Distributing Microwave Signals via Polymer Optical Fiber (POF) Systems

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A technique to distribute GHz microwave signals via Graded Index Polymer Optical Fiber (GIPOF) is proposed. The method employs fast sweeping of the optical frequency at the headend and a periodic filter at the remote station, where high frequency microwave signals are generated and fed into antennas. The sweeping rate of the optical frequency is kept within the modal dispersion-limited bandwidth of GIPOF. Simulation results with and without data modulation show this to be a promising technique with possible application in distributing wireless LAN signals. GIPOF offers lower installation and maintenance costs than silica fiber and yet higher performance than copper cables.

Introduction

There is a general demand driven trend towards broadband services on mobile (wireless) communication networks. This is evident from new communication networks such as Universal Mobile Telecommunication Systems (UMTS) offering up to 2 Mbps, wireless LANs (WLAN) offering up to 54 Mbps and other third generation systems such as the Mobile Broadband Systems/Services (MBS) to offer 150 Mbps B-ISDN data rates. However, increasing capacity entails increasing carrier frequencies. For instance WLAN carriers for 11Mbps per carrier systems (IEEE802.11b) operate in the 2 GHz band, while the IEEE802.11a offering 54Mbps per carrier operates in the 5 GHz band. The MBS will need millimeter wave (60 GHz) carriers. As the frequencies go up, radio cells become smaller (micro- and pico-cells) enabling more efficient spectrum utilization. However, this leads to more complex systems requiring numerous access points to achieve the required coverage.

Optical techniques have emerged as cost effective means of distributing GHz microwaves because they lead to simplified remote stations (RS) and enhance sharing of expensive switching and modulation equipment located in the central station (CS) [1]. Many radio over fiber (RoF) techniques using the high bandwidth standard single mode fiber (SMF) have been developed and demonstrated [1]-[5]. However, these methods are not suitable for GIPOF due to modal dispersion, which limits its bandwidth. Nevertheless, GIPOF is emerging as a more attractive fiber for business and residential environments because its large core and flexibility make it easy to handle leading to lower system installation and maintenance costs. State-of-the-art GIPOFs offer 1 GHz-km bandwidth products and 10dB/km attenuation [6] [7] [8].

We propose a novel technique, which overcomes capacity limitations in GIPOF links to generate high frequency microwaves at the remote station as well as perform data modulation. The technique relies on optical frequency multiplication.

A Novel Technique Using Optical Frequency Multiplication

The proposed system is shown in Figure 1. A low frequency RF signal, f_{sw} is used to drive a fast tunable laser or an FM modulatable laser. This results in optical frequency multiplication since the peak-to-peak optical frequency deviation, Δf_{opt} will be multiple times greater than the drive frequency, f_{sw} and will depend on the laser's FM index. Ignoring data modulation for now, the FM modulated optical signal is transported via the GIPOF link to the RS. At the RS the optical signal is fed into a periodic filter preferably a Fabry Perot (FP) etalon placed between two lenses. The lensing system performs imaging of the large GIPOF core onto the small photodiode's (PD) active area.

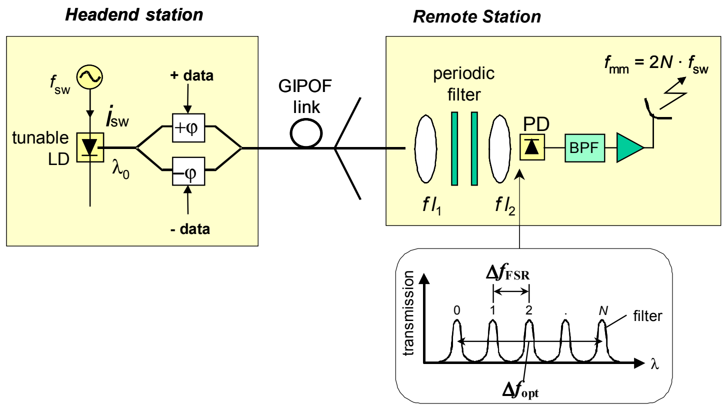

Figure 1: Generating Modulated Microwave Signals via Polymer Optical Fiber Links

The filter's free spectral range (FSR), Δf_{FSR} must be N multiple times smaller than Δf_{opt}. Each complete optical frequency swing will traverse N peaks of the FP twice, in the positive and in the negative directions. Therefore, the total number of peaks traversed in one swing period is $2N$. Now, each time a transmission peak is passed, a high intensity optical signal impinges on the PD and is subsequently translated into a corresponding peak current signal. Therefore, in one optical swing period a total of $2N$ electrical signal peaks are generated at the PD resulting in an up-conversion $f_{mm} = 2N \cdot f_{sw}$ of the drive signal. The electrical signal is filtered to remove unwanted harmonics, amplified and fed into the antenna.

To add data modulation, the data is directly used to intensity modulate the FM modulated signal at the headend. Since the intensity modulated data signal forms the envelope of the FM modulated signal, it will also be detected by the PD, but will not be up-converted in frequency. The maximum drive frequency that can be used is limited by the bandwidth of the GIPOF fiber. However, because $N = \Delta f_{\mathrm{opt}} / \Delta f_{\mathrm{FSR}}$, the microwave frequencies that can be generated by this method are not limited by the fiber bandwidth but by the ratio of the peak-to-peak optical frequency deviation to the filter's FSR. To minimize additional chirp in the intensity modulator a Mach Zehnder (MZM) driven symmetrically would suffice. The data rate should be lower than the drive frequency. If a linear drive signal such as a triangular wave shape is used then the Fourier series of the generated photocurrent on the surface of the PD is given by

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

where F =4R/(1-R)^2 and R is the reflectivity of the plates. The finesse of the FP is related to R by $\text{Finesse}=\pi\sqrt{R}/(1-R)$. The relative powers of the generated harmonics are shown in Figure 2. It is observed that the first harmonic ($f_{mm}=2N\cdot f_{sw}$) is the strongest and power levels drop steadily for subsequent harmonics.

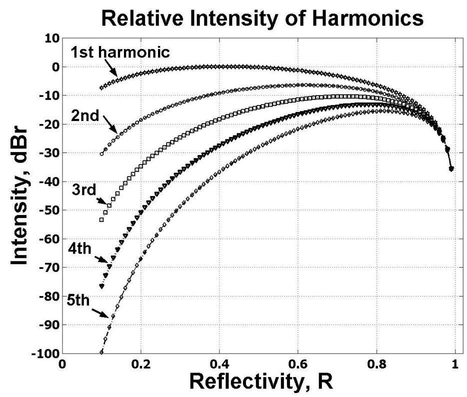

Figure 2: Relative Powers of Spectral Components

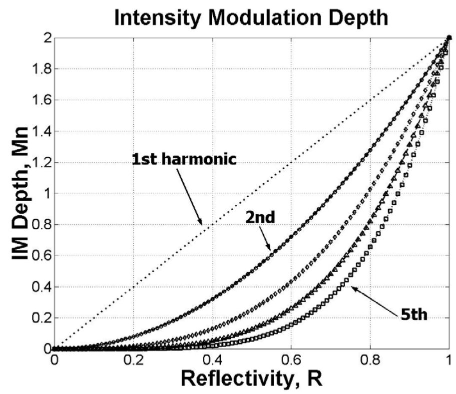

Figure 3: Intensity Modulation Depth of Harmonic Components

The maximum power for the first harmonic occurs at the value of $R=\left(\sqrt{2}-1\right)$ = 0.41. However, with a nearly flat power curve, a wide range of operating points on either side of the optimum R are just as good. Nevertheless, lower values of R give a better suppression of higher harmonics. If we define the intensity modulation depth, M_n of the nth harmonic as the ratio of the amplitude of the alternating photocurrent at the nth harmonic to the dc photocurrent, then $M_n=2R^n$. A plot of M_n for the first 5 harmonics given in Figure 3 shows that the maximum theoretical modulation depths achievable with this technique are greater than those achievable with the modulation sideband technique using MZM non-linearity and the FM-IM technique [4] [5], which do not exceed 1.2. Therefore, this is an efficient up-conversion technique.

Simulation Results

In order to simulate the system, the output of a 10mW CW laser emitting in the 1310nm range was phase modulated by driving an ideal PM with an integrated triangular signal of frequency $f_{sw}=900MHz$. This resulted in a triangularly FM modulated optical signal with a peak-to-peak optical frequency deviation of $\Delta f_{opt}=28.8GHz$. The FSR of the FP was set to $\Delta f_{FSR}=9.6GHz$, which corresponds to 15.6 mm plate spacing. Plate reflectivity $R=20\%$ representing a FP finesse = 1.8, was used to give a better suppression of higher harmonics. The generated RF spectrum at the PD without data modulation is shown in Figure 4. As the figure shows, the first harmonic appears at $f_{mm}=2N\cdot f_{sw}=(6\cdot f_{sw})$ = 5.4 GHz. The second harmonic (10.8 GHz) is 14dB down compared to the first harmonic confirming the theory above. A MZM driven with 225 Mbps baseband NRZ data was then used to intensity modulate the FM modulated optical signal. Figure 5 confirms that the digital data forms the envelop of the generated microwave and is itself not up-converted. The electrical signal was filtered at 5.4 GHz with a 3rd order Bessel BPF having 315 MHz FWHM bandwidth.

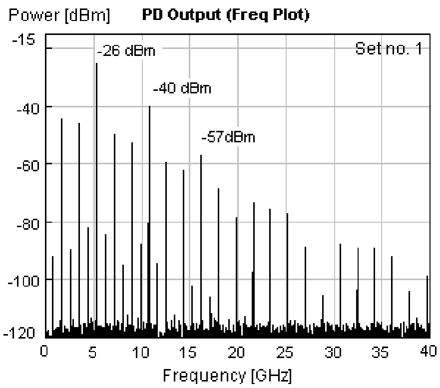

Figure 4: RF Spectrum at the Output of the Photodiode

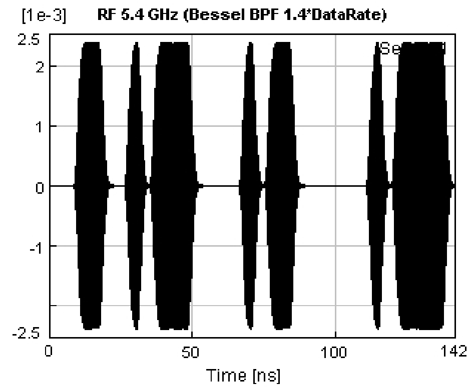

Figure 5: Time plot of Electrical Signal Filtered at 5.4 GHz

Conclusions

A novel technique that performs both frequency up-conversion and data modulation in GIPOF links has been presented. The technique shows the potential to generate high frequency microwave signals since the generated frequency is not limited by the GIPOF bandwidth, but by the ratio of the peak-to-peak frequency deviation of the FM signal to the periodic filter's free spectral range. The approach shows a potential for cost-effective distribution of microwave signals via GIPOF networks, which are attractive for business and residential network environments but offer reduced bandwidth due to modal dispersion.

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