A Photoconductive Correlation Receiver for Time-Hopped Wireless Spread-Spectrum Radio

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***Abstract*—We present the first demonstration of a new receiver for digital time-hopped spread-spectrum wireless communications. The time-hopped system is based upon the transmission of short radio frequency (RF) pulses with bandwidths exceeding 200 MHz. The new receiver used photoconductive switching to perform front-end correlated reception. This type of receiver was designed to provide a large dynamic range in the presence of noise and interference. Results show a bit error rate of better than 10^{-7} at a 250-kB/s data rate.**

***Index Terms*—Photoconductive switch, spread-spectrum, ultra-wideband.**

I. Introduction

There is an ever-increasing demand to provide high-bit-rate low-transmit-power wireless local area network (WLAN) capability. In a multipath environment, extra transmitter power is often required in order to sustain reasonable performance during deep multipath fades. Spread-spectrum (SS) techniques are now being used in order to mitigate frequency-selective fading and to enable spectrum sharing among multiple users. Time-hopped (TH) spread-spectrum multiple access schemes have recently been proposed [1], [2].

The TH architecture is based on the transmission of short RF bursts, typically one to three RF cycles long, during preassigned time-slots determined by a code sequence. Each user is given access to a different set of time slots by assignment of distinct code sequences. A pseudorandom distribution of access times provides extra security and jam resistance. Assuming that each nanosecond slot represents a single bit, raw aggregate channel rates can potentially exceed 100 Mb/s.

II. Theory

The TH system will typically operate over a bandwidth of greater than 200 MHz near a 1-GHz center frequency. As such, the power at the front-end of the TH receiver will include noise and interference power integrated over this large bandwidth. A strong carrier from a nearby narrow-band transmitter could potentially saturate amplifiers and mixers, thereby masking the intended signal.

In order to address this potential limitation, we have chosen a design which maximizes the receiver's dynamic range. Rather than passing the spread-spectrum signal through limited dynamic range components, correlated reception [3] can be performed in the receiver's front-end, before amplification.

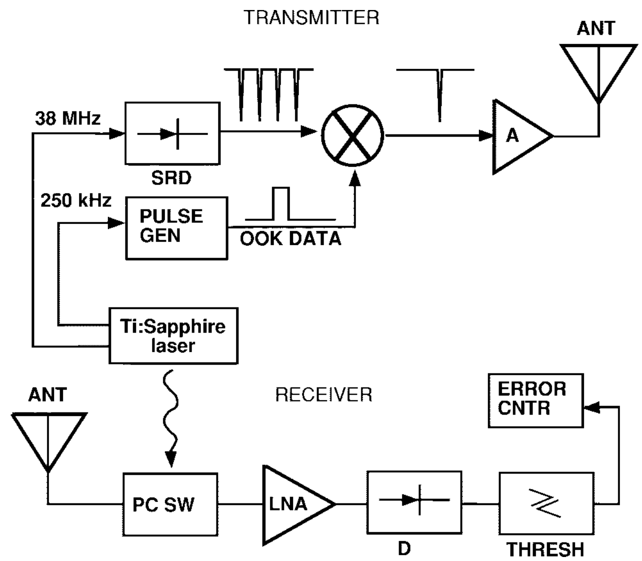

Fig. 1. System architecture. SRD: step-recovery diode circuit, A: power amplifier, ANT: broad-band antenna, PC SW: photoconductive switch, LNA: low-noise amplifier, D: detection diode, THRESH: threshold detector.

A basic correlation receiver which would be appropriate for a broad-band burst is included in Fig. 1. The receiver consists of an antenna feeding a gating switch. The switch is momentarily closed to sample the signal at the precise moment a radio frequency (RF) burst is expected. The switch is normally in the open state, providing significant isolation between the antenna and the amplifiers which follow. The sampled signal is amplified and, when on–off keying (OOK) is used, fed to a threshold detector. To improve performance, a matched filter could be added before the gating switch to produce peak signal-to-noise ratio at the moment the switch closes.

The gating switch is the key element in this receiver. The switch must be fast closing and opening, jitter-free, and exhibit a large dynamic range. The photoconductive switch [4]–[6] satisfies all of these criteria and is the ideal candidate for this receiver architecture. Hence, a proof-of-principle system using a photoconductive switch was constructed.

III. Experiment

The proof-of-principle system is shown in Fig. 1. The transmitter is on–off keyed with a binary message. A transmitter rate of 250 kB/s was chosen. This rate provides significant

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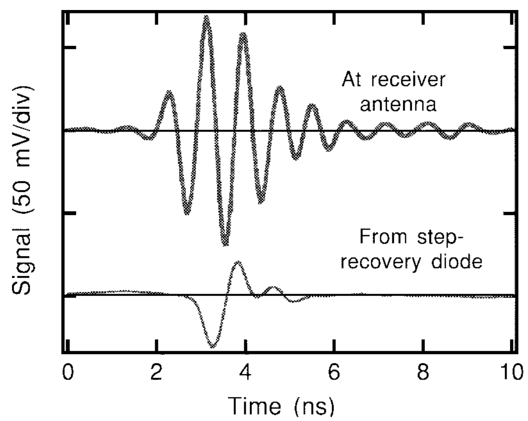
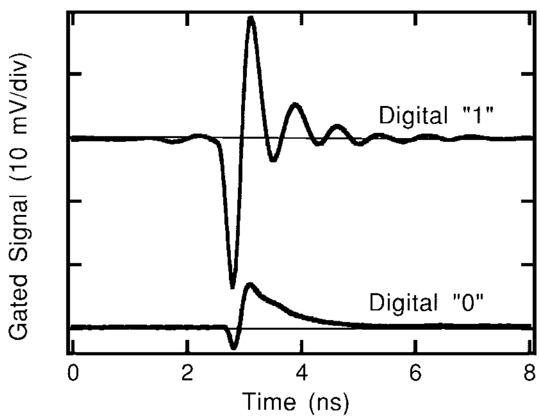


(a)



(b)

Fig. 2. Wide-band RF signal from generation to reception. (a) Signal generated by step-recovery diode (below) and received at the antenna terminals (above). (b) Signal measured after the photoconductive switch.

headroom for coding assuming that each user will want wireless access to a standard 64-kB/s DS-0 hardwired channel.

We have shown previously [7], [8] that photoconductive switches can be used to transmit wide-band RF pulses with true-time-delay beamsteering capabilities. In this work, we emphasize the use of the photoconductive switch in the receiver, and we use a step-recovery diode (SRD) circuit to generate wide-band pulses in the transmitter. As shown in Fig. 1, the SRD is driven by a 38-MHz reference which is derived from our Ti : sapphire laser/regenerative amplifier system. The laser produces subpicosecond optical pulses at a 250-kHz repetition rate which is subdivided from the 38-MHz reference. A 250-kHz synchronization signal from the laser system is reclocked by an HP8013B pulse generator to form a square pulse train with 15-ns pulsewidths. In this setup, data modulation occurs by on–off keying (OOK) the pulses in the train. This pulse train is mixed with the SRD output to form a data stream of OOK SRD pulses at 250 kHz. Each pulse represents 1 bit. This arrangement was used to take advantage of the lower jitter in the 38-MHz reference signal. The RF pulses are amplified and radiated by a custom broad-band reciprocal bow-tie antenna. The low directivity bow-tie antenna ensures easy antenna alignment.

The receiver uses an identical bow-tie antenna located 1 m from the transmitter's antenna. Fig. 2(a) shows the received

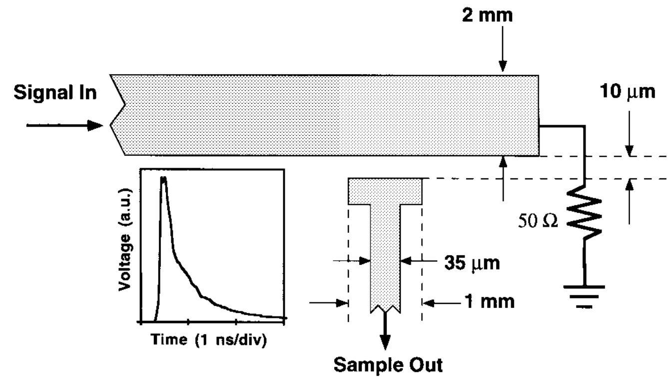


Fig. 3. Layout of photoconductive switch. Inset: Measured output with dc input and load resistor removed.

RF pulse at the antenna terminals and the RF pulse generated by the SRD circuit in the transmitter. The 3-dB bandwidth of the received pulse is 210 MHz. The multiple cycles of RF are due primarily to bandlimiting in the bowtie antennas and power amplifiers. In this demonstration, no additional filtering beyond the bandlimiting in the amplifiers and antennas was used.

The received signal is routed from the antenna to a photoconductive switch. When triggered by the synchronized ultrashort optical pulse, the switch gates the incoming pulse. This process of gating provides a potential TH spread-spectrum processing gain [3] in direct proportion to the reciprocal of the switch's duty factor. At our data rate of 250 kB/s, a processing gain of up to 36 dB is available from an ideal 1-ns gate. Processing gain will be measured in future experiments by adding interfering signals to the environment.

Our photoconductive switching structure consisted of a 50-Ω microstrip signal input line and an output line fabricated on O^+ ion-bombarded GaAs. The output line was perpendicular to the signal line and separated from the signal line by a 10-μm photoconductive switching gap as shown in Fig. 3. The dynamic range of the switch was assessed by biasing the input line with a variable dc voltage of 0–10 V with the matched load removed. The switch was then activated and the switched-out voltage on the output line was observed. A typical response is shown on the inset of Fig. 3. The response was found to be linear with respect to the input bias voltage with less than 1-dB droop over the test range when account was taken for a small photovoltaic response of 8-mV peak. Thus, the sampling gate would be linear for RF signals up to at least +30 dBm, providing a higher level of jam resistance than typical front end components. A conversion loss of 9 dB was also observed for the gate. For the proposed system to be practical, the increase in jam resistance must be greater than any loss in sensitivity. The isolation of the switch in the off state was measured at 1 GHz and found to be 44 dB.

The photoconductive switch is triggered by an 810-nm 270-nJ subpicosecond, optical pulse. The gated RF pulse is shown in Fig. 2(b). Note that there is a signal generated in the receiver when a binary zero is sent (no RF pulse); this is the photovoltaic response of the switch. This undesired response can be suppressed by applying a small dc bias to the input of the correlator through a bias-tee. Alternatively, a pair of differential sampling structures could be used. Next, the sampled signal is amplified and detected with a diode detector. The detector responds to the negative portion of the signal and provides good contrast between the primarily positive photovoltaic signal and the negative portion of the RF pulse. The detected signal is then sent to a threshold detector and error counter. For this experiment, an EG&G PARC 1182 amplifier/discriminator served as a threshold detector and an HP3761A error counter was used to measure the bit error rate. The threshold level was manually adjusted to provide a low bit error rate (BER) averaged over an equal number of ones and zeros.

The simplified modulator in this setup could only produce all ones or all zeros. A BER of better than 10^{-7} was measured for both digital zeros and digital ones using the same threshold. This rate meets or exceeds the BER specification for any of the T1 or T2 wired transmission systems to which the wireless receiver would likely be interfaced. Because the minimum pulse spacing is 4 μs and the transmitted pulses are less than 4 ns in duration, this system is not expected to exhibit intersymbol interference and the results would hold for a random sequence. The average power contained in the transmitted data pulses was measured numerically from oscilloscope traces of the signal output from the final amplifier. Less than 7 μW for digital ones and 0 μW for digital zeros was measured. This yields an average power of less than 3.5 μW for a random sequence.

IV. Conclusion

These initial results show, for the first time, that photoconductive switching can be used to realize a wide-band correlation receiver for a TH communications system. This type of front-end correlation is essential in a large bandwidth spread-spectrum system where practical limitations almost guarantee that other wireless and broadcast services share the same spectrum.

In this work, a laboratory tabletop Ti : sapphire laser was used. However, a compact Q-switched laser diode [9] or laser diode array could also be used as an optical source. In addition, optical trigger energy can be significantly reduced if our ion bombarded switch is replaced with an undoped mechanical grade GaAs switch.

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