Using Multimode Fibres for Broadband In-door Wireless Coverage

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Using a novel optical frequency multiplication technique, microwave signal carriers exceeding 20-GHz are delivered to a significantly simplified remote radio access unit fed by a multimode fibre link having modal bandwidth below 2-GHz. Measurement results show that the remotely generated carriers have very narrow linewidths below 20-Hz. Thus existing in-building silica multimode fibre infrastructure, and the emerging polymer optical fibres may be used to not only transport fixed data services such as gigabit Ethernet but also to transparently distribute in-doors, signals of present WLANs as well as future broadband WLAN services leading to significant system-wide cost reduction.

Introduction

Indoor or in-building wireless coverage will become more and more important in future, going by the fast paced proliferation of wireless local area network (WLAN) hotspots in public places, which we are witnessing today. And it is envisaged that future WLANs will offer integrated broadband services (combining voice, data, and multimedia services), with capacities well beyond the present day 11 – 54 Mbps IEEE802.11a/b WLAN standards as well as the 3G mobile networks (IMT2000/UMTS). Consequently, these systems will operate at higher carrier frequencies above 6 GHz, including 60 GHz. Providing wireless coverage inside a building from outside as well as distributing RF signals within the building are hampered by radio losses induced by the walls. The situation becomes even more difficult for high carrier frequencies exceeding 6 GHz. That means that a large number of radio access points are needed to provide coverage throughout the building. In addition, an extensive feeder infrastructure is also required to connect the numerous access points. Therefore, unless both the radio access points and the feeder network are cheap, the costs of installing and maintaining such networks become prohibitive.

A reduction in the complexity and cost of the radio access points can be achieved by consolidating RF signal processing functions at a shared headend [1], while multimode fibre (which is already found in some buildings) can be used to feed the remote radio access points instead of the costly single-mode fibre (SMF). Alternatively Graded Index Polymer Optical Fibre (GIPOF) can also be used due to its low cost potential and easier handling required in in-building networks [2]. A technique to transport RF carriers up-to around 5 GHz over MMF has been demonstrated in [3]. In [4] we proposed a novel optical frequency multiplication technique to overcome modal bandwidth limitation in MMFs to deliver modulated high frequency RF carriers exceeding 6 GHz. This paper discusses the experimental demonstration [5] of the delivery of up-to 20 GHz un-modulated microwave carriers via 300 m of a GIPOF link.

Experimental Set-up

To demonstrate the transmission of high frequency carriers well above the modal bandwidth of GIPOF, the experimental set-up shown in Figure 1 was used. The headend comprised a CW laser, optical phase modulator and a low frequency signal generator. A 2 GHz RF signal was used to drive the $LiNbO_3$ optical phase modulator in order to sweep back and forth the optical frequency of the 10 mW CW optical signal from the DFB laser. The frequency sweep, and its magnitude were verified by using the time-resolved frequency chirp measurement method outlined in [6]. Adjusting the power of the RF signal controlled the depth of the frequency deviation. The swept optical signal was then fed into a 330 m GIPOF fibre via an FC PC/SC connector, and transmitted over the length of the fibre.

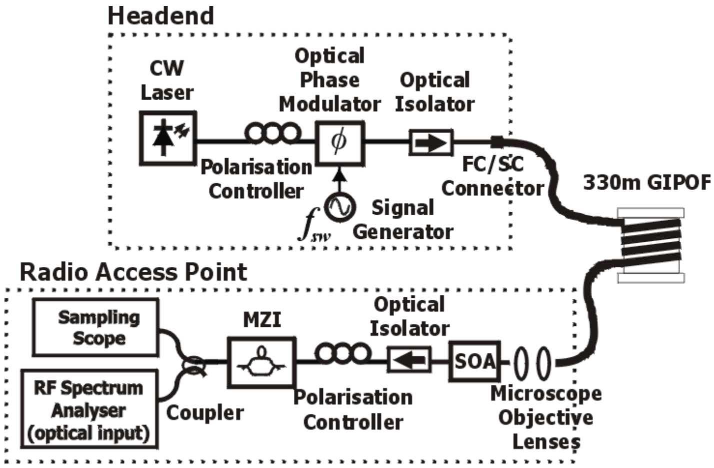
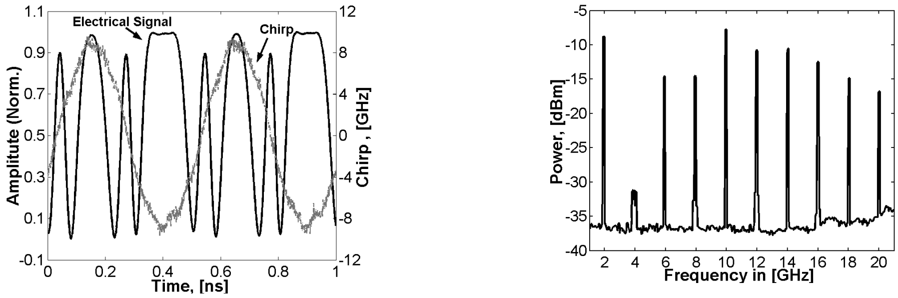


Figure 1: Experimental Set-up

At the remote antenna unit, high-NA microscope objective lenses were used to couple light into a SMF patch cord to enable the use of SMF-pigtailed signal processing components and measuring equipment. A semiconductor optical amplifier was used to partially compensate for the coupling loss. A Mach Zehnder Interferometer (MZI) made from spliced short SMFs served as the periodic filter in the receiver. In the back-to-back configuration, the output of the phase modulator was connected directly to the input of the MZI via an isolator. Finally, the signal leaving the MZI was recovered, converted into electrical form, and monitored by an RF spectrum analyser and a sampling scope, both of which had inbuilt optical direct detection capability. The source of the trigger signal for the sampling scope and the source of the RF signal were synchronised in a master-slave configuration.

Results

The measured chirp induced by the optical phase modulator is shown in Figure 2(a) together with the electrical signal generated in the back-to-back system. The RF signal power was adjusted in order to obtain a peak-to-peak optical frequency deviation of around Δf_{opt}=20 GHz. The free spectral range (FSR) of the MZI was determined by using a high-resolution optical spectrum analyser, and a tunable laser/detector configuration, and found to be about 9.6 GHz around λ=1316.35 nm. The contrast ratio



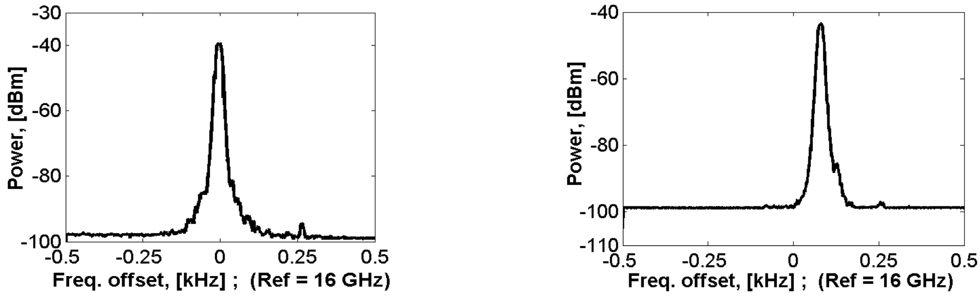
(a) **(b)**

Figure 2: Measured optical chirp, and generated electrical signal without POF

of the MZI was found to be about 10 dB. The generated electrical signal shows that 4 signal peaks are produced during each period of the RF signal, giving a base up-conversion factor of 4. The 4 intensity peaks are produced as the optical frequency sweeps back and forth across 2 peaks of the MZI in one period. This confirms the simulated results and the predicted base frequency up-conversion factor attributed to the multiplication effect given by $K = 2 \cdot \frac{\Delta f_{\text{opt}}}{\text{FSR}} \cdot n$, where n is the harmonic order.

The spectrum of the electrical signal generated without GIPOF is given in Figure 2(b). Several carriers (harmonics of the 2 GHz RF signal) up-to 20 GHz, are clearly visible. The upper limit to the measurable frequencies was given by the bandwidth of the RF spectrum analyser, which was 22 GHz. The –3dB linewidths of the carriers were found to be less than 20 Hz, thanks to the inherent optical phase noise cancellation at the periodic filter.

In the GIPOF fed system, the observed spectrum was similar to Figure 2(b), with harmonic components up-to 20 GHz also clearly visible. There was no degradation of the –3dB linewidths observed. As Figure 3 shows the signal purity of the 16 GHz carrier generated by optical frequency multiplication at the remote radio access point fed by 330m of GIPOF is the same as that of the back-to-back system. Therefore, considering the 16 GHz signal carrier, and bearing in mind the 2 GHz sweep signal at the headend, we can say that a total up-conversion factor of $K = 4 \cdot n = f_{mm} / f_{sw} = 8$ was achieved.



(a) back-to-back **(b) after 330m GIPOF**

Figure 3: The 16 GHz signal generated through Optical Frequency Multiplication (resolution = 10 Hz)

The power stability of the 16 GHz carrier in both the back-to-back, and the GIPOF based systems was observed over 30 minutes. As expected the stability of the carrier in the GIPOF based system deteriorated due to modal noise effects induced by spatial filtering through the GIPOF-SMF coupling lenses, which caused the received optical power to fluctuate prior to periodic filtering. Further investigation showed that it is possible to reduce this power fluctuation to under 0.7 dB by using an appropriate imaging system, and coupling to a 50 μm core MMF fibre instead. This would greatly improve the stability of the generated carriers (w.r.t. to modal noise effects) to well below 0.7 dB due to the averaging effect. In that case, a Fabry-Perot cavity placed in between two lenses, or a MMF-based fibre Bragg grating Fabry-Perot could be used as a periodic filter in combination with a high-speed MMF-pigtailed or free-space-illuminated photodetector to achieve a complete multimode fibre-based system.

Conclusions

Using a novel optical frequency multiplication concept, high-frequency narrow-linewidth carriers exceeding 20 GHz can be delivered to remote radio access points fed by modal bandwidth limited multimode fibres or graded index polymer optical fibre links or networks. The frequency up-conversion factor is determined only by the ratio of the peak-to-peak optical frequency deviation to the free spectral range of the periodic filter.

Graded index polymer optical fibre is an attractive alternative to difficult-to-handle silica fibres for deployment in in-building environments. Therefore, using the proposed concept, fixed services such as gigabit Ethernet and broadband wireless services can be integrated on the same fibre infrastructure, thereby further reducing system costs. Furthermore, the proposed concept enables the transparent use of a hybrid single-mode/multimode fibre infrastructure.

References

[1] L.A. Johansson, and A.J. Seeds, "Millimeter-Wave Modulated Optical Signal Generation with High Spectral Purity and Wide-Locking Bandwidth Using a Fiber-Integrated Optical Injection Phase-Lock Loop", IEEE Photonics Technology Letters, Vol. 12, No. 6, pp. 690 – 692, 2000.

[2] Y. Watanabe, "Current Status of Perfluorinated GI-POF and 2.5 Gbps Data Transmission over it", in Proceedings of OFC '03, Vol. 1., USA, 2003, pp. 12 - 13.

[3] P. Hartmann, M. Webster, A. Wonfor, J.D. Ingam, R.V. Penty, I.H. White, D. Wake, and A.J. Seeds, "Low-Cost Multimode Fibre-based Wireless LAN Distribution Systems Using Uncooled, Directly Modulated DFB Laser Diodes", in Proceedings of the European Conference on Optical Communication (ECOC) Conference, 2003, Vol. 3, pp. 804 – 805.

[4] Ton Koonen, Anthony Ng'oma, Peter Smulders, Henrie van den Boom, Idelfonso Tafur Monroy, Giok-Djan Khoe, : "In-house networks using multimode Polymer Optical Fibre for broadband wireless services", Photonic Network Communications, Vol. 5, No. 2, pp. 177-187, 2003.

[5] Anthony Ng'oma, Ton Koonen, Idelfonso Tafur-Monroy, Henri van den Boom, Peter Smulders, Gjok-Djan Khoe, "High-Frequency Carrier Delivery to Graded Index Polymer Optical Fibre Fed Next Generation Wireless LAN Radio Access Points", in Proceedings of the European Conference on Optical Communication (ECOC) Conference, 2003, Vol. 3, pp. 508 – 509.

[6] Simo Tammela, Hanne Ludvigsen, Timo Kajava, and Matti Kaivola, "Time-Resolved Frequency Chirp Measurement Using a Silicon-Wafer Etalon", IEEE Photonics Technology Letters, Vol. 9, No. 4, pp. 475 – 477, APRIL 1997.