Microwave phase shifter based on fibre Bragg grating

B. Ortega, J.L. Cruz, M.V. Andrés, A. Díez, D. Pastor and J. Capmany

A variable delay line is presented for phased array antennas based on a fibre Bragg grating which has a uniform period and operates at constant optical wavelength. The Bragg wavelength of a localised part of the fibre grating is modified by straining the fibre, the optical carrier is reflected by the strained part of the grating and the time delay of the microwave modulating signal is determined by the position where the strain has been applied. In this initial experiment time delay variations up to 330ps in the frequency range 1–14GHz have been achieved.

Introduction: The use of fibre Bragg gratings for implementing phase shifters for phased array antennas has been investigated since the first demonstration reported in 1994 [1]. Two configurations are used to implement the optical RF beamforming network [2]. The first one consists of a set of discrete uniform gratings of different Bragg wavelengths along a fibre. The phase shift of this line is determined by the optical path length between gratings [1, 2]. The second configuration is based on a chirped fibre grating and the phase shift is given by the position in the grating where the optical carrier is reflected [2 – 4]. The time delay of these lines is varied by tuning the wavelength of the optical carrier. Phased array antennas based on these lines need at least a tunable light source and a demultiplexing system, hence the architecture of the beamforming network could be tremendously simplified by using a system operating with a single optical wavelength.

In this Letter, we present an alternative tunable delay line for RF applications based on a single fibre grating of uniform period that works with only one optical wavelength. This line operates by straining a small part of the grating. The optical carrier is reflected by this part of the grating and the phase delay of the microwave modulating signal is determined by the position where the strain has been applied. The fibre has been strained by a magnetic field and a magnetostrictive transducer [5]. In this first experiment a line capable of producing delays of 330ps in the frequency range 1–14GHz has been demonstrated.

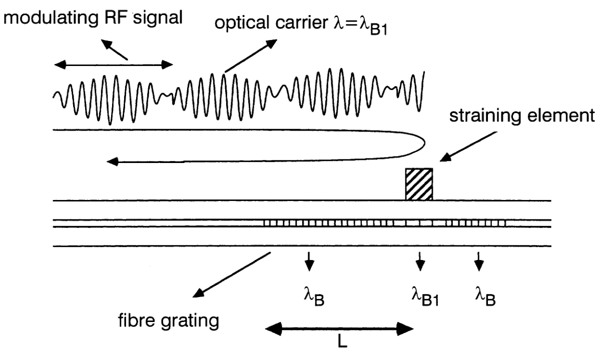

Fig. 1 *Schematic diagram of strained grating working as microwave phase shifter*

Phase delay of microwave modulating signal depends on position of straining element along fibre

Principle: Consider a fibre grating with Bragg wavelength λ_B. By straining a specified point of the grating its local Bragg wavelength can be shifted to a different value λ_{B1} as illustrated in Fig. 1. An optical carrier of wavelength $\lambda = \lambda_{B1}$ will then be reflected by the strained section of the grating. If the carrier is modulated by a microwave signal of frequency f_{RF}, the modulating signal will suffer a phase delay $\Delta\Phi_{RF}$ given by the fibre length L traversed by the light: $\Delta\Phi_{RF} = 4\pi f_{RF} L n_{EFF}/c$, where n_{EFF} is the effective refractive index along the grating and c is the velocity of light. Hence, the fibre grating produces a linear phase shift in the modulating signal and the phase slope can be continuously varied by displacing the strained point along the grating. Note that this device behaves as a true time-delay line provided that the linewidth of the modulated signal is negligible in comparison with the bandwidth broadening of the grating.

Experiment: In this experiment we used a uniform fibre grating 5cm in length with central Bragg wavelength at 1526.1nm and 0.7nm bandwidth (see Fig. 2, top). A tunable laser was intensity modulated by an electro-optic modulator with a radiofrequency signal supplied by an RF network analyser. The modulated light was launched into the grating via a 3dB coupler and the reflected light was measured by the network analyser.

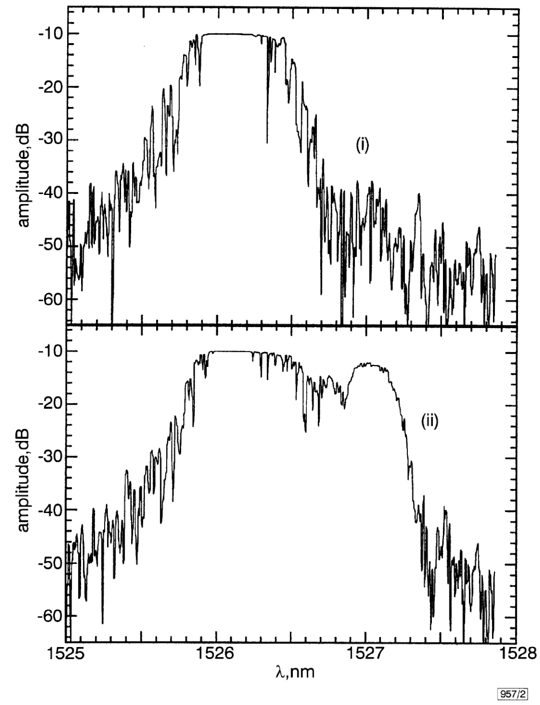

Fig. 2 *Reflectivity of fibre grating*

(i) original grating response
(ii) modified grating response (magnet position: 40mm from grating beginning to middle of magnet)

The grating has been strained by a magnetic field and a magnetostrictive transducer. The grating was held on a magnetostrictive rod and subjected to a magnetic field created by a permanent magnet. The composition of the magnetostrictive material is $Tb_{0.27}Dy_{0.73}Fe_2$ and its sensitivity is of the order of 10ppm/mT. The rod is 100mm long and has a diameter of 6mm. The magnet was 10mm long, with a diameter of 22mm and a maximum magnetic field of 120mT.

The effect of the magnet on the reflectivity of the grating is shown in Fig. 2. When the magnetic field is applied, the grating bandwidth broadens ~0.7nm. The grating spectrum preserves the flat response of the original grating at 1526.1nm and a secondary peak appears a 1527.0nm with 0.3nm bandwidth. This peak corresponds to the Bragg wavelength of the part of the grating strained by the magnet.

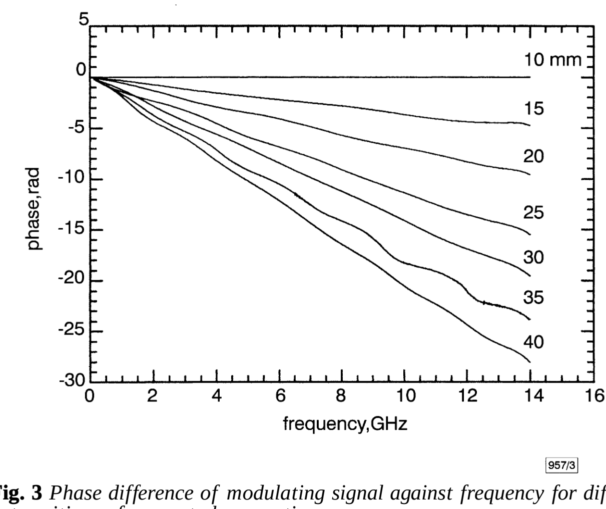

Fig. 3 *Phase difference of modulating signal against frequency for different positions of magnet along grating*

All distances measured from beginning of grating to middle of magnet

To test the grating as a microwave phase shifter the wavelength of the laser was set at 1527 nm. The linewidth of the modulated light (~0.16 nm at 10 GHz) is smaller than the bandwidth of the grating sidelobe (0.30 nm), hence the lightwave will be reflected by the part of the grating where the magnet is located. Fig. 3 shows the phase of the microwave signal after reflection from the grating. The phase has a linear dependence on frequency in the 1–14 GHz range and the phase slope can be controlled by changing the position of the magnet along the grating.

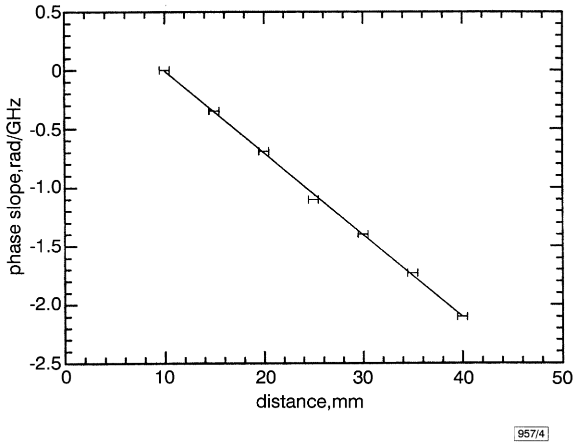

Fig. 4 *Slope of phase response against magnet position along grating*

The slope of the phase curves for different positions of the magnet is plotted in Fig. 4. The delay can be tuned in the region of 330 ps and exhibits a linear dependence on magnet position. These measurements indicate that the strained part of the grating has a phase centre well defined despite the length of the magnet (10 mm) is not negligible with respect to the grating length (50 mm).

Conclusions: We have demonstrated a novel delay line based on a standard fibre grating for microwave applications. The line operates with a single optical wavelength and the time delay is tuned by applying a local strain at different points of the grating.

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