Considering a non-uniform filter bank in an UWB Multi Band On-Off Keying transceiver

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Abstract— **Ultra Wide Band (UWB) wireless systems based on impulse radio have the potential to provide very high data rates over short distances. One of the solutions for the UWB communication systems is the Multi Band On-Off Keying (MB-OOK) which consists in an OOK modulation generalized over multiple frequency sub-bands and associated with a demodulation based on a non-trivial energy threshold comparison. This article presents the analysis and simulations of an UWB MB-OOK transceiver in the 6-8.5GHz band. This study is focused on the band-pass filter bank in the transceiver's architecture. The use of a Bulk Acoustic Wave (BAW) filter bank in the transceiver is considered. Finally, system performance is estimated for the proposed architecture.**

Index Terms— **UWB, MB-OOK, high data rates, BAW filters**

I. INTRODUCTION

Impulse radio Ultra Wide Band (IR-UWB) offers a wireless communication solution in order to share the electromagnetic spectrum with already deployed systems. UWB systems occupy a very large frequency band to transmit information under existing systems noise level and offer robustness to multi-path fading.

Different definitions of UWB technology exist. ITU-R Task Group 1/8 defines UWB as a "technology for short-range radiocommunication, involving the intentional generation and transmission of radio-frequency energy that spreads over a very large frequency range, which may overlap several frequency bands allocated to radiocommunication services. Devices using UWB technology typically have intentional radiation from the antenna with either a −10 dB bandwidth of at least 500 MHz or a −10 dB fractional bandwidth greater than 0.2" [1].

In the United States, Federal Communications Commission (FCC) has authorized UWB signals emission without license for indoor applications and mobile point to point outdoor links. UWB's intended use is in the 3.1 - 10.6 GHz bands for short-range communications. UWB transmission device has an FCC-imposed power limit of –41.3 dBm / MHz.

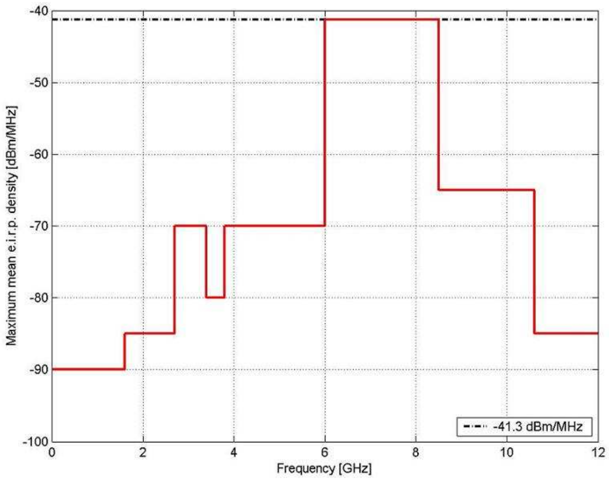

Figure 1. Spectral mask for UWB systems in Europe [3].

In Europe, the Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT) has adopted in March 2006 a decision on the harmonised conditions for devices using UWB technology in bands below 10.6 GHz [2]. This decision has been amended on July 2007 [3]. Devices permitted under last ECC decision are exempt from individual licensing and operate on a non interference, non-protected basis.

A maximum mean e.i.r.p. spectral density level of -41.3 dBm/MHz is allowed for UWB communications in the frequency band comprised between 6.0 and 8.5 GHz in Europe (Fig. 1) [1]. UWB devices placed on the market before 31st December 2010 are permitted to operate in the frequency band 4.2 - 4.8 GHz with a maximum mean e.i.r.p. spectral density of - 41.3 dBm/MHz. The long term targeted band for UWB deployment in Europe is then the 6 GHz – 8.5 GHz band. For this reason, we focus on that frequency band in our transceiver architecture study.

UWB technology holds potential for a wide variety of new Short Range Devices (SRD) for communications, measurement, location tracking, imaging, surveillance and medical systems [2]. We target the high data rates

(HDR) application of UWB technology over short distances.

IEEE initiated a standardization process, referred to as task group 802.15.3a (disbanded in Jan.06), to define a HDR physical layer for wireless personal area networks. During the last years two approaches have been confronted: a pulse radio solution using Direct Sequence - Code Division Multiple Access (DS-CDMA) supported by UWB Forum, and a multi-carrier multi-band solution based on Orthogonal Frequency Division Multiplex (MB-OFDM) proposed by the Multi-Band OFDM Alliance (MBOA) consortium. On this context a third solution was proposed by Mitsubishi Electric ITE-TCL in 2004: an Impulse Radio (IR) architecture based on a Multi-Band On-Off Keying modulation (MB-OOK) and non-coherent reception [4].

DS-CDMA, MB-OFDM and MB-OOK approaches allow UWB HDR transmission on a multi-path channel. Nevertheless, coherent receiver's implementation in an UWB channel is complex because of the numerous paths to recover. Non coherent MB-OOK approach is interesting because it relaxes the constraints in receiver's hardware architecture [4,5].

The next section will introduce the MB-OOK transceiver architecture. This approach requires a bank of band-pass filters. Given the importance of this stage in the transceiver architecture, filter bank is considered carefully in section III. Results of the transmitter architecture simulation are presented in section IV. A method to estimate the MB-OOK UWB system performances is presented in section V and performances of the proposed architecture are calculated. Finally, section VI concludes this article.

The contribution of this study is to suggest the use of Bulk Acoustic Wave (BAW) filters in the UWB MB-OOK transceiver architecture, to give a first approach of their design using Aluminum Nitride (AlN) technology, and to analyze their impact on the system performances.

II. MB-OOK TRANSCEIVER ARCHITECTURE

The MB-OOK solution consists in an OOK modulation generalized over multiple frequency sub-bands. Information is then carried by signal amplitude in each band. Demodulation is based on a non-trivial energy threshold comparison. A non coherent receiver structure per sub-band is shown in Fig. 2.

Figure 2. Non-coherent receiver: energy integration.

It includes a band-pass filter, a square law device and a gate integrator. Integration time in reception (T_i) and repetition time in transmission (T_r) are chosen considering the channel delay spread (T_d). To avoid inter-symbols interference, the symbol repetition period is chosen so that $T_r > T_d + T_s$ where T_s is the duration allocated to the symbol waveform [6,7].

TABLE I. MAXIMAL THROUGHPUTS

	Throughput in Mbps				
T_r	***6 bands***	***8 bands***	***10 bands***	***12 bands***	***14 bands***
11 ns	545.45	727.27	909.09	1090.91	1272.73
30ns	200.00	266.67	333.33	400.00	466.67
40ns	150.00	200.00	250.00	300.00	350.00
60ns	100.00	133.33	166.67	200.00	233.33
80ns	75.00	100.00	125.00	150.00	175.00

Maximal throughput of the communication system can be estimated multiplying its number of sub-bands and the pulse repetition rate ($1/T_r$). In Table 1, maximal expected throughputs are summarized for different repetition time values (obtained for typical channel delay spread).Link budget is computed from symbol repetition period, sub-bands number and frequency width in each sub-band for a fixed throughput.

Fig. 3 shows the transmitter architecture proposed by [7]. A pulse covering the allowed frequency band is generated with a repetition period T_r. The pulse generator is followed by a multiplexer that splits the input signal in N sub-bands. Pulses in each band are filtered and modulated by digital data at a rate $1/T_r$. Then, the modulated signals are combined and amplified before being sent through the UWB antenna.

In this approach, the pulse generator must generate a single pulse covering the available frequency band. To relax this constraint a second solution proposed by [8] uses a bank of local oscillators, ensuring the frequency transposition toward each sub-band. Oscillators are only used to provide transposition. Coherence is not required and the OOK modulation controls the activation of each oscillator. Nevertheless, frequency bandwidth dedicated to UWB transmissions in Europe is 2.5 GHz (and not 7.5 GHz as in North America) and we decided to run our simulations using direct architecture proposed by [7].

The receiver architecture is symmetrical. It includes a low noise power amplifier (LNA), a splitter, a band-pass filter bank and then in each band, a squarer and an integrator. The splitter and the filter bank are common elements in transmitter and receiver.

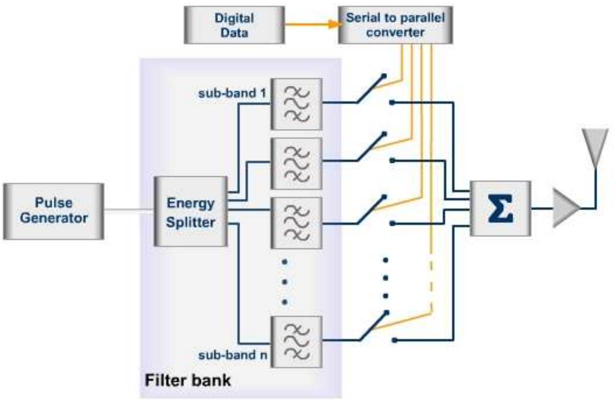

Figure 3. UWB MB-OOK Transmitter architecture.

Some devices involved in this architecture have been studied independently in other transceiver architectures and could be exploited for the MB-OOK non-coherent transceiver [9]. For example pulse generators proposed in [10], [11], LNAs in [12], [11] and squarer and integrator in [11]. Furthermore, a microwave (de)multiplexer for this architecture is investigated in [9]: a microstrip passive quadriplexer build upon second order filters was designed in the 3.1-4.25 GHz frequency band. Nevertheless, this solution is not easy to integrate in the frequency band of 6 GHz – 8.5 GHz.

MB-OOK solution is promising for high data rate communications. Due to its importance in the transceiver architecture, our analysis is specially focused on the filter bank.

III. BAW BAND-PASS FILTER BANK

The use of Film Bulk Acoustic Resonators (FBAR) for filters design makes possible the development of high performance RF filters because of their high quality factor. Bulk Acoustic Wave (BAW) filters, which are designed employing FBARs, could become an alternative for commonly used Surface Acoustic Wave (SAW) filters, because of their significant band rejection and higher maximal operation frequency. Moreover, they can be integrated "above IC", which means size reduction and package simplicity [13].

To realize the filter bank, it's possible to use different technologies, but among most important constraints are losses and integrability. BAW technology using Aluminum Nitride (AlN) piezoelectric material allows frequency operation up to 12 GHz.

BAW band-pass filters are made with FBAR resonators which are associated in Ladder or Lattice topologies. The particularity of this type of resonator is that each frequency response depends on the thin film piezoelectric thickness. Fig. 4 shows an example of resonator frequency response.

An important parameter defining the filter bandwidth is the value of the difference between resonance frequency and anti resonance frequency. This value depends on the physical material properties. The relative bandwidth F is defined as the ratio between the filter bandwidth (Δf) and its central frequency (f_c) (1).

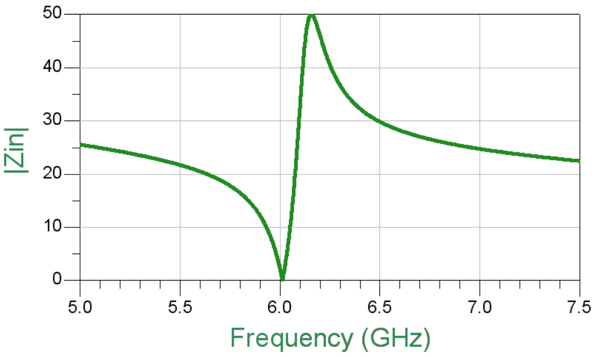

Figure 4. FBAR resonator frequency response.

$$F = \frac{\Delta f}{f_c} \qquad (1)$$

A good value of F for AlN BAW filter is 3%. In order to simplify the filter design, we made the choice of the same F factor for all filters.

A. Calculation of theoretical maximum throughput for MB-OOK using uniform or non-uniform filter-bank

Let's suppose that B is the total available bandwidth, F_{min} and F_{max} are the minimum and maximum frequencies, and N_F is the number of filters in the filter-bank. We will also suppose that impulse-response duration T_f of a bandpass filter with a 3 dB bandwith B_f is proportional to $1/T_f$ with $T_f = \gamma/T_f$.

For a uniform filter-bank, all bandwidths are equal to $B_f = B/N_F$. Taking into account the filters impulse-response duration, the symbol waveform duration is increased from T_s to $T_s + T_f$ and the repetition rate must be chosen so that: to $T_r > T_s + T_f + T_d$. The theoretical maximal throughput R_U is given (2) with to $T_0 > T_s + T_d$:

$$R_U = \frac{N_F}{T_r} = \frac{N_F}{T_0 + T_f} = \frac{N_F}{T_0 + \gamma N / B}, \qquad (2)$$
$$\lim_{N \to \infty} R_U = \frac{B}{\gamma} = \frac{F_{\max} - F_{\min}}{\gamma}.$$

For a non-uniform filter-bank with $\alpha=(1+F/2)/(1-F/2)$, the recurrence between successive bandwidths is given by: $B_{fn} = \alpha B_{f(n-1)}$ and the number of filters that can fit into the total bandwidth B is limited by:

$$N_F < \frac{\log(F_{\max}/F_{\min})}{\log(\alpha)}. \qquad (3)$$

The theoretical maximal throughput R_{NU} is limited by N_F and by the longest impulse-response duration:

$$R_{NU} < \frac{\log(F_{\max}/F_{\min})}{\log(\alpha)} \frac{1}{T_0 + (\gamma/(\alpha - 1)F_{\min})}. \qquad (4)$$

To increase N_F (in order to increase R_{NU}) it is necessary to make F decrease to 0 or equivalently α to 1. And the theoretical limit for R_{NU} is:

$$\lim_{F \to 0} R_{NU} = \frac{F_{\min}}{\gamma} \ln(F_{\max}/F_{\min}). \qquad (5)$$

B. Study of BAW filters

Examining the BAW filters viability of use in an UWB MB-OOK transceiver architecture leads to a deeper and innovating analysis of the system performances. As a matter of fact, former research studies on this subject had always considered that all the filters had the same bandwidth.

Measures and simulations made in [14] established that the Cauer or elliptic filters behavior is a good approximation to the BAW filters response. For this reason and because Agilent-Advanced Design System (ADS) software library doesn't include the BAW filter model, Cauer filters were used on simulations.

For a fixed F value and a given number of sub-bands, filter bank frequency distribution in the frequency band between 6 GHz and 8.5 GHz is calculated using (1).

Filters parameters are: band pass ripple in dB (R_p), stopband attenuation in dB (R_s), and transition frequency in MHz (b_s).The choice of R_p, R_s, and b_s values is made seeking for maximal attenuation between sub-bands with the purpose of reducing the intersymbols interference in reception. These parameters also determine the filter's order. Filter order is an important parameter from a technological point of view. For BAW filters an order of 7 or lower is reasonable.

Stopband affects the interference among symbols in reception, so this parameter should be as elevated as possible, but the higher this parameter is, the higher the filter order is. For a given R_s, filter order can be diminished with a high transition frequency band (b_s) but this will not optimize the available frequency use and maximal expected throughput will be reduced. High R_p value relaxes filters order but degrades in-band signal. MB-OOK architecture is based on energy detection, so values of ripple less than 3dB have been considered acceptable.

Frequency responses of a ten filters bank with Rp = 2.5 dB, Rs = 40 dB and bs = 40 MHz are shown in Fig. 5. Filters order on this case is 5. For this ten filters bank, *F* factor is 3% (the theoretical maximal number of filters in that case is 11 (3)).

A higher number of sub-bands would allow the system to reach higher throughput. Nevertheless, required electronic components (filters, switches, combiners, isolators) also mean increased active surface, power losses and higher power consumption. Therefore, there is a trade-off between throughput and system complexity. On this analysis, a 10 filters bank was studied. This configuration offers an interesting throughput (125 Mbps) over NLOS (Non Line Of Sight) conditions, an suitable *F* factor for AlN BAW filters design and a reasonable number of sub-bands.

IV. ANALYSIS AND SIMULATION RESULTS

Transmitter simulations on ADS have been conducted using a transient simulation controller.

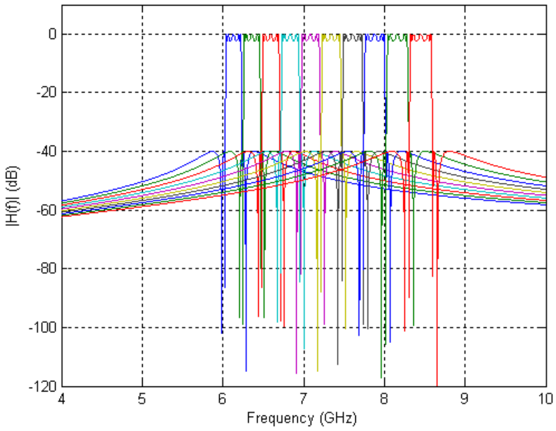

Figure 5. Ten Cauer filters bank frequency response.

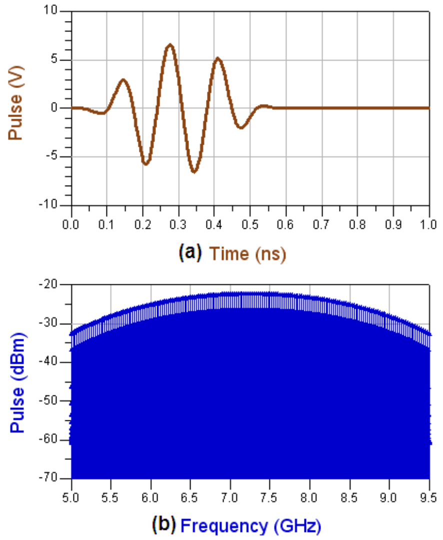

Figure 6. Pulse generator a) First generated pulse in time b) Periodical output in frequency.

A windowed cosine UWB pulse model has been used in simulations because it offers the possibility of controlling central frequency and spectral envelope separately [15]. Central frequency was fixed to 7.25 GHz (Fig. 6). Pulse repetition frequency (PRF) was chosen taking as a reference the IEEE 802.15.3a channel model [16].

This model proposes four different scenarios. Channel model (CM) type 1 is applied for the LOS (Line Of Sight) case and covers distances between 0 and 4 meters. CM2, CM3 and CM4 are all NLOS and respectively valid from 0 to 4 meters, from 4 to 10 meters and for extreme multi path configurations.

Channel delay spread values vary between 11 ns for the best case and 150 ns for the worst case. A repetition period of 80 ns corresponds to CM3 and was considered as an adequate value for simulation. Splitter, switches and combiners were represented as ideal elements.

A ten sub-bands transmitter was simulated in ADS (signal duration = 5µs) using the ten filters bank previously presented (*F* = 3% and order = 5 for all the filters). Fig. 7 presents the obtained results.

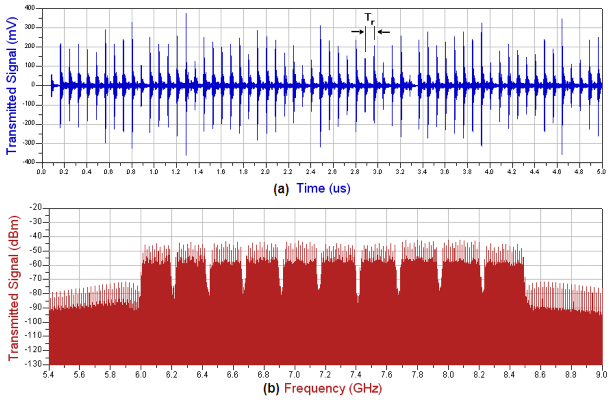

Figure 7. Transmitter simulation results a) in time b) in frequency.

Duration of filter impulse response can be longer than channel delay spread. In Fig. 6a the generated pulse duration is shorter than 1ns, however, in Fig. 7a, filtered pulse duration is longer than 80 ns, hence inter-symbol interference – ISI is introduced.

The time domain simulation results illustrate the theoretical analysis (III.A) by showing how the filter's bandwidth affects the duration of the transmitted pulse (after OOK modulation).Thereby, even if there are excellent channel conditions, the pulse repetition period T_r can not be deliberately reduced to reach high throughput.

To achieve high data rates and approach the maximal value (5) it is necessary to decrease the relative bandwidth F but it is limited by technology.

V. PERFORMANCES ESTIMATION

The number of bands establishes the filters frequency distribution and also the link budget. Mean error probability ($\overline{P_e}$) can be calculated, for a given link budget, as a function of distance between receiver and transmitter for each sub-band.

The $\overline{P_e}$ of a multi-path channel computed according to [3], depends on average received energy to noise ratio (E_{av}/N), gamma function (Γ) and factor M, an even value defined as the product of the integration time and the filter bandwidth.

$$\overline{P}_e\left(\frac{\varepsilon_{av}}{N}\right)=$$

$$\frac{q^q}{2^{M-1}\left(q+\frac{1}{2}\frac{\varepsilon_{av}}{N}\right)^q}\sum_{k=0}^{\frac{M}{2}-1}\sum_{l=0}^{\frac{M}{2}-k-1}\left(\frac{(M-1)!}{k!(M-1-k)!}\right)\frac{\Gamma(l+q)}{\Gamma(l+1)\Gamma(q)}\left(1+\frac{2q}{\varepsilon_{av}/N}\right)^{-l} \quad (6)$$

Where gamma function is defined as:

$$\Gamma(p)=\int_0^\infty t^{p-1}e^{-t}dt, \quad p>0 \qquad (7)$$

and q is expressed in terms of M as [1]:

$$q \approx 1.07 * M \ . \qquad (8)$$

Transmitter performances are calculated as a function of average energy to noise ratio in reception (E_{av}/N). Transmitted signal, transmitter thermal noise and channel path losses must be estimated to obtain (E_{av}/N).

ε_{TX} is the maximum mean transmitted energy allowed by regulation, according to the band and the pulse repetition rate. N is the thermal noise amplified by the receiver noise figure.

Channel losses are function of central frequency of the filter (Path loss at one meter from transmitter $PL_{0dB}=20\log(4\pi f_c/c)$) and channel conditions coefficient n (LOS or NLOS) computed according to [10].

Average energy to noise ratio as a function of the distance is calculated as [4]:

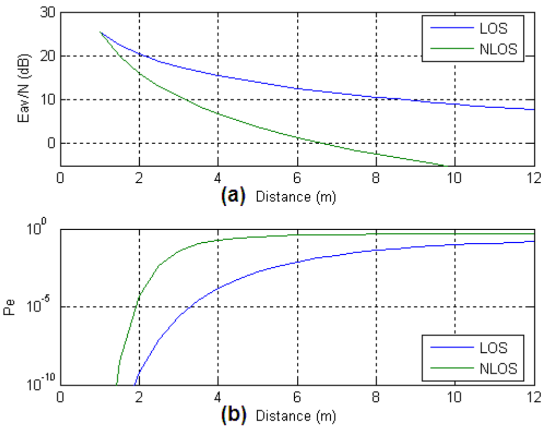

Figure 8. Performances estimation: 10 filters bank a) E_{av}/N b) $\overline{P_e}$.

$$\left(\frac{\varepsilon_{av}}{N}\right)_{dB}=\left(\frac{\varepsilon_{TX}}{N}\right)_{dB}-PL_{0dB}-10n\log_{10}(d)\,. \quad (9)$$

As the passbands of filters are different, an error probability could be computed for each sub-band. Nevertheless, the system performances are conditioned by the worst possible behavior, in this case, evidenced by filter with the highest central frequency of the bank.

Performances results are displayed as (E_{av}/N) in Fig. 8a and $\overline{P_e}$ in Fig. 8b. For a maximal $\overline{P_e}$ of 10^{-5}, the covered distance is 3.3m on the LOS case and 1.9 m on the NLOS case.

These results differ from those obtained with an eight filters bank [17]: throughput is increased from 100 Mbps to 125 Mbps but for maximal $\overline{P_e}$ of 10^{-5}, covered distance is not 4 m but 3.3 m on the LOS case and not 2 m but 1.9 on the NLOS case.

VI. CONCLUSION

The impact of a non-uniform band-pass filter bank in the UWB MB-OOK transceiver is studied in this paper. The theoretical maximal throughput value is calculated. Moreover, the potential of BAW filters in this UWB architecture is highlighted. System performances for the proposed architecture are estimated.

This article illustrates that pulse repetition frequency in an UWB MB-OOK transceiver design, is not only defined by the channel delay spread but also by filters impulse response duration. This means that maximal expected throughput depends on channel conditions and filters features.

Agilent ADS simulations demonstrate the viability of using BAW filters on UWB MB-OOK architecture with F factor kept constant, simplifying design and silicon implementation. System performances confirm the potential of this technological approach. The chosen factor F of 3% is reasonable for technological BAW filters manufacturing.

The ten bands OOK transmitter architecture requires order five filters to offer low interference among symbols in reception. Simulations show that after filtering, the emitted signal respects the European emission mask and makes an optimal use of the UWB communications allowed frequency.

REFERENCES

[1] CEPT/ECC, “Final CEPT Report in response to the second EC Mandate to CEPT to harmonise radio spectrum use for Ultra-wideband Systems in the European Union”. *Doc. RSCOM05-73*, 2005.

[2] CEPT/ECC, “ECC Decision of 24 March 2006 amended 6 July 2007 at Constanta on the harmonised conditions for devices using Ultra-Wideband (UWB) technology in bands below 10.6 GHz”. *Doc. ECC/DEC/(06)04*, 2006.

[3] CEPT/ECC, “ECC Decision of 24 March 2006 on the harmonized conditions for devices using Ultra-Wideband (UWB) technology in bands below 10.6GHz”. *Doc. ECC/DEC/(06)04 amended 6 July 2007*, 2007.

[4] L. M. Aubert, S. Paquelet, “Mise en place d’une couche physique pour les futurs systèmes de radiocommunications hauts débits UWB”. *PhD Report*, Mitsubishi Electric Information Technology Center Europe and Institut d’Electronique et de Télécommunication de Rennes/ INSA Rennes, 2005.

[5] J.-B. Dore, B. Uguen, S. Paquelet and S. Mallegol, “UWB Non-coherent high data rates transceiver – Architecture and implementation”. *IWCT’05*, Oulu, 2005.

[6] S. Paquelet and L.-M. Aubert, “An energy adaptive demodulation for high data rates with impulse radio”. *IEEE Radio and Wireless Conf. RAWCON*, Atlanta, 2004

[7] S. Paquelet, L.-M. Aubert and B. Uguen, “An impulse radio asynchronous transceiver for high data rates”. *IEEE Joint UWBST&IWUWBS2004 Conf.*, Kyoto, 2004.

[8] S. PAQUELET, C. MOY et L.-M. AUBERT, « RF front end considerations for SDR Ultra Wideband communications systems ». RFDesign, 2004.

[9] Mallegol, S.; Coupez, J.-P.; Person, C.; Lespagnol, T.; Paquelet, S.; Bisiaux, A., “Microwave (De) Multiplexer for Ultra-Wideband (UWB) Non-Coherent High Data Rates Transceiver”. *IEEE Microwave Conf., 2006. 36th European*. 2006.

[10] S. Mazer, C. Rumelhard, M. Terré, and M. Mehdi, "Emitter circuit for ultra wide band system," *Communication Systems and Networks Conference*, Spain. 2004.

[11] L . Stoica et al., "An ultrawideband system architecture for tag based wireless sensor networks," *IEEE Trans. Vehicular Tech.*, vol. 54, no. 5, Sept. 2005.

[12] Y. Park et al., "Ultra-wideband (UWB) RF front-end module implementation for multi-band OFDM system," *IEEE Int. Microwave Symp.*, Session TH4B, June 2005.

[13] K. Lakin. “Thin Film BAW filters for Wide Bandwidth and High Performance Applications”. *IEEE MTT-S* 2004.

[14] A. Diet, M. Villegas, C. Vasseure, G. Baudoin. “Impact of BAW emission filter’s characteristics on 3rd Generation standards modulations”. *WPMC*, Denmark, 2005

[15] D. Marchaland, M. Villegas, G. Baudoin, C. Tinella, D. Belot. “Systems concepts dedicated to UWB transmitter”. *ECWT*, France, 2005.

[16] IEEE, *Channel Modeling sub-comitee report*, IEEE P802.15, Wireless Personal Area Networks.

[17] M.L. Suarez Peñaloza, M. Villegas, G. Baudoin. “Non-uniform Band-Pass Filter Bank for an UWB MB-OOK Transceiver Architecture”. *ICWMC '07*, Guadeloupe French Caribbean, 2007.

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