OPLL

In co-operation with the group of Prof. Smit, now part of Eindhoven University of Technology, a number of integrated coherent beamformers have been designed, the most advanced facilitated 16 elements. The beamformers were realised on InP and were tested with the OPLL mentioned above. The OEICs incorporate individual phase and amplitude control for all elements, and require an OPLL to be functional. Measurement results show that more than 360 degrees phase control can be obtained and up to almost 20 dB attenuation for all channels. A four-channel beamformer was developed as a derivative.

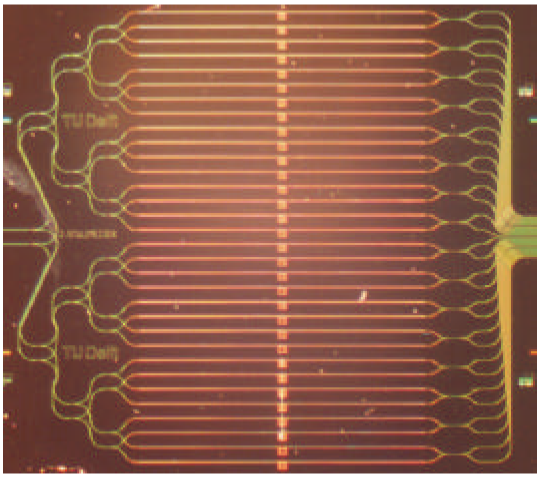

Figure 4: Photograph of integrated 16-channel InP beamformer

Conclusion

In conclusion, optical beamformers providing very wideband beamforming solutions and capable of providing more than 100 dB Hz^(2/3) dynamic range have been shown. The beamformers are based on telecommunication components and 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.

References

[1] Raymond van Dijk , Jaap D. Bregman , Anton Roodnat and Frank E. van Vliet, "Photonic True Time Delay Beamformer Demonstrator for a Radio Astronomical Array Antenna", Proceedings of MWP 2000, 11-14 Sep. 2000

[2] J. Stulemeijer, R. van Dijk, F.E. van Vliet, D.H.P. Maat M.K. Smit, "Photonic chip for steering a four element phased array antenna", Proceedings of MWP2000, 11-14 Sep. 2000

[3] J. Stulemeier, F.E. van Vliet, K.W. Benoist, D.H.P. Maat, M.K. Smit, "Compact Photonic Integrated Phase and Amplitude Controller for Phased-Array Antennas", IEEE Photonics technology Letters, vol. 11, no. 1, 01-Jan-99