BROADBAND MILLIMETER-WAVE FIBER-RADIO NETWORK INCORPORATING REMOTE UP/DOWNCONVERSION

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ABSTRACT

A high capacity full-duplex millimeter-wave fiber-radio network which incorporates remote up and downconversion is demonstrated. This technique minimizes fiber dispersion-induced phase noise, allowing higher-order modulation formats to be incorporated which increase network capacity and spectral efficiency. Remote up and downconversion also enables lower cost components to be employed throughout the network.

INTRODUCTION

Millimeter-wave (mm-wave) radio networks are being proposed for the efficient delivery of broadband services. The larger RF propagation losses at these frequencies reduce the cell size covered by a single base station and allow an increased frequency reuse factor to improve the spectrum utilization efficiency. The subsequent need for more base-stations (BSs) therefore demands the implementation of low-cost BSs. This requirement has led to the development of system architectures where functions such as signal routing and processing, hand-off, and frequency allocation are carried out at a central office (CO), rather than at the BS. Furthermore, such a centralized arrangement allows sensitive equipment to be located in safer environments and enables the cost of expensive components to be shared between a larger number of users. An attractive solution for linking a CO and BSs in a mm-wave radio network is via an optical fiber network, since fiber has low loss, is immune to EMI, and is capable of transmitting large bandwidth signals. However, devices and techniques for optical modulation at mm-wave frequencies are still at the research stage and although commercial optical receivers with mm-wave bandwidth are available, their responsivity is extremely poor.

This paper outlines a technique that incorporates remote up/downconversion at BSs so that cheap, readily available components can be used in full-duplex millimeter-wave fiber-radio networks. We describe how fiber chromatic dispersion effects can be reduced with such a technique, so that dispersion-induced power variations and phase noise degradations are minimised, allowing signals with high-order modulation formats to be used. Remote up/downconversion therefore improves the capacity and spectral efficiency of fiber-radio networks. Two upconversion schemes are implemented experimentally to confirm these improvements. The first incorporates a subharmonically-pumped image reject mixer (SHPIRM) at the BS, while the second incorporates a multiplier scheme at the BS. Since the schemes are very similar, this paper only describes the subharmonic mixing scheme, however both schemes will be described in the

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presentation. Both these remote up/downconversion techniques also permit very simple and cheap upstream architectures to be implemented and this is demonstrated for the subharmonic mixer scheme by implementing a full-duplex mm-wave fiber-radio network consisting of 40 km of standard single mode fiber (SSMF) and a 5 m radio link.

PRINCIPLE OF REMOTE UP/DOWNCONVERSION TECHNIQUES

In mm-wave radio systems, the maturing of monolithic microwave integrated circuit (MMIC) foundary technologies has resulted in significant cost reductions for chip fabrication and improvements in circuit performances. As a result, low-cost and extremely compact mm-wave radio transceiver units have been commercially developed. However, MMIC local oscillators (LOs) have yet to be produced with sufficiently low phase noise to ensure that the resulting amplitude jitter in multi-level modulation formats do not degrade the bit-error-rates [1]. In addition, in order to maintain the simplicity and compactness of the BS transceivers and to share the cost of the required low phase noise LO equipment, it is necessary to remove the LOs from the BSs and locate them instead at the CO.

If the LO signals are distributed from the CO to the BSs with a fiber network, the effect of chromatic dispersion cannot be ignored. In conventional optical intensity modulation, dramatic decreases in the carrier-to-noise ratio (CNR) of the received signal can result after propagation through fiber [2]. With only a small penalty in circuit complexity, these CNR reductions can be reduced by implementing optical single sideband (SSB) with carrier modulation [3,4]. However, dispersion continues to cause a differential propagation delay between the optical signals, introducing a partial phase decorrelation and thus increasing the phase noise in the detected electrical signals [5]. In remote up/downconversion schemes, incorporating either subharmonically-pumped mixers or frequency multipliers within the BS enables this dispersion-induced phase noise to be reduced since lower frequency LO signals are employed. In addition, the lower LO frequencies reduce the bandwidth requirements for the optical modulators and receivers, thereby significantly reducing the cost.

EXPERIMENTAL DEMONSTRATION OF REMOTE UP/DOWNCONVERSION NETWORK

Fig. 1 shows the architecture implemented experimentally to demonstrate a high capacity, full-duplex, millimeter-wave fiber-radio network incorporating remote up/downconversion techniques.

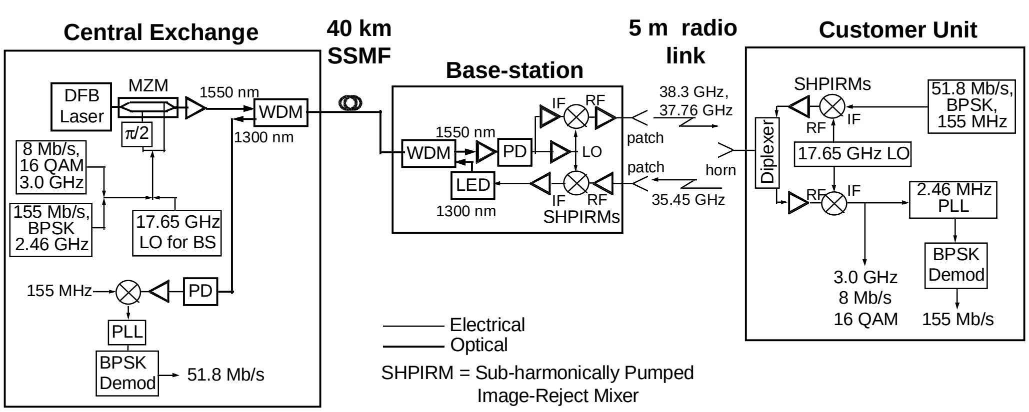

Figure 1: Schematic diagram of the full-duplex mm-wave fiber-radio network incorporating remote subharmonic up/downconversion at the base-station

A distributed feedback (DFB) 1550 nm laser provides an optical downstream carrier which is modulated by two IF subcarriers carrying data and an LO signal using an optical SSB arrangement [3,4]. In this experiment, a 155 Mb/s NRZ PRBS (2^{15}-1) modulates the phase of a 2.46 GHz subcarrier (BPSK format) and is frequency multiplexed with a 3.0 GHz subcarrier. This latter subcarrier is amplitude modulated with an 8 Mb/s NRZ PRBS (2^{15}-1) in 16 QAM format. The resulting optical signal is amplified with an EDFA, input into a WDM coupler, and transported through 40 km of SSMF. The signals are then directed to another WDM coupler and the downstream signal detected with a photodiode (PD) at the BS.

The output from the PD was divided into two paths: in the first the two IF channels are amplified and directed to the IF arms of the upconverting 38 GHz subharmonically-pumped image reject mixer (SHPIRM). In the second path the 17.65 GHz LO signal is amplified to a power of approximately +10 dBm and directed to the LO arm of the SHPIRM. The measured phase-noise for the 17.65 GHz LO signal at a frequency offset of 100 kHz was -105 dBc/Hz. Fig. 2 shows the upconverted rf spectrum that was transmitted over the 5 m radio link.

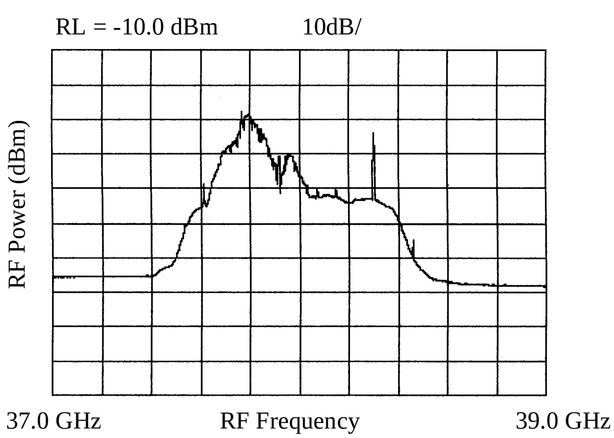

Figure 2: Measured rf spectrum transmitted from the BS after remote subharmonic upconversion (RBW = 1 MHz)

At the customer unit (CU), a SHPIRM downconverts the mm-wave signals back to IF signals. The 2.5 GHz,155 Mb/s BPSK signal is amplified and fed into appropriate phase locking circuits to recover the baseband data. Fig. 3 shows the measured downstream 155 Mb/s eye diagrams for error-free data reception. The IF signal containing the 16 QAM data is directed to a spectrum analyser and generated the constellation diagrams shown in Fig. 4.

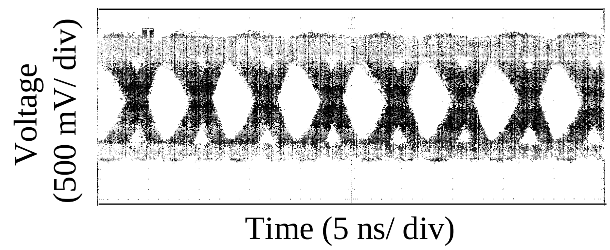

Figure 3: Measured eye diagram for the recovered downstream 155 Mb/s, NRZ, PRBS (2^{15}-1) data after 40 km of SSMF and 5 m of radio transmission

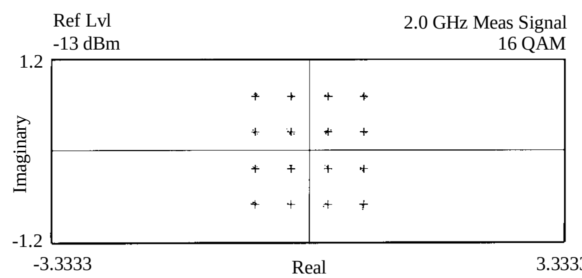

Figure 4: Measured constellation diagram of the recovered 8 Mb/s 16 QAM signal after 40 km of SSMF and 5 m radio transmission

An upstream path was also incorporated into the fiber-radio network. A 51.8 Mb/s, NRZ, PRBS (2^{15}-1) at an IF of 155 MHz was upconverted to a frequency of 35.45 GHz and transmitted over the 5 m radio link. At the BS, another MMIC SHPIRM, using the same LO as for the downstream mixer, was employed to downconvert the mm-wave signal to a 155 MHz IF. This signal directly modulated a low cost 1300 nm LED and was transmitted over the 40 km of SSMF, where it was fed into the WDM coupler and directed to a low frequency photodiode and phase-locking circuit to recover the baseband data. Fig. 5 shows the received eye-diagram of the recovered upstream data after the radio and fiber network, for a bit-error-rate of less than 10^{-9}.

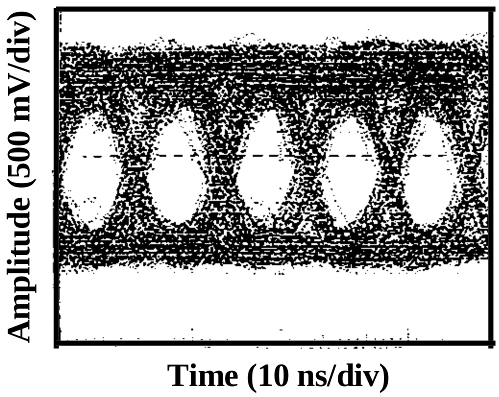

Figure 5: Measured eye diagram for the recovered upstream 51.8 Mb/s, NRZ, PRBS (2^{15}-1) data after transmission through a 5 m radio link and 40 km of SSMF.

CONCLUSIONS

High quality transmission has been demonstrated in a mm-wave fiber-radio network incorporating remote up/downconversion. LO signals with very low phase noise were transported over fiber links with techniques employed that minimized dispersion effects and permitted higher-order modulation schemes. A full-duplex experimental network was implemented consisting of 40 km of SSMF, a 5 m mm-wave radio system and employing low cost equipment throughout. IF subcarriers with 155 Mb/s BPSK and 8 Mb/s 16 QAM were transported downstream, while 51.8 Mb/s BPSK was carried upstream.

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