Microwave Photonics

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Abstract: Microwave photonics is the use of photonic techniques for the generation, transmission, processing and reception of signals having spectral components at microwave frequencies. This tutorial reviews the technologies used and gives applications examples.

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1. Introduction

The definition of the research area of microwave photonics can be considered as falling into two parts: 1) the study of opto-electronic devices and systems processing signals at microwave frequencies, and 2) the use of opto-electronic devices and systems for signal handling in microwave systems [1]. This tutorial paper highlights some of the recent developments in Microwave Photonics from the authors' own laboratory and from other leading groups.

2. Developments in Microwave Photonics

The concept of sending radio signals over optical fibre (ROF) has been explored over three decades and commercial products for carrying multiple broadband wireless services are already available [2]. However the new multiple-input multiple-output (MIMO) wireless transmission technique presents different technical challenges, as existing commercial ROF systems are not designed to carry multiple wireless signals of the same carrier frequency together over a single fibre. Recently we have proposed and demonstrated transmission of three 2.45 GHz MIMO signals using a novel phase quadrature double sideband frequency translation technique [3]. The key to the technique is the use of a *single* low-frequency (MHz) source to rearrange *two* such signals in the radio spectrum so that they can be transmitted over fibre together with a third one. This represents an almost 50% reduction in implementation costs compared with sub-carrier multiplexed (SCM) systems. Further, the new technique does not require expensive optics as with wavelength division multiplexed (WDM) solutions.

Recently, an interesting approach to digitising radio signals for transmission through fibre has been proposed by Gamage *et al* [4]. This digital approach reduces the demands on the modulation linearity of the laser or external modulator relative to analogue techniques. Most wireless services only occupy a fraction of the radio spectrum. By using bandpass sampling, the required sampling rate need only be at least twice the RF modulation (information) bandwidth. However, the input of the analogue-to-digital converter (ADC) must still be able to function at the highest signal frequency. Gamage *et al* demonstrated a digitised ROF link of 29 km in length for a 2.475 GHz 6 MS/s 16 QAM WiMAX signal. It was further reported that 8-bit resolution can achieve satisfactory signal-to-noise ratio (SNR) and error vector magnitude (EVM). Yang *et al* [5] from the same group went on to demonstrate digitised SCM transmission of three vector modulated signals with a 100 kHz symbol rate around a carrier frequency of 20 MHz. The bit rate of the digital data that needs to be transmitted is directly proportional to the sampling rate. Li *et al* [6] proposed reducing the transmission bit rate by first processing the raw sampled data, and then transmitting only the actual symbols in the signal. A reduction of the data rate from 1.6 Gb/s (with a 16 bit ADC at 100 Msps) to 7.68 Mb/s was demonstrated.

We have investigated using ROF systems not only to carry communication related services, but also radio frequency identification (RFID) tag signals for location finding purposes [7]. A commercially available ROF system has was used as the optical fibre backbone in an indoor real-time location system for tracking an active RFID tag [8]. The active tag generated an 83.5 MHz wide linear FM chirp radio signal in the 2.4 GHz ISM band. The chirp signal was then received by three antennas whose locations were known. The received signals were returned to a central location using the ROF system. By measuring the time difference of arrival (TDOA) between the received tag signals at the three antennas, the location of the tag was calculated using multilateration. The use of TDOA removes the need to synchronise individual antenna units. Fig. 1 shows the schematic of the experimental arrangement and a photo of the 6.6-m-by-15.6m venue where the experiment was carried out. An overall positional error of 0.72 m RMS was achieved.

In Microwave Photonic receiver technology we are investigating the uni-travelling carrier (UTC) photodiode as an optoelectronic mixer [9]. In this configuration, mm- or THz-wave signals received by an antenna are applied to the

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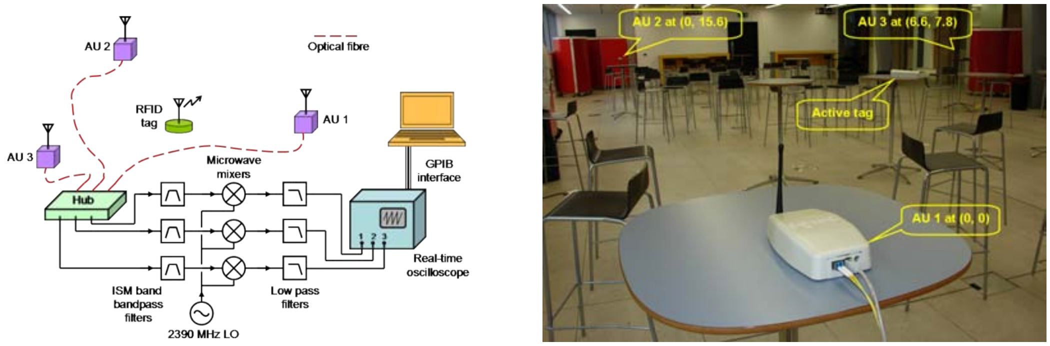

Fig. 1. Schematic of the hardware implementation of the location system and a photograph of the measurement venue.

UTC terminals, while the optical heterodyne signal from a photonic signal generator is applied to the optical input. Non-linear mixing between the received signal and the heterodyne local oscillator signal generates a signal at an intermediate frequency, which can be in the RF band, allowing easy amplification and processing. This heterodyne detection technique could be used as part of a mm- or THz-frequency communications system (Fig. 2), or for high-sensitivity spectroscopy or scanning applications.

In a proof-of-concept communication link demonstration, we used a commercial, multiplier-based source operating at 80.000 GHz, modulated with BPSK data at 500 kb/s and connected to a horn antenna with a gain of 20 dBi. The heterodyne receiver used a UTC optoelectronic mixer coupled to an identical horn antenna via a co-planar probe and driven by a photonic signal generator optical local oscillator at 79.995 GHz. The IF signal at 5 MHz was demodulated using a vector signal analyser. An example received eye diagram is shown in Fig. 2 for antenna separation of 5 cm. In this experiment, the transmission distance and data rate were limited mainly by the low mixer conversion gain of approximately -74 dB due to low optical local oscillator power. Other UTCs operated at higher optical local oscillator

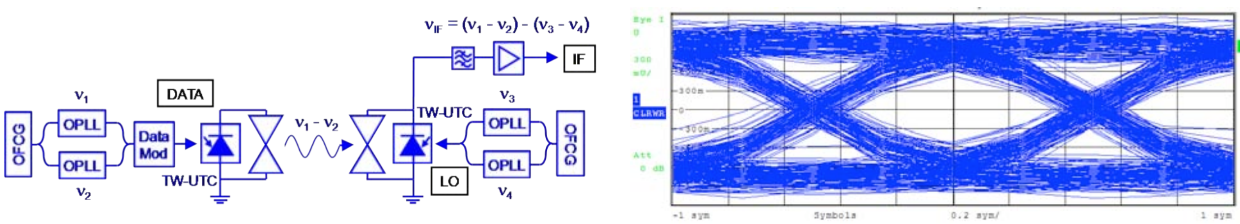

Fig. 2. THz communications system employing a UTC optoelectronic mixer for heterodyne detection and received 500 kb/s BPSK eye diagram from 80 GHz communication link using heterodyne receiver.

powers have given conversion gains as high as -20 dB for down-conversion from 10 GHz, suggesting that much improved conversion gain should be possible.

3. Conclusion

A number of significant recent developments in Microwave Photonics have been reviewed. With the technology maturing, it is anticipated that Microwave Photonics will find new applications in areas previously dominated by silicon electronics, such as high-speed analogue-to-digital conversion.

4. References

[1] A. J. Seeds and K. J. Williams, "Microwave Photonics," Jnl. Lightwave Tech. vol. 24, no. 12, 4628-4641 (2006).

[2] http://www.zinwave.com

[3] C. P. Liu and A. J. Seeds, "Transmission Of MIMO Radio Signals Over Fibre Using A Novel Phase Quadrature Double Sideband Frequency Translation Technique," pp. 23-26, 2008 IEEE Topical Meeting On Microwave Photonics, September 30 – October 3, 2008, Gold Coast, Australia.

[4] P. A. Gamage, A. Nirmalathas, C. Lim, D. Novak and R. Waterhouse1, "Experimental Demonstration of Digitized RF Transport over Optical Fiber Links," pp. 15-18, 2008 IEEE Topical Meeting On Microwave Photonics, September 30 – October 3, 2008, Gold Coast, Australia.

[5] Yizhuo Yang, Christina Lim, Prasanna Gamage and Ampalavanapillai Nirmalathas, "Demonstration of SCM Signal Transmission based on Digitized Radio-over-Fiber Technique," 2009 IEEE Topical Meeting On Microwave Photonics, TH.2.5, 14 – 16 October, 2002, Valencia, Spain.

[6] Tongyun Li, Michael Crisp, Richard V. Penty and Ian H. White, "Low Bit Rate Digital Radio over Fibre System," 2009 IEEE Topical Meeting On Microwave Photonics, FRI.1.5, 14 – 16 October, 2009, Valencia, Spain.

[7] P. V. Brennan, A. J. Seeds and Y. Huang, "RF-ID Tag Location Using RF-over-fibre Techniques," in Proc. of Progress in Electromagnetics Research Symposium, Prague, 2007, pp. 255-260.

[8] Chin-Pang Liu, Yanchuan Huang, Tabassam Ismail, Paul Brennan and Alwyn Seeds, "Demonstration of an Indoor Real-Time Location System with Optical Fibre Backbone," 2009 IEEE Topical Meeting On Microwave Photonics, post-deadline, 14 – 16 October, 2009, Valencia, Spain.

[9] A. J. Seeds, M. J. Fice, C. P. Liu, L. Ponnampalam, F. Pozzi, C. C. Renaud, E. Rouvalis and R. Steed, "New Applications for Microwave Photonics," The 22nd Annual Meeting of the IEEE Photonics Society, Belek-Antalya, Turkey, 4-8 October 2009, ThK6.