UWB WAVE-RADIO

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ABSTRACT

In this work, new six-port interferometer architecture is used for wave-radio modulation and de-modulation. In transmission mode, the interferometer phase-modulates a monocycle pulse, while in receiving mode, and with the same architecture it demodulates the transmitted ultra-wide-band (UWB) signal. Results show that the new interferometer architecture operates efficiently in the 3.0 GHZ - 4.0 GHz UWB channel. As a testing criterion for overall wide band wave-radio performance, it is shown that the proposed wave-radio interferometer architecture exhibits a favourable bit error rate (BER) performance compared with other wideband radio communication systems utilizing QPSK modulation and related software radio engineering.

1. INTRODUCTION

Initially, the six-port circuit was utilized as an instrument for measurement of different parameters of microwave linear and non-linear components. Component measurements included: S-parameters, harmonic load-pull characteristics, intelligent sensor responses, etc. From 1972 to 1994, the six-port interferometer (SPI) was used by Engen et al. [1]–[3] at the National Bureau of Standards (NBS) in Colorado for instrumentation and measurement applications. During the same period other laboratories did similar six-port instrumentation and measurement work, including Poly-Grames Research Center (CRP) [4]–[6].

At École Polytechnique de Montréal, the six-port interferometer circuit was utilized for the first time in 1994 in two variants, as a millimetre wave modulator/demodulator. The six-port receiver operates as a direct digital receiver with sinusoidal signals at millimetre-wave and radio frequencies (RF) [7]-[10]. In [7]-[10], the broadband six-port receivers directly demodulate the data information carried on a single carrier using quadrature phase shift keying (QPSK), quadrature amplitude modulation (QAM), or other types of modulation.

Standard direct conversion usually uses two quadrature carrier paths to do the direct conversion without intermediate frequencies (IF), i.e., the in-phase (I) and quadrature (Q) signal are separated at RF stage [11]. The previously reported six-port based direct conversion receivers [12], however, use only one carrier and separate I and Q signals by analog or digital signal processing after the four outputs at base band stage. A frequency division spread spectrum (FDSS) UWB six-port receiver was reported in [13]. However, four widely separated discrete carriers were used to obtain wideband simulations classified as multi-carrier UWB (MC-UWB) [14]. A modified six-port circuit was introduced as a direct phase modulator for a single carrier signal in [15].

This paper introduces a novel receiver and transmitter six-port architecture using six-port circuits to digitally modulate and demodulate the phase of an UWB signal with 1 GHz full spectrum. The proposed quaternary phase spectrum modulation (QPSM) scheme encodes the information in phase spectrum of a signal over a single wideband channel. Common choices of modulation scheme in UWB communication include pulse position modulation (PPM), pulse amplitude modulation (PAM), and pulse shape modulation (PSM). In previous modulation methods, data information is conveyed either in position, amplitude or shape of a pulse but do not use wideband single channel phase spectrum modulation. However, previous studies have shown that six-port technology compared to conventional wide-band radio (heterodyne or super-heterodyne) has several advantages such as identical circuits for modulation/demodulation, ruggedness, simplicity, and low-cost planar integrated circuit fabrication (e.g. CMOS).

The simulated test bench using Advanced Design System (ADS) software tool of Agilent Technologies is shown in Fig. 1. The results obtained confirm that with the aid of proper digital signal processing (DSP) algorithms, the new SPI architecture can be utilized to operate efficiently with more sophisticated signal processing techniques (OFDM, CDMA) used in short-range wireless applications.

The remainder of this paper is organized as follows. First, we introduce the new six-port interferometer (SPI) architecture and compare it with previous versions of SPI in Section 2. In Section 3, we discuss in further details the transmitter and receiver parts of the simulated test bench with SPI used as a modulator/demodulator. Simulation results are demonstrated in Section 4, with emphasis on the bit error rate achieved with the new SPI architecture. Finally, conclusions and comments are given in Section 5.

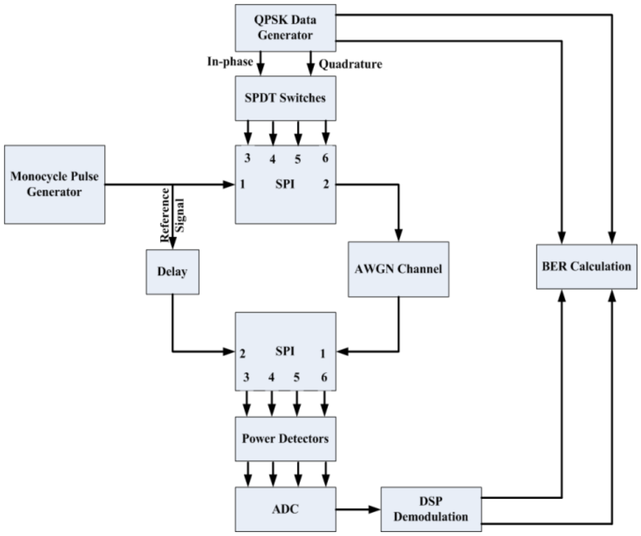

Figure 1: Simulated test bench in ADS.

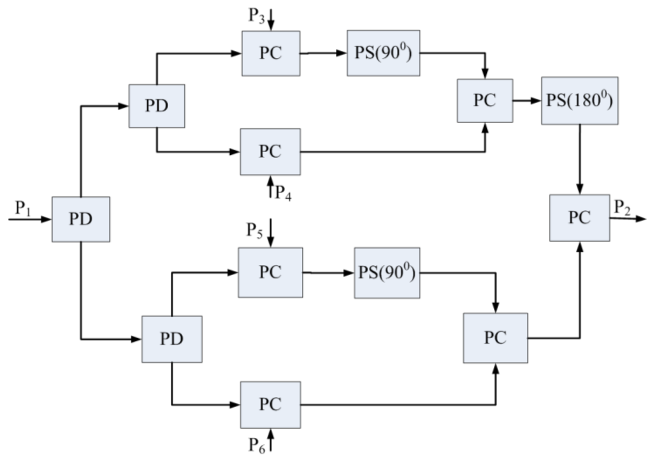

Figure 3: SPI architecture using power dividers/combiners (PDC) and phase shifters (PS).

2. SIX-PORT INTERFEROMETER (SPI)

As shown in Fig. 2, earlier circuit implementations of SPI radio interferometer involved simple planar passive linear components such as power dividers (D), hybrid couplers (Q), and transmission lines (**Φ**) to provide desired vector additions of reference and unknown waves to enable fast decoding of data. The proposed SPI interferometer architecture used in this work for wave-radio modulation and de-modulation is shown in Fig. 3. The new interferometer architecture is composed solely of power dividers/ combiners (PDC), and phase shifters.

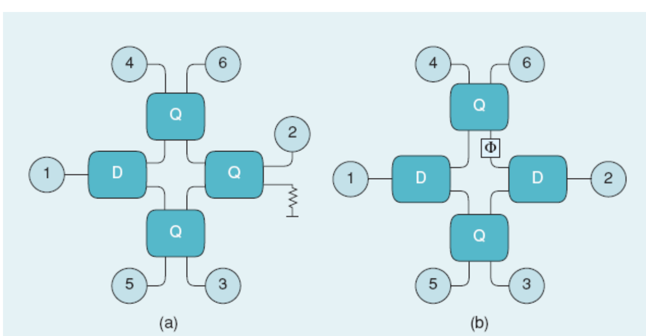

Figure 2: (a) SPI architecture using three hybrid couplers (Q) and one power divider (D). (b) SPI architecture using two power dividers (D), two hybrid couplers (Q), and a delay line.

As reported in [16], the modifications required to transform six-port instrument function to useful radio function was not obvious in 1994, and it was necessary to introduce different approaches to previous six-port designs.

The first changes reported were for narrow-band single-carrier demodulation of digital data. These changes were presented in 1994/1995 publications and in subsequent publications with new phase spectrum modulation/demodulation schemes (PSMS/PSDS) using SPI modulator/demodulators. The new radio derives its name from interferometer modulator and demodulator fundamental functions. The SPI radio modulator performs analog signal processing (vector divisions and additions) of reflected spectrum phase modulated pulse waves with phase spectrum of reference pulse waves. The SPI radio demodulator does the reverse analog signal processing to directly obtain data with a decoder (analog or digital) from interferometer output signals. The changes made to the six-port interferometer to operate as an SPI radio is summarized below:

- The reference signal and the modulated signal are fed to separate input ports of the six-port in the SPI radio modulator and demodulator. The reference signal can be a single carrier frequency, multiple carriers, or an UWB pulse (channel bandwidth of at least 500 MHz) in the range of 3.1 GHz to 10.6 GHz.
- New PSMS is introduced. The PSMS phase modulates digital data on the entire phase spectrum of monocycle pulse, on single frequency carrier, or on multiple carriers. This modulation allows unique SPI radio hardware to be utilized for narrow-band and UWB communications.
- Development of digital signal processing (DSP) algorithms for PSMS (modulation) and PSDS (demodulation) as reported.

3. SIMULATED TEST BENCH

The test bench simulated using ADS is shown in Fig. 1. The SPI radio platform contains two six-port interferometers (one for modulation and the other for demodulation), a monocycle pulse generator, a QPSK data mapper, four single-pole double-throw (SPDT) switches, an analog-to-digital converter (ADC) and a DSP demodulation module for BER calculation. The functions of these components in the test bench are as follows.

The monocycle pulse signal in the chosen channel (3.0 to 4.0 GHz) is generated using a rectangular pulse generator, a differentiator, a low pass filter, an upconverter, and a band pass filter as shown in Fig. 4. Here, the reason for the use of an upconverter is simply the lack of UWB pulse signal generator in the lab, in addition to the need of setting the output signal in the desired frequency range. In fact, single-carrier UWB has been reported in several works before [17]. The pulse generator generates a rectangular pulse train at a repetition frequency of 20 MHz. The width of each pulse is 2ns. The upconverter operates at a center frequency of 3.5 GHz and it converts a portion of the rectangular pulse signal spectrum to a signal spectrum occupying 1 GHz bandwidth between 3.0-4.0 GHz. Only phase spectrum is considered for modulation and demodulation.

The six-port modulator in Fig. 3 provides a simple means to convert quaternary data from base band to a single channel phase modulated spectrum with 1GHz bandwidth. For this purpose, a switch matrix under DSP control presents either a short (S) circuit or an open (O) circuit termination to ports 3 to 6 of the transmitter according to the criteria given in Table 1. The output signal at port 2 subsequently acquires different phase states depending on the terminations applied at modulator ports 3 to 6.

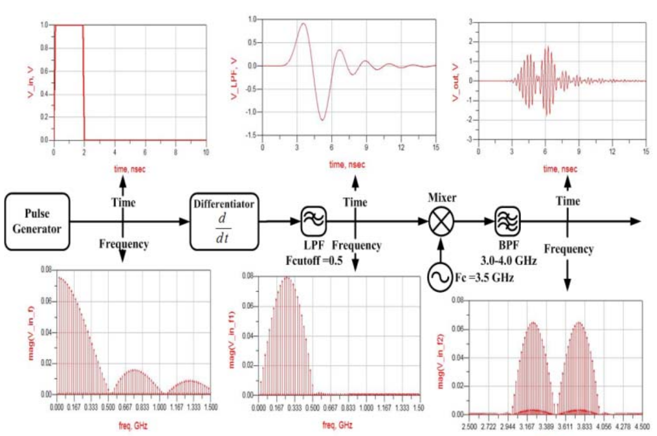

Figure 4: Block diagram for the generation of an UWB Monocycle pulse in 3.0-4.0GHz channel.

As for the six-port demodulator in Fig. 1, the determination of the symbol is obtained by simply comparing and determining the minimum power available at ports 3 to 6, then with the aid of proper digital signal processing algorithms, demapping of the transmitted symbol can be achieved efficiently. The signal processing in the SPI radio demodulator is relatively simple and it may be done with analog circuits for high data rates.

It is noted that the output of the modulator in the test bench is fed directly to the input port of the demodulator, and the input pulse signal of the modulator is fed directly to the reference terminal of the demodulator. This requires the reference signal to be synchronized to incoming data with a suitable algorithm [18].

The modulation data rate is essentially limited by the speed of the switching matrix. On the other hand if the transmitted symbol is determined with a DSP then the data rate is limited by the speed of the analog to digital converters (ADCs) in the DSP platform also.

Table 1: Open and short circuit terminations criteria choices for the four modulation states.

Modulation State	Port Number				$\Delta\Phi$	I	Q
	3	4	5	6			
0	O	O	O	S	0^0	0	0
1	O	O	S	O	90^0	0	1
2	O	S	O	O	180^0	1	0
3	S	O	O	O	270^0	1	1

3.1. SPI AS A MODULATOR

The transmitter in the test bench shown in Fig. 1 consists of a six-port circuit, a switching matrix, and open and short terminations. Each component has wideband characteristic. The modulator SPI shown in Fig. 3 operates as follows: port 1 is fed with a monocycle pulse signal which is routed to ports 3, 4, 5, and 6 through the different branches of the six-port circuit. Signals present at ports 3 to 6 are routed to different terminations by the switching matrix which is controlled by baseband data. Port 2 outputs the digitally modulated signal which acquires different phase states depending on the terminations applied at ports 3 to 6.

Compared with the six-port modulator for sinusoidal signals reported in the previous work [15], the essential differences while operating with non-sinusoidal signals lie in the linear phase response over the wide band and uniform spectral phase modulation over the channel bandwidth.

3.2. SPI AS A DEMODULATOR

The receiver in the test bench shown in Fig.1 is composed of the same wideband six-port circuit structure, with the exception that inputs and outputs are acquired from different ports this time (Fig. 5). Ports 1 and 2 are fed with the modulated and reference signals, respectively. Ports 3 to 6 simultaneously provide four signals to the power detectors. Output signals from power detectors are then sampled and digitally processed in the baseband for demodulation. The adoption of digital signal processing in the proposed test bench is for the purpose of increasing the flexibility of the system and adapting to software defined radio (SDR) needs [19], [20].

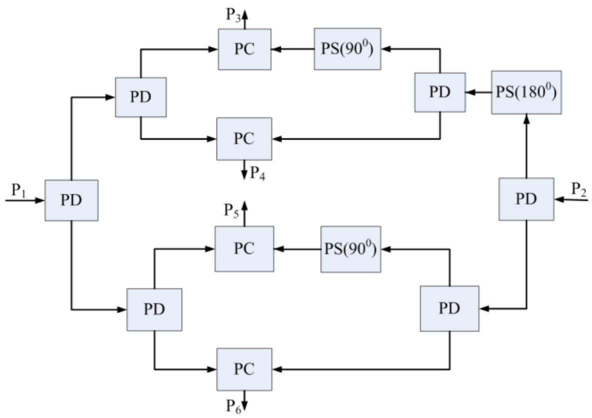

Figure 5: SPI with the same architecture used as a modulator (note the arrow directions compared to Fig. 3).

4. SIMULATION RESULTS

In order to test the SPI as a modulator/demodulator, Fig. 6 shows the output voltages of power detectors versus phase difference between the RF input modulated and reference signals to the demodulator. These results are valid for any frequency within the channel bandwidth (3.0 – 4.0 GHz), and hence for the phase modulated monocycle signal.

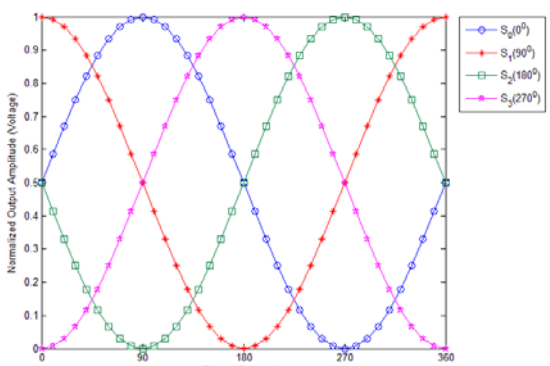

Figure 6: SPI demodulator normalized output voltages versus phase difference between the input and reference signals at any frequency within the operating channel.

Fig. 7 shows the normalized amplitude voltages at the four demodulator interferometer outputs obtained using ADS. It is clear that for this modulation state, zero pulse amplitude is obtained at one port (port 6) and nonzero pulse amplitude is obtained at the remaining ports.

Assuming an additive white Gaussian noise (AWGN) channel, the proposed SPI wideband radio was simulated with ADS. An ideal six-port model has been implemented for this simulation. In resemblance with the available testing equipment in the lab, the test bench simulation was carried out at data rates of 20Mbps. The data rate can be further increased by using higher speed switches and ADCs, however in reality, further limitations arises in regard to the speed of ADCs. The simulated BER results are compared in Fig. 8 with the theoretical BER. These results demonstrate that SPI with its new architecture provides simple, efficient and elegant means as a radio interface for UWB applications.

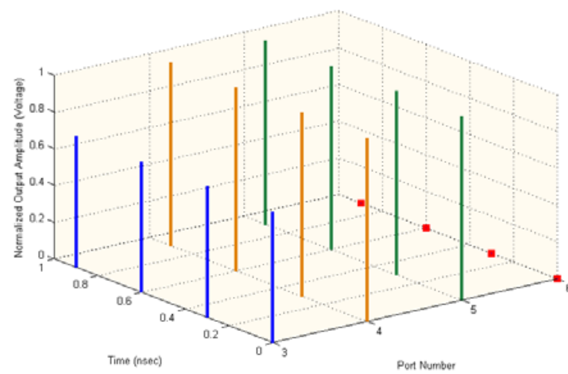

Figure 7: Normalized output voltages at ports 3 to 6 of SPI demodulator for modulation state 2.

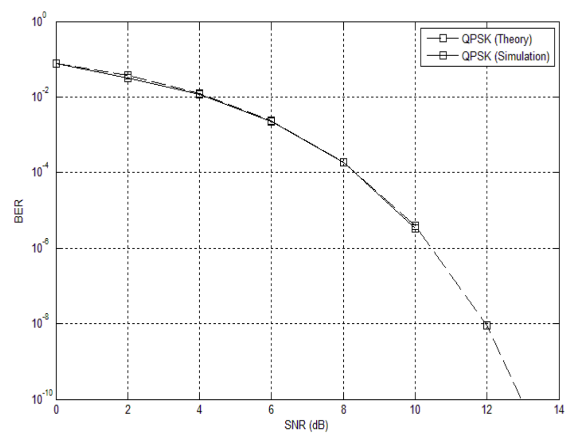

Figure 8: BER simulation and theoretical results comparison for SPI test bench.

5. CONCLUSION

This paper has presented a new SPI architecture as a radio used for QPSK data transmissions at high data rates. The single-band transceiver in this paper illustrates both quaternary phase spectrum modulation and demodulation in

UWB radio. It can be induced from these results that six-port circuits can cover with proper hardware entire 3.1-10.6 GHz frequency band allocated to UWB communications. With its unique hardware/software setup, SPI technology based radios offer great compatibility with wired/wireless digital data transmission for UWB, single-carrier and multi-carrier communications. Further system studies can shed light on benefits of wave-radio technology that can be applied to short range radar, RF tagging and SDR applications.

6. REFERENCES

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