POLYMER OPTICAL FIBRE NETWORK FOR FEEDING WIRELESS LAN ANTENNA STATIONS

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ABSTRACT

A novel method is presented to transport microwave signals over graded-index polymer optical fibre (GIPOF) networks feeding radio access points in high-capacity wireless LANs. It relies on optical frequency multiplying, by sweeping a laser wavelength over a number of free spectral ranges of a simple periodic optical filter at the access points. It enables a cost-effective system implementation, and easy upgrading by offering data signal transparency. Microwave frequencies at several tens of GHz carrying multi-point digital data signal constellation formats such as QPSK and QAM are achievable in GIPOF networks with a reach of several hunderds of metres.

1. INTRODUCTION

Wireless LANs are being installed at increasing pace in office and residential environments. Current products operate in the ISM 2.4 GHz band, offering data rates up to 11Mbit/s per microwave carrier. HiperLAN/2 systems exploit the 5.2 GHz band, transporting up to 54 Mbit/s per carrier, and future high-capacity wireless LANs may use microwave frequencies above 10 GHz to convey more than 100 Mbit/s per carrier. Along with this trend towards higher carrier frequencies and higher bitrates, the microwave radio cells are becoming smaller. This necessitates more antenna stations, and a more extensive in-house wiring to feed these stations with higher data rates. Next to that, it becomes attractive to consolidate the signal processing needed for mobility functions (such as macro-diversity and soft handover) at a central headend station. Thus the antenna stations can be relatively simple, and therefore more reliable and (potentially) cheaper. To reap these benefits, however, the microwave signals should be carried transparently from the headend station to the antenna stations and vice versa. This will also ease future system upgrades. Optical fibre is well suited for transporting the microwaves, due to its very high bandwidth and low losses. By means of heterodyning optical carriers, transparent transport of the data signals via single-mode fibre has been demonstrated [1]. However, single-mode fibre is relatively costly to install in in-house environments. Perfluorinated graded-index polymeric optical fibre (GIPOF) is coming up as a promising medium which is easy to install due to its large core diameter and its flexibility, and is making fast progress towards lower losses (currently about 10 dB/km at 1300 nm) and higher bandwidths (currently around 1 GHz·km) [2], enabling short to medium-haul high bitrate data links [3]. However, heterodyning techniques are not feasible due to the multimode light guiding nature of the GIPOF.

This paper reports on a novel technique termed optical frequency multiplying, which allows carrying data signals on multi-GHz microwave carriers which stretch beyond the bandwidth of in-house GIPOF links (with lengths up to 500 meters, implying bandwidths up to 2 GHz).

2. TRANSPORTING MICROWAVE SIGNALS ACROSS A GIPOF LINK

The proposed system is based on a tree-and-branch polymer optical fibre network, with a wavelength-tunable laser diode at the headend site, and an optical filter with multiple equally-spaced passbands at the sites of the receivers, as shown in Fig. 1.

In the Headend station, the wavelength of the tunable laser diode is swept with a sweep frequency f_{sw} , while keeping its light output power nearly constant. Subsequently, the data signal is impressed on this wavelength-swept optical carrier by means of a low-chirp external intensity modulator (such as a differentially-driven Mach-Zehnder modulator).

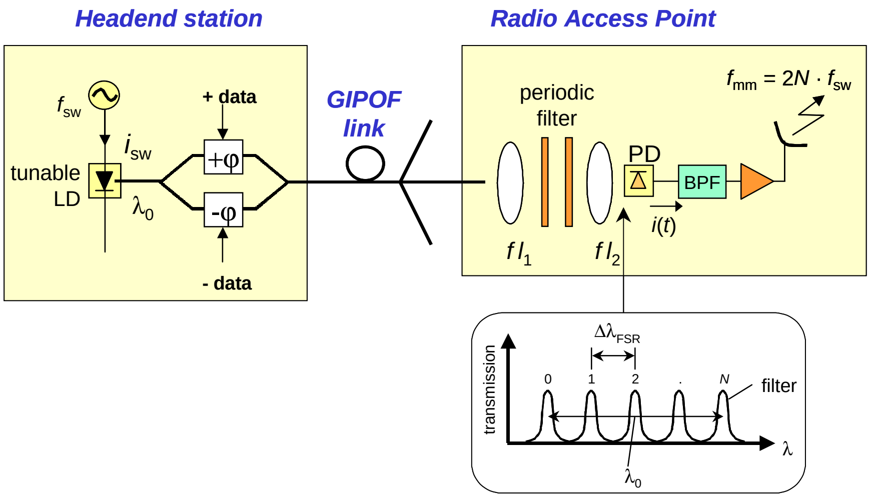

Fig. 1 Carrying microwave signals through a Polymer Optical Fibre network

After traveling through the point-to-multipoint GIPOF network, the signal arrives at a Radio Access Point. It passes through the periodic optical bandpass filter, and then impinges on a high-frequency photodiode. When the wavelength-sweep of the signal is adjusted to encompass an integer multiple N of the Free Spectral Range (FSR) of the optical bandpass filter, each sweep of the signal generates $2N$ intensity fluctuations at the photodiode, and thus a microwave signal with a frequency f_{mm} which equals $2N$ times the sweep frequency f_{sw}. This periodic optical filtering process, however, does not affect the data intensity modulation (as long as the data rate is lower than the sweep frequency f_{sw}). Thus a transparent transport of the data signal is accomplished. An electrical bandpass filter after the photodiode suppresses the unwanted harmonics of the microwave signal, and reduces the noise. Subsequently, the signal is fed to the antenna, and the microwave signal carrying the data is radiated to the end user terminals.

The signal data rate and laser sweep frequency are limited by the modal dispersion in the GIPOF link. For link lengths up to 500 meters, sweep frequencies up to 2 GHz should be feasible. It should be noted that the microwave frequency generated is not limited by these two factors, as the optical multiplication factor is only determined by the ratio between the sweep range of the optical frequency and the FSR of the periodic optical filter.

The periodic optical bandpass filter can be advantageously implemented by means of a Fabry-Perot (FP) filter, which can be inserted between the GIPOF and the photodiode using a lens system for collimating the optical beam and imaging the large fibre core on the small light-sensitive area of the photodiode. Such an FP filter consists of simply two parallel optical reflective plates with a small spacing, and can be realised at low cost in a compact size.

To get a nice periodic microwave frequency signal, it is preferable to sweep the laser wavelength as a triangular function of time, as illustrated in Fig. 2. The resulting periodic microwave signal waveform $i(t)$ at the output of the photodiode in the Radio Access Point will then have the same shape as the FP transmission curve. It can be expanded in a Fourier series, of which the n-th harmonic (with frequency $n \cdot 2N \cdot f_{\mathrm{sw}}$) has a relative amplitude $2 \cdot R^{n}\,(1\text{-}R)/(1+R)$, according to

$$i(t) = \frac{i_0}{1 + F \cdot \sin^2(2\pi\, N\, f_{sw}\, t)} = i_0 \cdot \frac{1-R}{1+R} \cdot \left\{ 1 + 2 \sum_{n=1}^{\infty} R^n \cos(4\pi\, n\, N\, f_{sw}\, t) \right\}$$

The powers of these harmonics thus clearly depend on the reflectivity R of the plates of the FP, as shown in Fig. 3. The fundamental first harmonic $2N \cdot f_{\mathrm{sw}}$ reaches its maximum for R=0.41, but this optimum is not very sharp, so that the value of R is not very critical.

When sweeping the laser wavelength as a sinusoidal function of time, also a periodic microwave signal will be generated, but next to the desired harmonics $n \cdot 2N \cdot f_{\mathrm{sw}}$ a lot of spectral lines spaced at twice the sweep frequency $2 \cdot f_{\mathrm{sw}}$ will be present.

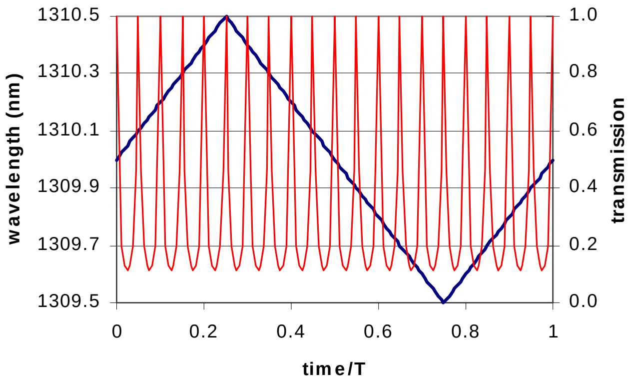

Fig. 2 Generated microwave signal using a triangular wavelength sweep at the laser transmitter and a Fabry Perot periodic optical filter at the receiver

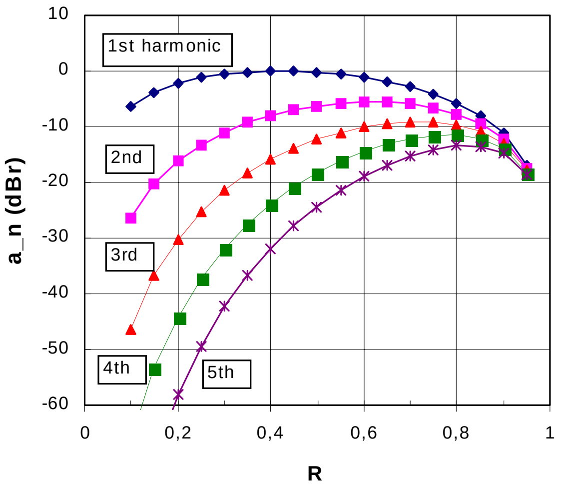

Fig. 3 Strength of the various harmonic components in the generated microwave signal

3. SYSTEM PERFORMANCE SIMULATIONS

The performance of the proposed system has been simulated using the Virtual Photonics Inc. software package. Assumed is a triangular wavelength sweep at frequency f_{sw} = 900 MHz over an optical frequency range of 28.8 GHz (amounting to a wavelength range of 0.16 nm), and a Fabry-Perot filter with Free Spectral Range *FSR* = 9.6 GHz (corresponding to a 15.6 mm plate spacing) and plate reflectivity *R* = 20% (which is lower than optimum, but provides a good compromise between strength of the fundamental frequency and suppression of the higher harmonics). The optical frequency multiplication factor obtained is $2N = 6$, thus yielding a 6 x 900 MHz = 5.4 GHz carrier frequency. Fig. 4 shows the spectrum of the generated unmodulated microwave carrier.

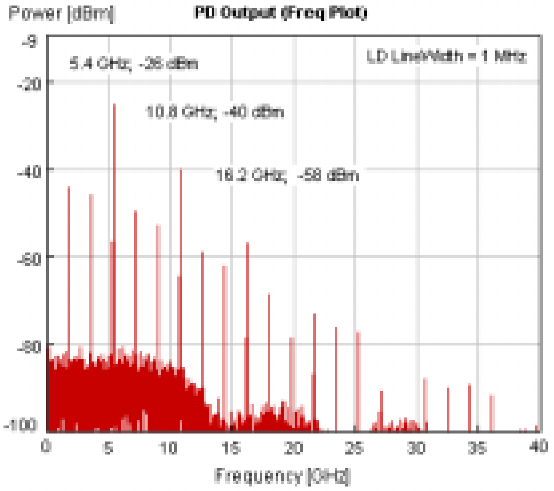

Fig. 4 Spectrum of unmodulated microwave signal at the output of the photodiode, before the bandpass filter

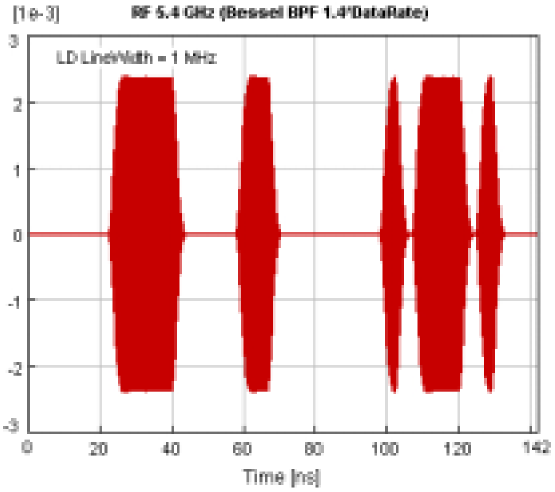

Fig. 5 Microwave signal on-off modulated with 225 Mbit/s data, at output of the bandpass filter centered at 5.4 GHz

Adjusting the central frequency of the electrical bandpass filter allows also operating at a higher harmonic frequency, e.g. 10.8 GHz, while maintaining data signal transparency. Assuming an 225 Mbit/s on/off keyed data signal and a third-order Bessel electrical bandpass filter with a FWHM bandwidth of 315 MHz (140% of the data rate; it may go up to $4 \cdot f_{sw}$) centered at 5.4 GHz, a nice signal waveform at the filter output is obtained, illustrating the transparency for the data signal; see Fig. 5. Also, by adjusting the electrical filter's central frequency, at the second harmonic at 10.8 GHz a nice signal waveform is obtained. The shape of the data signal remains clearly unaltered, which underlines the potential of the system for upgrading to even higher microwave frequencies while maintaining data signal transparency.

As shown by simulations, also other data signal multi-point constellation formats, such as QPSK and x-level QAM, can be carried by putting these on a subcarrier wave which is subsequently fed to the Mach-Zehnder device modulating the optical-wavelength swept laser signal at the headend site. The subcarrier frequency should be below the optical sweep frequency, but higher than the data rate.

3. EXTENSION TO BIDIRECTIONAL OPERATION

The system is extendable to a half-duplex bi-directional system, as shown in Fig. 6. In the silent downstream periods, the unmodulated microwave carrier signal obtained in the antenna base station can be used for downconverting to baseband the signal which is received at the microwave frequency at the antenna for upstream transmission. This baseband signal is subsequently modulated on a low-cost laser diode at the antenna site, and sent upstream along the GIPOF network. Preferably the upstream laser diode operates at a different wavelength than the downstream laser diode at the headend site, and simple wavelength multi/demultiplexers are used at both ends to improve the directivity and thus sufficiently reduce near-end crosstalk.

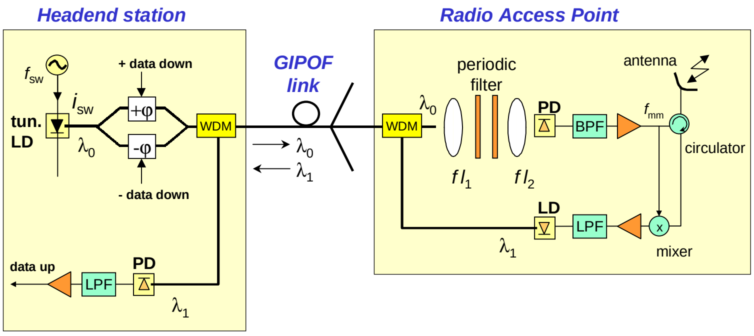

Fig. 6 Extension to half-duplex bidirectional system

5. CONCLUSIONS

A novel method for application in wireless LANs has been presented to carry microwave signals over graded-index polymer optical fibre networks, surpassing their limited bandwidth. This optical frequency multiplying method relies on wavelength sweeping an optical source at the headend station across the intensity transfer function of a periodic optical filter at the antenna base stations. It combines the installation easiness of polymer fibre with the consolidation of mobility functions at the headend and simplification of the antenna stations.

Microwave carrier frequencies significantly beyond the bandwidth of the polymer optical fibre can be realised; frequencies above 60 GHz are realistically obtainable in a POF network with a reach of up to 500 m (having a bandwidth up to 2 GHz), by e.g. sweeping the laser wavelength at a rate of 1 GHz over a range of 1.2 nm (150 GHz) and using at the antenna site a periodic filter with FSR=5 GHz followed by a 60 GHz photodiode. The system is capable of transporting various signal modulation formats, such as ASK, BPSK, QPSK and x-level QAM.

This approach may enable cost-effective installation of high-capacity wireless LANs, and easy upgrading by offering data signal transparency.

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