Challenges for Ultra-wideband (UWB) CMOS Integration

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Invited Paper

***Abstract* — Various methods of utilizing the UWB spectrum have been developed to date, characterized by specific modulation schemes, such as pulse position, pulse amplitude or bi-phase modulation. A new method emerging today utilizes a multi-band approach, where information is encoded in multiple RF subbands at staggered time, each occupying 500MHz bandwidth. A description of multi-band modulation schemes for UWB is included in the paper.**

The long term vision for UWB-based products is to enable personal devices with integrated wireless connectivity. This requires 110, 200 and 480Mbps at 10m, and reasonably low power consumption. UWB requires CMOS designs in order to achieve low power and low cost integration with other devices, and to fulfill the vision of integrated connectivity.

One of the design challenges is the high operating frequencies (3.1-10.6GHz), an additional challenge is that low Q systems are more sensitive to parasitics, especially in pads and wire bonds. Some UWB receiver architectures require good isolation among subbands. They also require quick switching between subbands at different frequencies. Example transmitter and receiver architectures are described in the paper.

I. Introduction

The recent UWB spectral allocation for unlicensed spectrum and the new definition of UWB adopted by the FCC have induced the leading UWB manufacturers to develop a new method of using the UWB spectrum. It is not based on impulse radios [1], but on a new concept of using multiple bands of relatively lower bandwidth. This technique has several advantages, because the wireless transceivers employing this technique are more scalable, adaptive and have better co-existence levels with other system such as IEEE 802.11a.

Multi-band based UWB is the most likely technology to be adopted for IEEE 802.15.3a standard [2], which targets low complexity, low cost, low-power consumption and high data rate wireless connectivity among devices within or entering the personal operating space. Data rates must be in excess of 100, 200 and 480Mbps for 30ft range.

UWB transceivers must have complexity similar to Bluetooth, to meet the stringent requirements of the 802.15.3a standard, even if they operate at a much higher bit rate.

Implementation challenges include wideband Low Noise Amplifier (LNA) and correlator, fast switching reference Phase Locked Loop (PLL) and high bandwidth and sampling rate Analog to Digital Converter (ADC).

II. Definition of UWB

The Federal Communications Commission's (FCC) Report and Order (R&O) [3], issued on Feb 2002, defines UWB as any signal that occupies more than 500MHz in the 3.1-10.6GHz band and that it meets the spectrum mask shown in Fig. 1. A comparison with the other unlicensed bands currently available in the US is shown in Table I.

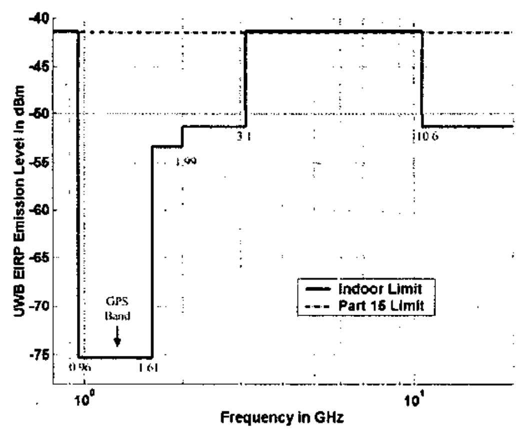

Fig. 1. UWB spectral mask for indoor communication systems.

This definition, which replaces the previous one that expressed UWB in terms of fractional bandwidth, opened up a new way of developing UWB systems.

TABLE I

US SPECTRUM ALLOCATION FOR UNLICENSED USE

Unlicensed bands	Frequency of operation	Bandwidth
ISM at 2.4GHz	2.4000-2.4835	83.5MHz
U-NII at 5GHz	5.15-5.35GHz 5.725-5.825GHz	300MHz
UWB	3.1-10.6GHz	7,500MHz

Given the recent spectral allocation and the new definition of UWB adopted by the FCC, UWB is not considered a technology anymore, but available spectrum for unlicensed use. This means that any transmission signal that meets the FCC requirements for UWB spectrum is acceptable. This, of course, is not just restricted to impulse radios or high speed spread spectrum radios pioneered by companies so far, but opened to any technology that utilizes more than 500MHz spectrum in the allowed spectral mask and with the current emission limit's restrictions.

III. IEEE 802.15.3A STANDARD

The purpose of this task group is to provide a specification for a low complexity, low cost, low-power consumption and high data rate wireless connectivity among devices within or entering the Personal Operating Space. The data rate must be high enough (greater than 110 Mbps) to satisfy a set of consumer multimedia industry needs for WPAN (Wireless Personal Area Networks) communications. The standard also addresses the quality of service (QoS) capabilities required to support multimedia data types.

Products compliant with this standard will complement, not compete with, products compliant with IEEE 802.11, because 802.11 is a standard for Local Area Networks, and 802.15.3a will be a standard for Personal Area Networks. The difference is similar to, in the wired world, Ethernet and USB or Firewire: provide connectivity to the network and to peripheral devices respectively.

Devices included in the definition of Personal Area Networks are those that are carried, worn, or located near the body. Specific examples of devices include those that are thought of as traditionally being networked, such as computers, personal digital assistants (PDAs), handheld personal computers (HPCs), and printers. It also includes other devices such as digital imaging systems, microphones, speakers, headsets, bar code readers, sensors, displays, pagers, and cellular & Personal Communications Service (PCS) phones.

TABLE II
IEEE 802.15.3A SUMMARY REQURIEMENTS

Parameter	Value
Bit rate (PHY-SAP)	110, 200, 480Mbps
Range	30ft, 12ft
Power consumption	100mW, 250mW
Bit error rate	1e-5
Co-located piconets	4
Interference capability	Robust to IEEE systems
Co-existence capability	Reduced interference to IEEE systems

Study group 802.15.3a has been working for the past year with strong involvement of leading UWB companies. Most of the presentations and discussions have been around UWB technology and it is likely that a UWB design will be selected as the basis for the new standard. Strong support from Consumer Electronics companies in 802.15.3 will ensure the standard results in products delivered to the market.

The technical requirements developed by the study group are summarized in Table II. There are two modes of operation: 110 and 200Mbps, and higher bit rates, such as 480Mbps, are desirable. The desired range is 30ft for 110Mbps and can be reduced for higher bit rates. The system must be able to operate effectively in the presence of other 802.15.3a systems and in presence of other IEEE systems such as 802.11a. It is also important that the power consumption be low, to enable wireless connectivity on battery operated portable devices.

II. MULTI-BANDS

UWB has been defined in the past as a method to encode information using impulses. These impulses can be modulated either with position, or with amplitude or with phase. The transmitter feeds these impulses to a very large bandwidth, non-resonating antenna, or sometimes the antenna itself shapes the impulses to the required frequency of operation.

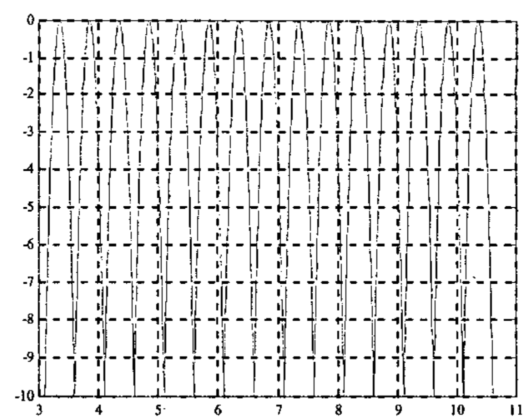

Fig. 2. Multi-bands frequency allocation. Picture shows power versus frequency (in GHz).

UWB companies have developed proprietary techniques to generate and detect such impulses, using non-resonating components. These impulses are especially effective for radar systems, were the resolution is proportional to the bandwidth, but have proven difficult to realize in CMOS so far.

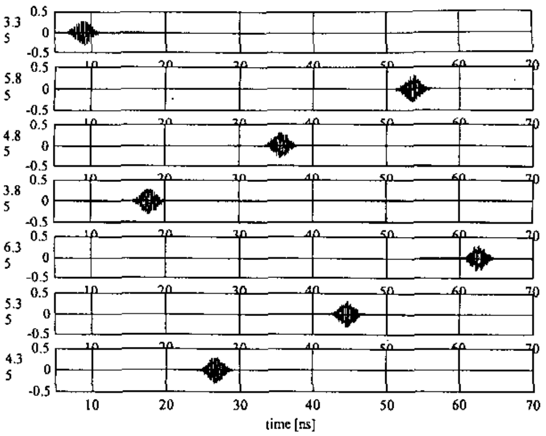

Fig. 3. Multi-band signals sequence.

The many years of research and development by several companies have produced systems based on impulse radios or high speed spread spectrum radios. So far such systems have found their way into niche markets such as radars, imaging, or military communications [1, 4-6].

The idea behind multi-bands is to use multiple frequency bands to efficiently utilize the UWB spectrum by transmitting multiple UWB signals at different frequencies. The signals don't interfere with each other because they operate at different frequencies within the UWB spectrum, as shown in the example Fig. 3. The available spectrum is broken down in 15 bands, each of them occupying 500MHz bandwidth.

The signals are staggered in time, similarly to a frequency hopping system. The signals relative to a sequence are shown in Fig. 3, for an example of 7 bands. Specific sequences can be used to reduce collisions with other users by using different sequences for different networks, similarly to frequency hopping schemes. In this example [7], each band occupies 500MHz bandwidth, and the hopping rate is 16MHz, while the symbol rate is 112MHz.

The link budget is shown in Table III, and shows that the system is capable of 112, 224 and 480Mbps at 10m, with the parameters and link margins shown in the table. Information is encoded with Quadrature Phase Shift Keying (QPSK), providing 2 bits/symbol. The raw bit rate is twice as much, because it uses ½ code rate.

TABLE III

MULTI-BANDS EXAMPLE LINK BUDGET

Parameter	Value	Value	Value	Unit
Throughput (Rb)	112	224	480	Mbps
Average Transmit Power	-8.3	-8.3	-6.0	dBm
Tx antenna gain (Gt)	0.0	0.0	0.0	dB
Geometric center frequency Fc	4.0	4.0	4.0	GHz
Path loss at 1 meter (L1=20Log(4PI*Fc/c))	44.5	44.5	44.5	dB
Path loss at 10 meters (L2=20log(10))	20.0	20.0	20.0	dB
Path loss at 4 meters (L2=20log(4))	12.0	12.0	12.0	dB
Rx antenna gain (Gr)	0.0	0.0	0.0	dBi
Rx power at 10m (Pr =Pt+Gt+Gr-L1-L2)	-72.8	-72.8	-70.5	dBm
Rx power at 4m (Pr =Pt+Gt+Gr-L1-L2)	-64.9	-64.9	-62.5	dBm
Average noise power per bit (N=-174 +10*log(Rb))	-93.5	-90.5	-87.2	dBm
Rx Noise Figure Referred to the Antenna Terminal (Nf)	7.0	7.0	7.0	dB
Average noise power per bit (Pn=N+Nf)	-86.5	-83.5	-80.2	dBm
Minimum Eb/No (S)	3.6	3.6	3.6	dB
Implementation Loss(I)	3.0	3.0	3.0	dB
No of Bands	7	7	12	
Symbol Rate	16	32	40	MHz
3 dB Bandwidth per band	0.28	0.28	0.28	GHz
Bits per symbol	2.0	2.0	2.0	
Raw Bit rate	224.0	448.0	960.0	Mbps
Code rate	0.5	0.5	0.5	
Pulse Tx power (Pt)	-4.3	-7.4	-8.3	dBm
Antenna Impedance	50.0	50.0	50.0	ohm
Transmit p-p voltage at PA	0.4	0.3	0.2	Volt
Link Margin at 10 m (M=Pr-Pn-S-I)	**7.1**	**4.1**	**3.1**	**dB**
Link Margin at 4 m (M=Pr-Pn-S-I)	**15.1**	**12.0**	**11.1**	**dB**

There have been several similar multi-band proposals submitted to the IEEE 802.15.3a group in March 2003, from companies such Discrete Time, Time Domain, Intel, Philips, Samsung, General Atonics, Wisair and others, and it is expected that a variation of these proposals will be chosen as a standard.

III. UWB TRANSCEIVERS

Wireless transceivers for multi-bands are more similar to standard wireless transceiver, unlike designs developed for impulse radios in the past. The major wireless transceiver components are shown in the block diagram in Fig. 4, with exception of the code/decode function.

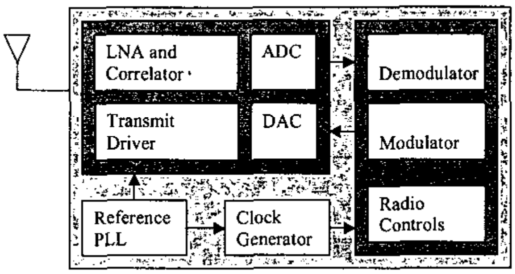

Fig. 4. Multi-bands transceiver block diagram.

The reference PLL creates the signal reference necessary to create the sequence in Fig. 3. The modulator generates the base-band signal that controls the transmit driver to launch the modulated signal at the antenna.

At the receiver, the received signal is first amplified and correlated with the expected signal, then sampled by the ADC, before it is demodulated. The reference PLL provides the required sequence to the correlator to detect the signals shown in Fig 5. A UWB transceiver's typical performance requirements are shown in Table IV.

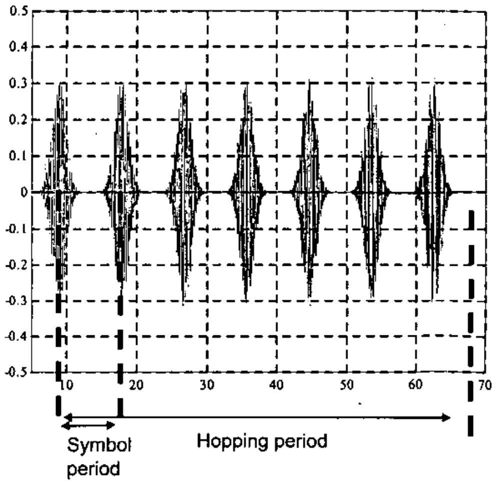

Fig. 5. Multi-band signal reference.

TABLE IV

UWB TRANSCEIVER'S SYPICAL PERFORMANCE

Item	Frequencies of operation	Switch / sample rate	Dyn. range
LNA and correlator	3.1-7.1GHz		30dB
Reference PLL	3.35, 3.85, 4.35, 4.85, 5.35, 5.85, 6.35, 6.85 GHz	250MHz	
ADC	DC-500MHz	500MHz	6 bits
Modulator/ demodulator		250MHz	

The LNA and correlator operate across the whole system's frequency spectrum, from 3.1GHz to 7.1GHz, in the example of Fig 3. Their 30dB dynamic range guarantees operation in the required range, 1ft to 30ft.

The reference PLL provides both transmit signals to the transmit driver and receive reference signals. It generates the sequence of short signals shown in Fig. 5, for that reason is capable of fast switching between different center frequencies.

The ADC samples the correlated signals at 500MHz, capturing the transmit signal's energy. Its 6 bits dynamic range matches the receiver's dynamic range with minimum gain or power control. Alternative designs can reduce the required number of bits by adding effective gain or power control to adapt to the changing environment.

V. CONCLUSION

The recently FCC frequency allocation for UWB has generated a lot of interest in UWB technologies. There are 7,500MHz of spectrum for unlicensed use. The main limitations are provided by the low power spectral density and by the fact that the transmit signal must occupy at least 500MHz at whole times.

The IEEE 802.15.3a standard is being developed for high bit rate Personal Area Networks applications and UWB is the most promising technology to support the stringent requirements: 110, 200 and 480Mbps.

The new UWB technology emerging today, mostly as a consequence of the recent FCC spectrum allocation, is based on multi-bands. A UWB multi-band systems that meet the stringent requirements provided by the IEEE 802.15 has been described in this paper.

There are still many technology's challenges ahead, mostly around the high level of integration that UWB products requires: they need to be developed at low cost and low power to meet the vision of integrated connectivity for Personal Area Networks.

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