ULTIMATE BEAM CAPACITY LIMIT OF FIBRE GRATING BASED TRUE-TIME-DELAY BEAM-FORMERS FOR PHASED ARRAYS

Robert A. Minasian and Kamal E. Alameh
Department of Electrical Engineering and Australian Photonics CRC,
University of Sydney, NSW, 2006, Australia.

ABSTRACT

A new grating based beam-former is presented which can synthesise a large number of beams with the minimum number of interconnects. A partitioned WDM grating topology is also described which removes the frequency and beat noise limits, and results are presented for the ultimate capacity of grating true-time-delay beam-formers.

INTRODUCTION

Future multi-beam radar and communication systems will require phased array antennas that can achieve true-time-delay beam-forming and which can synthesise a large number of beams. The important advantages of frequency-independent, wideband and squint-free operation motivate the use of optical beam-forming techniques. Recently, the ability of optical fibre Bragg gratings to achieve true-time delay has attracted special attention due to their compatibility with optical beamforming networks [1]-[5]. The exploitation of the wavelength domain of lightwaves in conjunction with discrete and chirped gratings provides one of the most promising approaches for the implementation of dense multi-beam phased arrays.

The ultimate beamforming capacities of these grating-based optically-controlled phased arrays is an important question. In this paper we consider the synthesis problem of a large number (500-1000) of beams, and present a new WDM grating-based beamforming architecture which has the lowest possible number of required optical interconnects. Fundamental limitations arising from optical interference beat noise, and grating characteristics including wavelength span and minimum time delay are also analysed. We also consider the operating frequency limits of the beamformnig network and present a partitioned WDM grating topology which eliminates the beat noise and frequency limits of the phased array beamformer.

MINIMUM INTERCONNECT GRATING-BASED BEAMFORMING ARCHITECTURE

Fig. 1 shows the architecture of the new grating-based WDM photonic beamforming network. The antenna elements are assigned equally-spaced wavelengths which are connected via a star coupler to the grating-based beamforming network which provides outputs for M independent beam directions. The required delays for equalisation have a linear time-wavelength characteristic, and are realised using chirped or discrete Bragg gratings, depending on the delay time differential required for each beam direction. The longer delay times (>10 ps) which comprise the large majority of the network are obtained using discrete gratings, whereas the few small delay times (<10 ps) are obtained using chirped gratings.

The number of interconnects required for an M beam array for this topology is shown in

0-7803-4471-5/98/$10.00 (c) 1998 IEEE

Fig. 2. The significant reduction in interconnect hardware in comparison to a conventional beamforming network which requires M^2 optical interconnects, can be seen. For example, for a 512-beam array a reduction in interconnect hardware of 99.6% is obtained, which is the lowest number of interconnects reported to date.

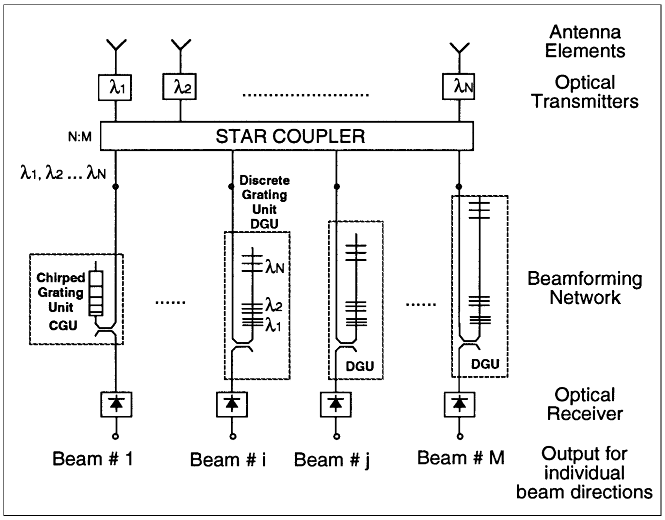

Fig. 1. Architecture of new grating-based WDM photonic beam-former.

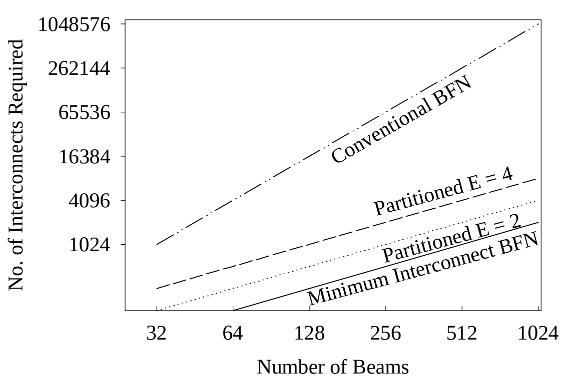

Fig. 2. Number of interconnects required versus number of beams in the phased array.

While resulting in the minimum number of interconnects possible, the ultimate limitation to the topology of Fig. 1 arises from the optical beat noise. Fig. 3 shows the required wavelength span of the grating delay units as a function of maximum microwave frequency, in order to avoid the optical interference between the various wavelengths or beat notes produced at the photodetectors. Also shown is the optical spectrum limit of an erbium doped fibre amplifier which would be used to provide optical gain in the BFN. It can be seen that for optical spectral span limits of 40 nm, and for 512 beams, the maximum microwave frequency that can be used is 5 GHz for the topology of Fig. 1 due to the beat noise limit.

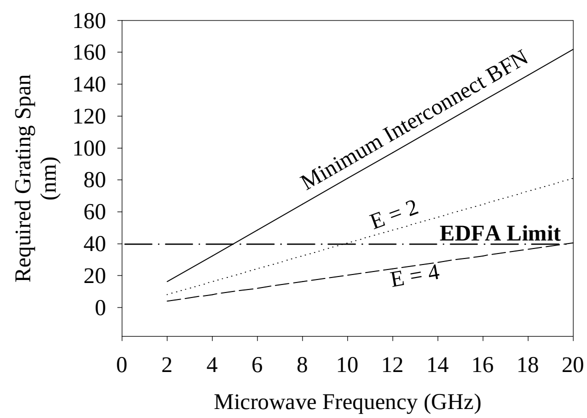

Fig. 3. Grating delay unit wavelength span requirement.

OPTIMUM WAVELENGTH PARTITIONING IN GRATING-BASED BEAMFORMING NETWORK

In order to increase the microwave frequency operation limit, we propose a partitioned WDM grating based beamforming network, shown in Fig. 4. The architecture is based on the partitioning concept [4]. The array is divided into E sets of P elements each. The antenna elements are assigned P equidistant wavelengths, which are the same for each set. Hence each set of P elements in the delay profile of Fig. 5 requires a Reference

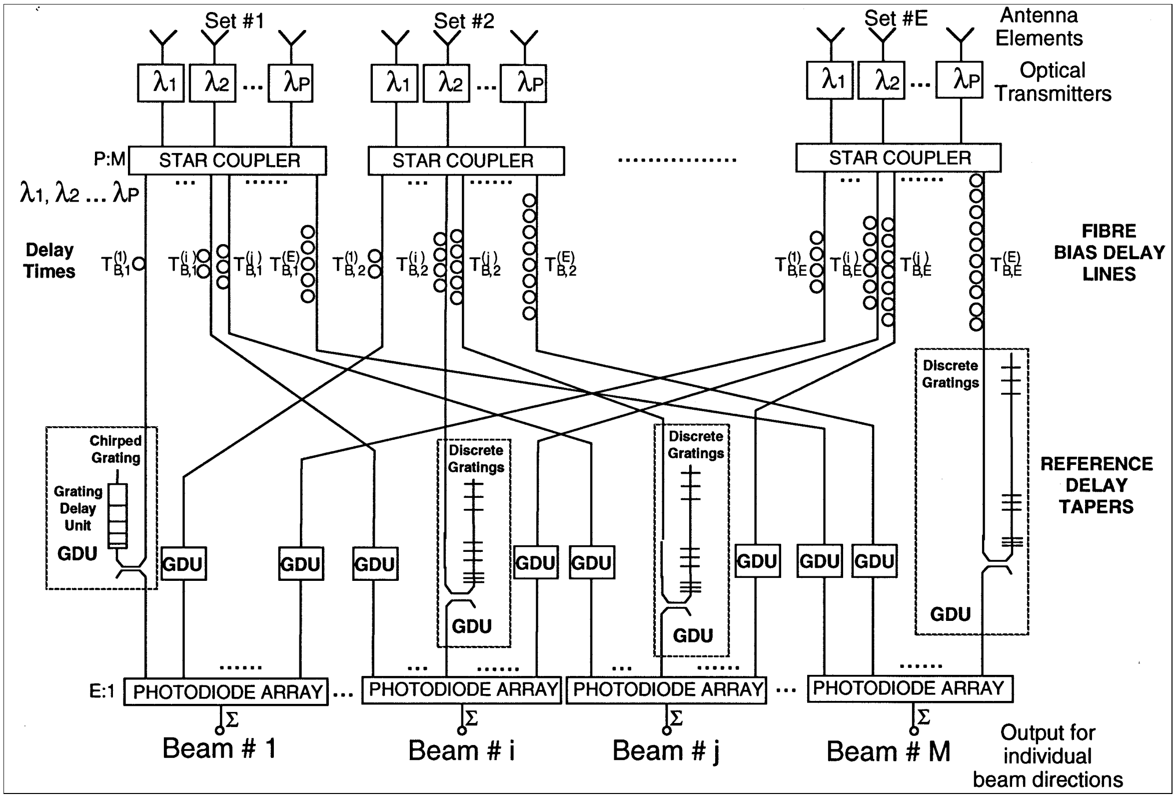

Fig. 4 Architecture of the partitioned WDM grating-based beamforming network.

linear delay taper which is the same for all sets, and a Bias delay which is the same for all elements within a set but differs between sets. Note that a photodetector array is used at each port, so each photodetector array element detects only P different wavelengths.

The required wavelength span of the grating delay units as a function of the microwave frequency for the WDM partitioned beamforming network of Fig. 4, is shown in Fig. 3. The results show that the limitation on the maximum microwave frequency is now removed by partitioning to higher levels, while eliminating the beat noise interference and operating within the EDFA spectral limit. This is an important advantage. For example, for E = 4 partitioning and 512 beams, the maximum microwave frequency that can be used is increased to 20 GHz.

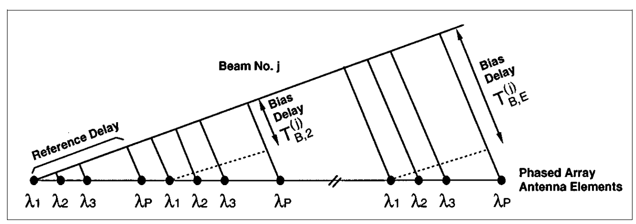

Fig. 5. Delay time profile and partitioning of wavelength sets.

The required minimum delay time of the grating units in the beam-forming network decreases with the number of beams and with microwave frequency, and this can set a limit. Fig. 6 shows the minimum time delay required in the grating delay unit as a function of frequency and beam number. Also shown is the minimum delay time that is achievable in practice for a chirped grating [6]. It can be seen that both high microwave operating frequency and high beam numbers can be realised using the grating units.

Finally, Fig. 2 shows the effect of partitioning on the interconnect number required. The results show that there is a small penalty in interconnect numbers compared to the minimum interconnect topology. However, even with E = 4 partitioning, the interconnect reduction for 512 beams is 98.4%, compared to the conventional beamforming network. This is a very substantial reduction, which is combined with the important advantage of enabling operation at higher frequencies and with lower grating spectrum span.

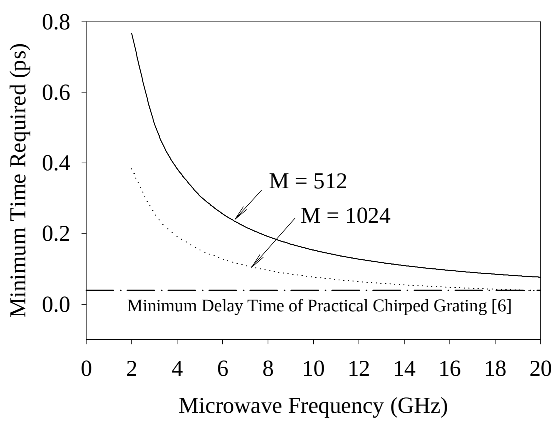

Fig. 6. Grating delay unit minimum time delay requirement.

CONCLUSION

We have presented a new WDM grating based beam-forming architecture for phased arrays that can synthesise a large number of beams with the minimum possible number of optical interconnects required. For a 512-beam array, a reduction in interconnect hardware of 99.6% is obtained, which is the lowest number of interconnects reported to date. Due to the beat noise limitation the maximum frequency of operation is limited to 5 GHz. We have also presented a partitioned WDM grating architecture which removes the frequency limit to beyond 20 GHz and maximises beam capacity, without beat noise limitations. Results for optimum partitioning are presented and show practical grating requirements, including wavelength span and minimum delay time, while still achieving a 98.4% reduction in interconnect number. The fibre grating based beamformers make possible high-resolution true-time-delay beamforming with wideband microwave capability.

ACKNOWLEDGMENT

This work was supported by the Australian Research Council.

REFERENCES

[1] R.A. Soref, "Fiber grating prism for true time delay beamsteering", Fiber Integr. Opt., 1996, 15, pp.325-333.

[2] H. Zmuda, R. Soref, P. Payson, S. Johns, and E.N. Toughlian, "Photonic beamformer for phased array antennas using fibre grating prism", IEEE Photon. Technol. Lett., 1997, 9, pp. 241-243.

[3] D.T.K. Tong and M.C. Wu, "Programmable dispersion matrix using Bragg fibre grating for optically controlled phased array antennas", Electron Lett, 1996, 32, pp. 1532-1533.

[4] R.A. Minasian and K.E. Alameh, "Optical-fiber grating-based beamforming network for microwave phased arrays", IEEE Trans. Microwave Theory Tech., 1997, 45, pp. 1513-1518.

[5] J.E. Roman, M.Y. Frankel, P.J. Matthews, and R.D Esman, "Time-steered array with chirped grating beamformer", Electron Lett, 1997, 33, pp. 652-653.

[6] A. Molony, L. Zhang, J.A.R. Williams, I. Bennion, C. Edge, and J. Fells, "Fiber Bragg-grating true time-delay systems: Discrete-grating array 3-b delay lines and chirped-grating 6-b delay lines", IEEE Trans. Microwave Theory Tech., 1997, 45, pp. 1527-1530.