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Optical Beamforming System for Satellite Communication

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We present an optical beamforming system for satellite communication using optical true time delay. A simple 2-by-1 optical beamformer is used as an initial step to validate the proof-of-concept of our proposed system. The beamformer uses a variable fibre-optic true time delay line to delay an optical signal which is used to control the phase of received radio frequency signal. Simulation results are used to further analyse the system performance. The goal is to realize an NxN beamformer with N >2 on a compact integrated optical chip. The proposed beamformer is shown to be a promising solution for a wideband satellite communication link.

Introduction

Satellite communication is an integral part of modern daily life including TV broadcasts, weather forecasting and research applications in radio astronomy. With the fast growing demand for satellite communication, the establishment of a wideband robust communication link is crucial. One way to achieve increased bandwidth for long-distance radio frequency (RF) communication is via beamforming [1]. In receive beamforming, an array of antennas known as a phased array antenna (PAA) system receives a signal from a space along a given direction. Then, the signals from each antenna element are phase shifted and later combined to give a boost in the received signal power. Traditional microwave beamformers use electrical phase shifters which have an equal phase shift for all frequency components of the signal. This causes the problem of *beam squint* [2, 3, and 4]. This means signals from each antenna element at different frequencies are not combined coherently which leads to the radio beam pointing in different directions for each frequency component. Wideband phase shifters in the digital domain are available but they are bulky and lossy [5]. Optically controlled beamforming solves this beam squint problem by delaying all spectral components equally in time causing the spectrum to experience a linear phase shift. This delay is realized by optical true-time delay lines (ODLs) and can be made ultra-small and compact using photonic integration technologies.

Operational Principles

Our proposed optical beamforming system architecture is shown in Fig. 1. The optical beamforming system consists of a central unit and a remote unit. A directly modulated laser (DML) and the photo detector (PD) are deliberately situated at the central unit, which allows having simpler and less expensive remote units. The DML driven by a local oscillator (LO) of frequency f_{LO}, generates a continuous wave optical signal which is transported to a remote unit via a single mode fibre (SMF). At the remote unit, a phased array antenna system with an inter-element distance of d receives RF signal from space in the frequency range from 20-40 GHz. When a signal is received in the

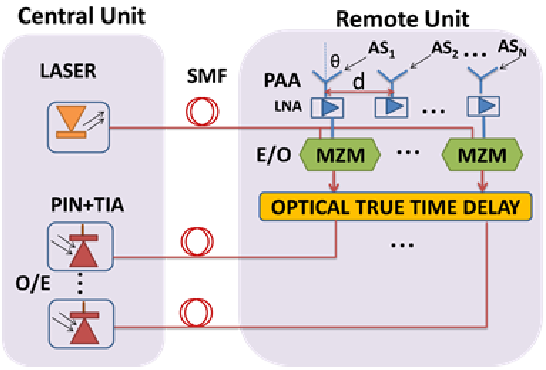

Fig.1. Optical beamforming system architecture

direction of θ, AS_2 is received with a time advance of $T = \dfrac{d\sin\theta}{c}$ before AS_1 is received, where c is the speed of light. That means there is a phase lag between each antenna signal due the time of arrival difference T. The MZM modulates the optical signal with antenna signal (AS_i) received from each antenna i $(i=1,\ 2\ldots N)$. After external modulation, ODL is used to compensate the delay between the antenna signals in the optical domain. This is done by applying an incremental delay of $(i\text{-}1)\times T$ to each channel i when the signal arrives at the 1^{st} antenna the latest. Then, the signal from each channel is transported back to central unit via SMF where the O/E conversion takes place at the PD. After the O/E conversion, combination of the signal in electrical domain produces a beam. As a result, the received signal is boosted in power due to constructive combination of the received antenna signals (beamforming).

Simulation Results

Simulation was performed to see the impact of the optical modulation technique used at the MZM on the receiver bit error rate (BER) in the frequency of interest i.e. 20 GHz. The simulation was done on **VPItransmissionMaker™**. A 2.5Gbps OOK data modulated on 20 GHz signal was received at the antenna unit. A 15GHz LO signal f_{LO} modulated a DML to generate a continuous wave optical signal and two subcarriers. Then, the optical signal was modulated with received antenna signal using MZM with a biasing voltage of $V_{\pi/2}$=1.25V. For comparison, suppressed carrier modulation was simulated by biasing the differential MZM with V_π and applying 180^0 phase shift in the dual arms. As a result, a 20 dB suppression of optical carrier was obtained as can be seen from Fig 2. A sweep attenuator was used to vary the received optical power at the photo detector in both cases. BER values simulated for different received optical power are shown in Fig 2. It can be observed from the figure that suppressed carrier modulation has less BER values for the same value of received power. This is because carrier suppression reduces the noise component related to the optical carrier.

Experimental Results

In this section, we present a simple experimental setup developed to verify the proof-of-concept of our proposed system. Fig 3a shows the schematic of the experimental set up of a 2-by-1 optical beamformer. Due to lack of optical and electrical components in our frequency of interest (20-40GHz), the experiment presented in this section was done at lower frequency. A LO signal of 6 GHz was used to drive the DML at 25^0C and with a biasing current of 80 mA. The measured spectrum of the laser is shown in Fig 3b.

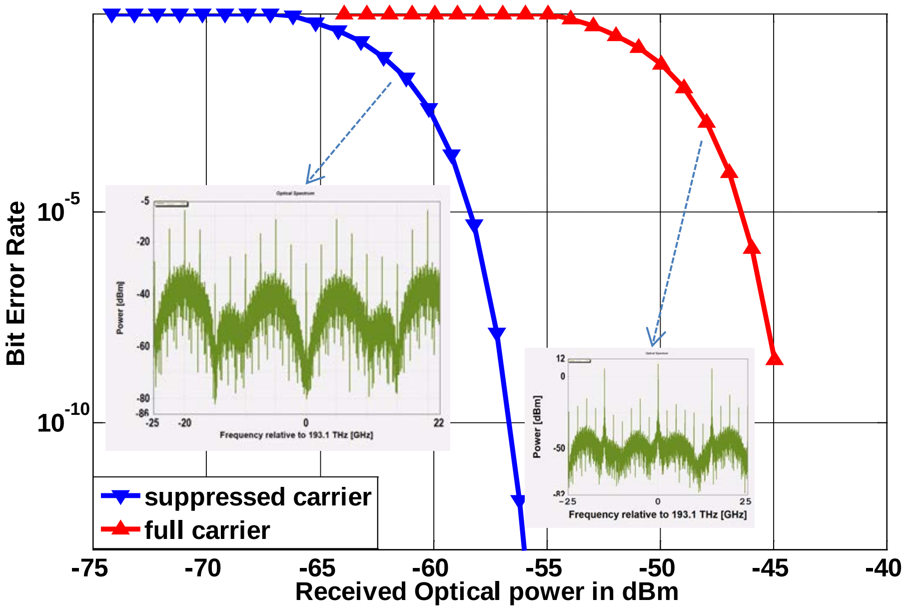

Fig. 2. Simulation of BER for full and suppressed carrier modulations

Then, an ODL was used in one of the channels to delay the optical signal. Fig 4a shows the measured linear relation of the phase shift of the RF signal with the time delay applied by ODL. A 360^{o} phase shift on the 6 GHz signal was achieved after 170 ps delay at ODL. A 10GHz PIN+TIA receiver was used to convert the signal back to electrical. The optical beating between the carrier and the subcarrier generated a 6 GHz electrical signal after photo detection. The time delay applied in the optical signal translates to phase shift of the RF signal after photo detection. A 2-by-1 optical beamforming was done with offline processing i.e. combination of the undelayed received signal (channel 1) with its delayed copy (channel 2). When the phase shift between the channels is zero, i.e. when the two signals are in phase a constructive addition of the signals happens and a maximum power level is received. When the two channels are out of phase, a destructive addition of the combined waveforms leads to a minimum received power level. We verified this by progressively changing the optical delay applied by ODL from 0-343 ps, and measuring the power level of the combined RF signal from the two channels. Fig 4b shows the normalised power level ratio in dB of the beamformer when the delay was varied. It can be seen from that maximum power levels were measured at 0,170,340 ps delay. In these cases the two signals are in phase, hence maximum power was measured. On the other hand, a minimum power level was received when the two channels were 180^{0} out of phase at 83 ps and 240 ps respectively. At these minimum points a power suppression ratio of 23 dB was achieved. This allows filtering out or suppression of unwanted radio signal. This can be very useful in applications where beamforming is employed for interference suppression. Hence, it is shown that we can control the beamformer power through dynamic control of the ODL.

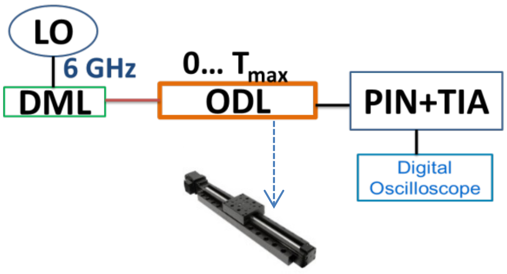

Fig.3a. Schematic of experimental setup

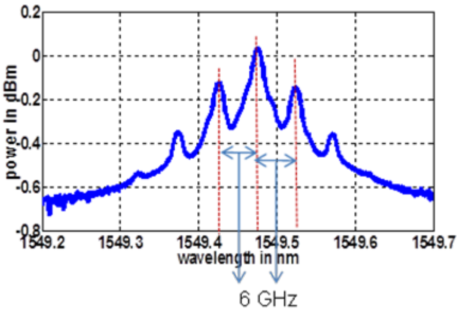

Fig. 3b. Spectrum of DML output

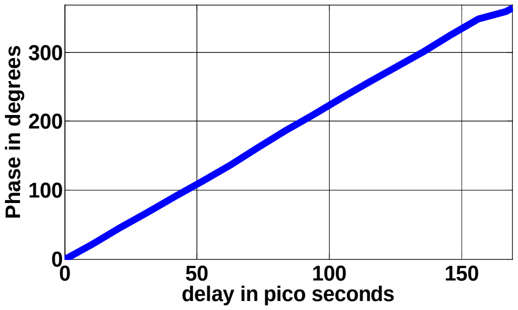

Fig. 4a. Phase delay linearity of ODL

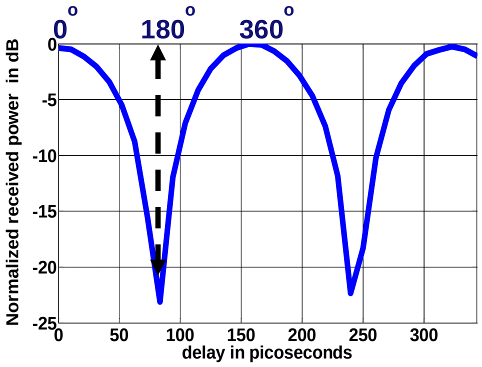

Fig. 4b. Normalised received power

Conclusions

A proof-of-concept of a 2-by-1 optical beamformer for satellite communication on an optical-fibre true time delay is successfully demonstrated experimentally. Simulation results also give an insight on how to further improve system link performance using suppressed carrier modulation.

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References

[1] A. J. Fenn, D. H. Temme, W. P. Delaney, and W. E. Courtney, “The development of phased-array radar technology,” Lincoln Lab. J., vol.12, no. 2, pp. 321–340, 2000

[2] B.Vidal, T. Mengual, and J. Martí, “Fast Optical Beamforming Architectures for Satellite-Based Applications,” Advances in Optical Technologies, vol. 2012, 385409, 5 pages, 2012

[3] A. Meijerink, C.G.H Roeloffzen, R.Meijerink, L.Zhuang, D.A.I.Marpaung, M.J.Bentum, M.Burla, P.Jorna, J.Verpoorte, A.Hulzinga, W. Etten, (2010), “ Novel ring resonators based on integrated photonic beamformer for broadband phased array receive antennas - Part I: Design and performance analysis. Journal of Lightwave Technology”, 28(1), 3–18.

[4] Z. Cao, F. Li, H. P. A. Van Den Boom, E.Tangdiongga, & A.M.J Koonen,Optical True-Time-Delay Microwave Beam-Steering with 1 Gb/ s Wireless Transmission for In-Building Networks, (1), 8–10.

[5] D.DCurtis, D.N.Spendley, D.Q.Luu, “Current Capablities of Digital beamforming”, Approved, F. (2007), Report documentation page, 298(0704).