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Demonstration of a wide band RF photonic transversal phase-shifter

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Abstract: A transversal phase-shifter using multiple MZMs is demonstrated. The device exhibits continuously variable phase-shift exceeding 360° at 2 GHz and amplitude uniformity within 3 dB over 0.2-2 GHz. The device stability and practicality are discussed.

OCIS codes: (060.2340) Fiber optics components; (350.4010) Microwaves

1. Introduction

Modern military RF and microwave systems and subsystems are required to process signals with significant bandwidth in order to maximise probability of intercept in an unpredictable environment. This demand has created much research interest in the area of microwave photonics [1]. In phased array antenna applications, broadband beam forming requires phasing systems to exhibit true time delay behaviour. Several techniques have been proposed over the years to achieve this. Examples are switched delay lines [2], dispersive fibre prism [3] and fibre Bragg grating approaches [4].

Even though TTD techniques can result in very broad system bandwidth, they tend to be expensive and complex which limit their use in practical applications. Other approaches have therefore been conceived. These approaches approximate true time delay behaviour over an operating frequency at the expense of behaviour outside the band. Examples of such device are the reflection type phase-shifter [5], the varactor loaded transmission line phase-shifter [6], the vector sum phase-shifter [7] and recently the transversal phase-shifter [8].

In [8], the transversal phase-shifter (TPS) has been proposed and analysed theoretically. In this paper, we present a practical demonstration of the TPS device. A particular implementation of the TPS is described in Section 2. Experimental results are then compared with the theoretical prediction. Section 3 discusses various aspects of the TPS implementations covering the system stability, controlling scheme and the practicality of the device. Future research direction is then drawn from these discussions. Conclusions are finally given in Section 4.

2. Demonstration of an RF photonic transversal phase-shifter

A seven tap TPS, which permits 360° phase shifting range at 2 GHz and has less than 1 dB amplitude variation over the entire 0.2 to 2 GHz band has been previously proposed and theoretically studied in [8]. In the current investigation, a five tap TPS is demonstrated practically.

The experimental setup is presented in Fig. 1. The TPS comprises of 5 taps, which each is implemented as a simple RF photonic link using a Mach Zehnder modulator (MZM). Separate lasers are employed to avoid undesirable coherent interference [9]. The input RF signal is split equally using a 1:8 active power splitter. Unused output ports of the power splitter are terminated in 50 Ω to avoid reflections. The taps are combined optically in a cascade of 50:50 fibre couplers. The time delay increment between taps is calculated to be 180 ps using an iterative numerical optimisation procedure. Using an RF network analyser, the required path lengths of these taps are matched within 0.5mm by carefully trimming the fibre.

The TPS tap weighting is calculated for various time delays using the method proposed in [8]. Table 1 presents the values of the tap's weights for some nominal values of the time delays. Delays have been chosen to illustrate the ability of the TPS to implement time delay in between the delays of the independent taps. The theoretical phase and magnitude responses of the TPS with the nominal time delays are presented as solid lines in Fig. 2 a) and b) respectively.

Table 1. List of coefficients for generating time delays. The first column represents the deviation from the delay of the central tap (τ = 360 ps). Note that these delays are not integer multiples of the tap delays.

Δt(ps)	C_0	C_1	C_2	C_3	C_4
-252	0.515467	0.743515	-0.200601	0.10827	-0.0690464
-100.8	-0.206133	0.70204	0.56445	-0.204039	0.123238
0	-0.0395802	0.0398948	0.96	0.0398948	-0.0395802
151.2	0.084906	-0.115864	0.216527	0.923175	-0.0958654
252	-0.0690464	0.10827	-0.200601	0.743515	0.515467

Using a vector network analyser to measure the RF response, the modulator bias is varied until a right tap weight is achieved. In addition to positive values, negative values of tap weight are obtained by utilising the negative slope of the modulator transfer function as illustrated in the inset of Fig. 1. The measured phase and magnitude responses of the TPS for time translation of Table 1 are presented as points in Fig. 2 a) and b) respectively.

The measured amplitude variation is within 3 dB over the entire band from 0.2-2 GHz and more than 360° phase-shifting range is available at 2 GHz. There is excellent agreement between the calculated and measured phase responses, and although having some deviations, the magnitude response traces well with the prediction. It is believed that the discrepancy between the measured and predicted responses could be caused by the variation in tap's weights due to the modulator bias drift.

3. Discussions

Although the RF photonic link gain depends on the polarisation of the optical carriers, it is not a source of instability in the system demonstrated in Section 2. The biggest source of instability in this system is the modulator bias drift, which results in an excess variation of the magnitude response on top of the TPS theoretical response. This problem could be avoided if modulator bias controls were employed. It is also of interest to note that modulator bias control can be programmed to detect and lock into a given modulation slope therefore allows the automation of the TPS control [10].

It is expected that varying the bias of the MZM as a mean of changing TPS' weights will result in reduction of the TPS dynamic range due to increasing power of the harmonic components of the RF signal. In particular, the second harmonic component of RF signal is maximised when the MZM is biased to maximum or minimum. This can significantly affect signal with bandwidth broader than an octave. It is therefore desirable to always bias the modulator at quadrature. Having fixed the bias at one of the quadrature points, the tap weights could be changed by varying the carrier powers. This can be achieved in two ways: varying the laser powers or employing variable optical attenuators. Negative weighting could then be obtained by changing bias to a quadrature point in the negative slope of the MZM transfer function.

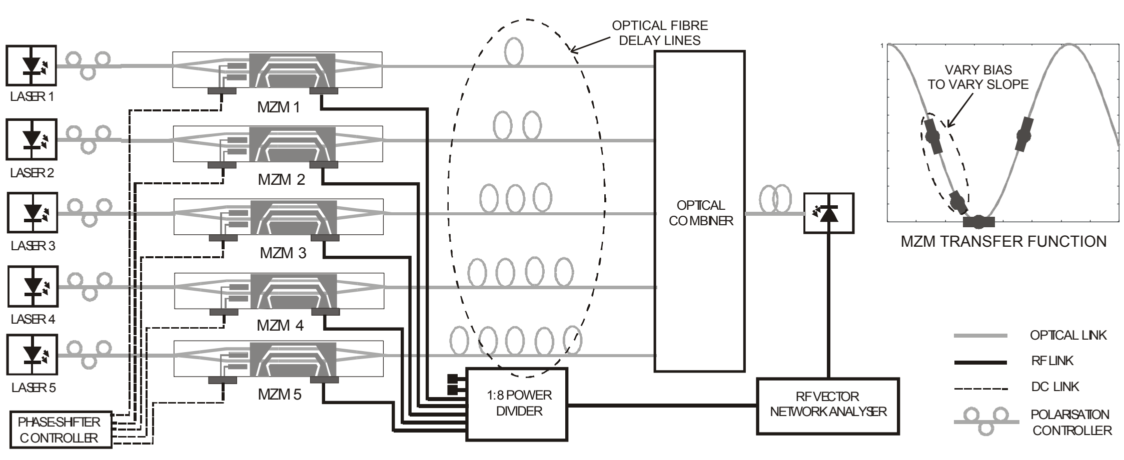
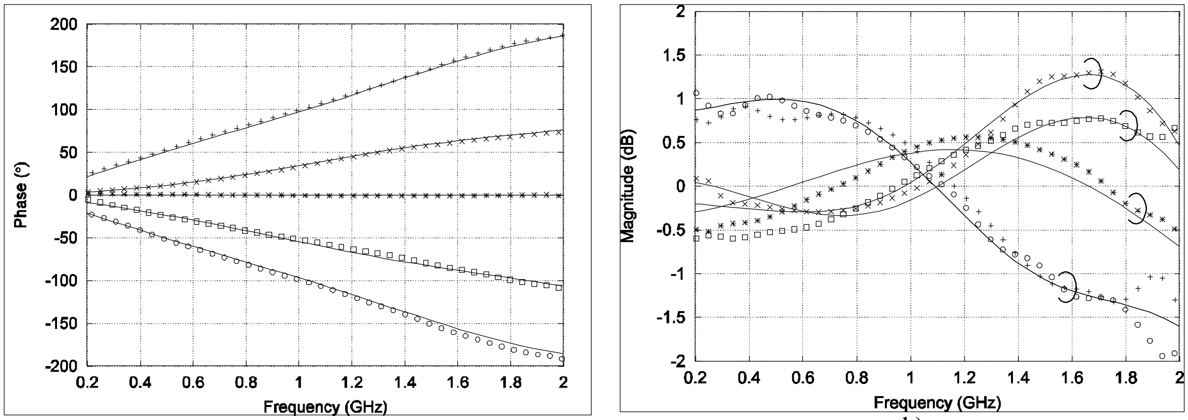


Fig. 1. Transversal phase-shifter demonstration setup



a) b)

Fig. 2. Response of the transversal phase-shifter. a) Phase response b) Magnitude response. Measurements are indicated as points and predictions are as solid lines. Responses are normalised to the centre tap response.

The TPS performance depends on the method used to weight the taps. It is therefore anticipated that significant research should be directed toward the algorithm used to select these tap weights. Numerical optimisation could be useful for this task.

It will also be important to minimise the complexity of the system. The requirement for an array of modulators could be met using a monolithic modulator array and optical combiners to minimise packaging requirements. Alternatively, WDM approaches using a single modulator could be considered.

4. Conclusions

An implementation of the transversal phase-shifter using multiple Mach Zehnder modulators is demonstrated. The device exhibits continuously variable phase-shift, which is linear with frequency over the 0.2-2 GHz band. The continuously variable phase shifting range is greater than 360° at 2 GHz and the measured magnitude response is uniform within 3 dB across the entire operating band. There is good agreement between measurement and prediction; hence the transversal phase shifter concept is validated. The major source of instability in this TPS implementation is the tap weight variation due to the modulator bias drift. This issue can be avoided by employing bias control circuits. Simplified implementation of the TPS using WDM techniques is currently under investigation.

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