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# Impulse Radio Ultra Wide-Band over Multi-Mode Fiber for In-Home Signal Distribution

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**Abstract—** We propose and experimentally demonstrate a high speed impulse radio ultra wide-band (IR-UWB) wireless link for in-home network signal distribution. The IR-UWB pulse is distributed over a multimode fiber to the transmitter antenna. Wireless transmitted bit-rates of 1 Gbps at 2 m and 2 Gbps at 1.5 m have successfully been demonstrated, with a simple envelope detection scheme. This system is remarkably simple and robust; this makes it very attractive for low-cost applications in short range high-speed wireless links with low radiated power.

## I. INTRODUCTION

Wireless communication using ultra wide-band (UWB) modulation formats is a promising technology for delivering high data rates with low power emission [1]. This feature allows its coexistence with other radio signals working in the same frequency region. As stated in the requirements of the Federal Communication Commission (FCC) for UWB transmission [2], the Effective Isotropic Radiated Power (EIRP) has to be below -41.3 dBm/MHz in the band from 3.1 to 10.6 GHz, which limits the transmission to a few meters. The two common approaches for generating UWB are orthogonal frequency division multiplexing (OFDM) and impulse radio (IR) based on  $n^{\text{th}}$  order Gaussian pulse generation. The latter method has the advantage of simplicity in generation and detection. The frequency range used for UWB transmission allows the use of small antennas, which increases the flexibility in system design, in terms of equipment selection and placement options; therefore the IR generator can be set in the home gateway. As a transmission medium, optical fiber offers a great advantage over copper cable, due to low losses and high bandwidth, and is a natural choice for extending the distance between signal generation point and the wireless antenna node. Cost is also an issue for in-home optical signal distribution, but this may be decreased using low-cost optical equipment, such as vertical cavity surface emitting LED (VCSEL) sources and multimode fibers (MMF) [3].

We present a solution for IR-UWB distribution for broadband ( $\sim$ Gigabit/s) in-home data networks, in which the pulse generator implements a part of the home gateway, and broadcasts a stream of data pulses to wireless access points via a multimode optical access infrastructure. Our implementation achieves significant simplification in wireless transceiver node hardware, and provides a level of ‘future-proofing’ of the network for supporting next-generation wireless networking protocols. After the fiber transmission, only filtering and amplification is needed for FCC-mask compliance. This scheme also avoids the limitations of copper cables for long-distance high-frequency links.

## II. UWB SIGNAL GENERATION AND DEMODULATION

To fit the frequency spectrum of a pulse into the FCC requirements of bandwidth different order Gaussian pulses are generally used. The 5<sup>th</sup> derivative of the Gaussian pulse has been demonstrated [4] to be the optimal in fitting the mask. Moreover it concentrates the energy in the lower part of the spectrum, which is less affected by the high-frequency attenuation during air-transmission. The pulse can be written as:

$$y(t) = A \left( -\frac{t^5}{\sqrt{2\pi}\sigma^{11}} + \frac{10t^3}{\sqrt{2\pi}\sigma^9} - \frac{15t}{\sqrt{2\pi}\sigma^7} \right) \exp\left(-\frac{t^2}{2\sigma^2}\right) \quad (1)$$

where  $A$  is the amplitude and  $\sigma$  represents the standard deviation of the pulse, which is chosen to better place the spectrum peak of the signal. In this paper  $\sigma=55$  ps is set for both bitrates. In the design of the pulse shape, it is also necessary to take into account the frequency response of the transmit antenna, as FCC mask refers to EIRP [5]. In our experiment an omnidirectional UWB antenna is used and included in the modified mask. To fully accommodate the spectrum to the requirements, high pass filtering at 3.1 GHz is needed to avoid exceeding the mask in the band from 960 MHz to 1.61 GHz. Figure 1 shows the FCC mask, the modified mask and the spectra of the 1 Gbps and 2 Gbps signals. As specified in the FCC regulation, the peaks due to

the pattern speed should not be considered in the EIRP. The pulses are generated using a high speed Arbitrary Waveform Generator (AWG) at 24 Gsamples/s.

Envelope detection is used to demodulate the received signal. The signal processing is done offline. The signal is squared and low-pass filtered. Fixed decision point and threshold is used to simplify the receiver. However, due to changes of power because of Inter-Symbol-Interference (ISI), variable threshold should improve the performance, especially for higher bitrates, where the tails from consecutive pulses add up.

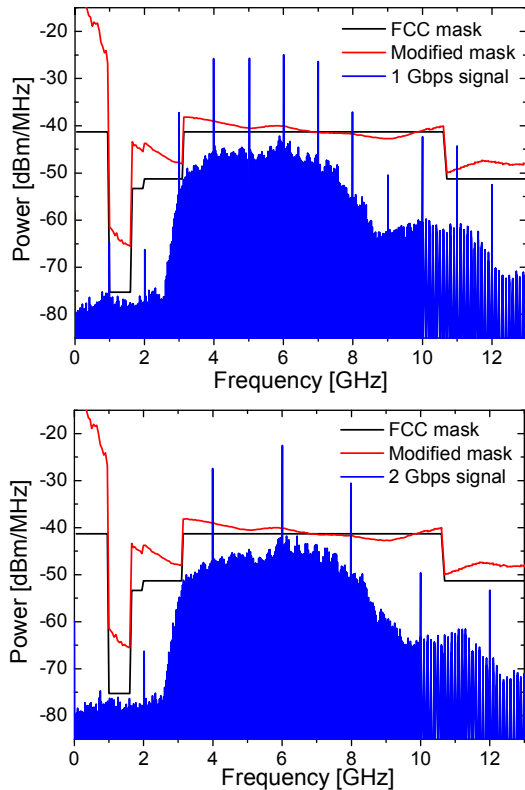


Figure 1. Spectra of transmitted 1 Gbps and 2 Gbps signals before transmission. Compliance with FCC regulation is clearly seen.

### III. SETUP DESCRIPTION

The setup description is shown in figure 2. The signal generated by the AWG, on-off keying with a PRBS length of  $2^7-1$ , directly drives the 850 nm VCSEL in balance mode with a  $V_{pp}$  of 0.35 V. The VCSEL, designed for 10 Gbps data communications gives the best response in terms of bandwidth with balance direct modulation. The bias current offset is set to 9 mA to operate in the linear zone of the VCSEL. The output optical power is -2 dBm. The fiber used is 100 m of standard 50/125  $\mu\text{m}$  silica Multi-Mode Fiber (MMF), with 2 dB of losses. On the receiver side, after the photodiode a wide-band amplifier and high-pass filter are used to better accommodate the signal to the transmission mask before driving the antenna. On the receiver side, a 10 dBi gain bowtie phased-array antenna is used to obtain higher gain in the reception. After that a 3.1 GHz high-pass pre-filter removes

the noise accumulated from air transmission and interferences. A low noise amplifier (28 dB gain and Noise Figure of 3 dB) is needed to raise the signal voltage to be saved in the sampling oscilloscope at 40 Gsamples/s.

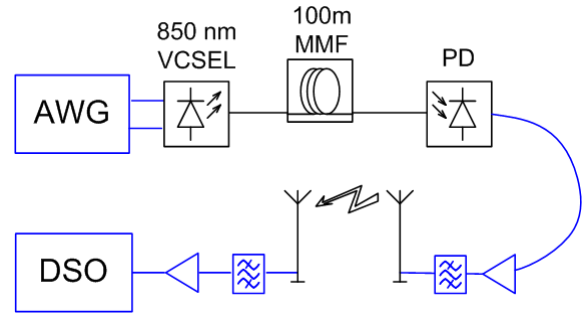


Figure 2. Experimental setup

### IV. RESULTS

To evaluate the capacity of the link, the air link was set to obtain the best performance for 1 and 2 Gbps. The maximum distance achievable was 2 m line of sight, due to lab limited space. The system performance has been evaluated for the link with direct modulation of the AWG to the antenna, and after 100 m of MMF transmission. In both cases the spectra before the antenna have been measured to ensure they are inside the mask. For 2 Gbps the signal gets distorted after 2 m of wireless transmission, giving a BER of  $7 \cdot 10^{-3}$  with the optical link. Therefore, the length was decreased to 1.5 meters.

The evolution of the pulses is shown in figure 3. The transmitted pulse is a clear 5<sup>th</sup> order Gaussian pulse with four oscillations. Due to air transmission and overall non-linearities of the system the pulse gets distorted but can be clearly detected. For the optical plus wireless link the presence of the pulse is still recognizable.

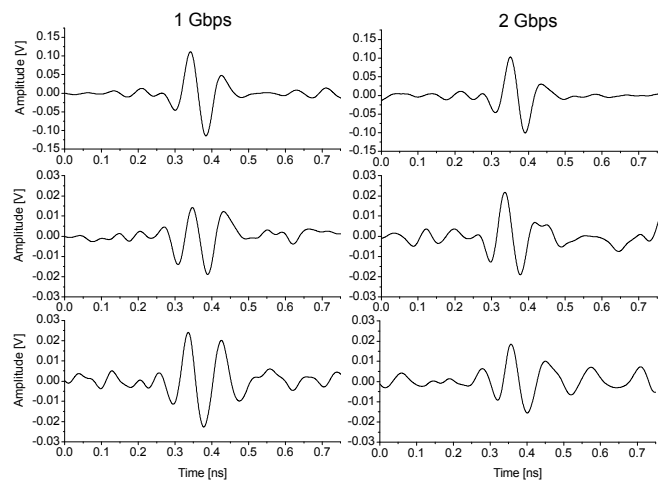


Figure 3. Examples of 1 Gbps (left) and 2 Gbps (right) pulses transmitted from AWG (upper) and its distortion due to air link (middle) and 100 m fiber plus air link (bottom)

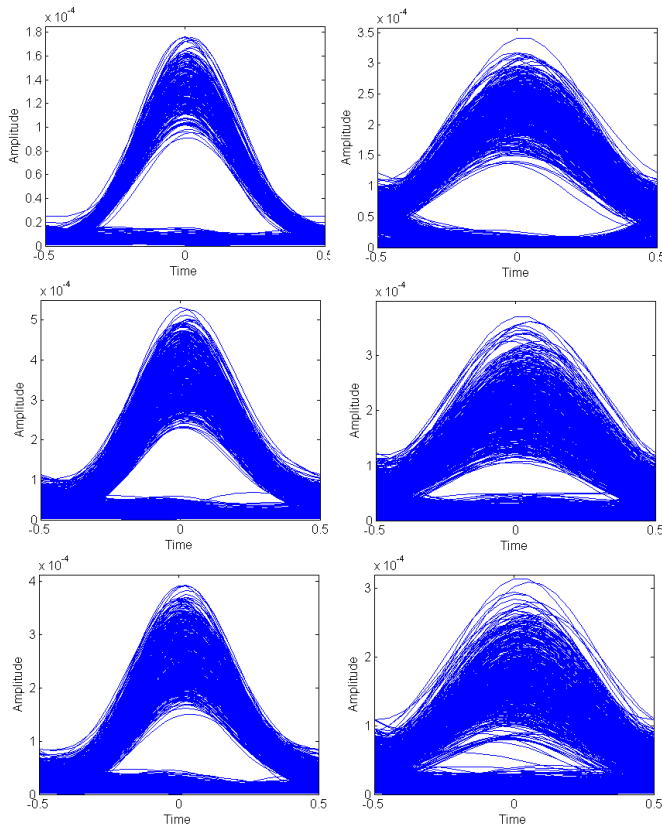


Figure 4. Eye diagram evolution for 1 Gbps at 2 m (left) and 2 Gbps at 1.5 m (right) of electrical, optical back-to-back and 100 m MMF transmission

Figure 4 shows the evolution of the eye diagram for both bitrates. The eye distortion is greater for 2 Gbps, mainly caused by ISI. However, the signal can still be demodulated, obtaining  $2 \cdot 10^{-4}$  of BER after fiber transmission, which is below forward error correction limit. For 1 Gbps, no errors were detected in the demodulated  $5 \cdot 10^5$  bits. The eye looks open and the transitions between bits are clear. The major

penalty for the link is the distortion due to the optical conversion but the fiber link does not affect in excess.

## V. CONCLUSION

We have successfully demonstrated the use of UWB impulse radio transmission for high bitrates over short distances and its application for an in-home scenario. Signals at 1 Gbps (up to 2 m) and 2 Gbps (up to 1.5 m) were successfully demodulated. To the best of our knowledge, these results define new records in bitrate-length product for UWB signaling over multimode fiber (2 Gbps·m and 3 Gbps·m). A simple demodulation method was used, decreasing the receiver complexity. The centralization of the pulse generation also reduces the requirements of the transmitting antenna node equipment, and therefore relaxes its location requirements.

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