Coexistence Measurements between IR-UWB and GSM/DCS Receivers

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***Abstract*—This paper summarises the process and results obtained from interference measurements between UWB and cellular systems, in particular GSM-900/DCS-1800 receivers. The measurement campaign has been developed in order to quantify the impact of impulse radio UWB transmitters on GSM/DCS receivers. Through conducted and radiated measurements it is concluded that a carrier to UWB interference ratio of 7 dB is enough to protect GSM-900, and 9 dB for DCS-1800 with no relevant degradation of the handset victim device.**

***Index Terms*—IR-UWB, GSM, DCS, Interference.**

I. Introduction

Ultra-Wideband (UWB) technology, although not new, is emerging as a promising method for an efficient use of the radio spectrum, due to its low power spectral density and huge bandwidth. It enables low power consumption, and low cost devices for wireless communications, from low data rate applications such as localisation and tracking, up to very high data rates applications. Several air interfaces foreseen for Wireless Personal Area Networks (WPAN) are based on UWB concepts.

However, its operation and use is not regulated in Europe nor Asia. Only in the USA there are clear guidelines on UWB directives, after the FCC issued the 'First Report and Order' in 2002 [1]. There is a lot of activity being faced now in Europe, under relevant working groups within CEPT and ETSI, and related to the Commission's mandate directed at CEPT, regarding the 'Harmonisation of Radio Spectrum use of Ultra-Wideband Applications in the European Union' [2]. The aim of UWB regulation and standardisation is the achievement of a regulatory status for UWB, on the basis of a low risk and a constructive regulatory process, taking into account the benefits of such technology, both economically and technically, due to its multiple useful applications.

UWB employs spectrum dedicated to other radio services. Therefore, it is a potential source of interference for users in the same frequency range, initially 3.1 to 10.6 GHz, and in other bands due to spurious emissions. A power spectral density (PSD) mask should be conformed, for both UWB in and out of band emissions, to minimise its impact on legacy radio services.

One of the critical parts of the regulatory process is the development of measurement campaigns and field trials, to compare and verify with theoretical results [3-4], and also to prove the accuracy of the assumptions adopted in such studies, defining a PSD mask based on empirical results. The current lack of experimental results makes them specially valuable within the regulatory bodies and national administrations.

This paper describes the process and results of the measurement campaign developed to quantify the impact of impulse radio (IR) UWB transmitters in one of those legacy systems, GSM/DCS. The most sensitive part of the system, the downlink, will be investigated. The results obtained are aimed to provide inputs to the regulatory processes.

The rest of the document is structured as follows: in section II, the employed equipment is presented, section III deals with the GSM/DCS measurement campaign, for both conducted and radiated measurements. In section IV, results are summarised, whereas most relevant conclusions are presented in section V. Finally, section VI covers the future work.

II. GSM/DCS Measurements Equipment

For the experimental study of the degradation introduced by impulse radio UWB transmitters in the downlink of a GSM/DCS system, the following equipment was required :

A. Agilent 8960 wireless communications test set

The wireless communications test set (Agilent 8960) served as an ETSI compliant base station (BS) with configurable parameters, that generated the GSM/DCS downlink signal, and established a communication link with a GSM/DCS handset, using the E1968A GSM/GPRS/EGPRS Test Application. The mobile station's performance was monitored in terms of loopback bit error rate (BER), as well as other receiver's parameters such as the received signal level (RxLevel). The wireless test set was remotely controlled via GPIB with a laptop running Matlab® scripts developed for the scope of the measurement campaign [5].

B. GSM/DCS handset with RF connection

In order to establish a connection, a commercial GSM/DCS handset was employed, equipped with a test SIM card that enabled the loopback mode with the BS emulator.

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C. UWB Transmitters

The UWB interference sources were a series of UWB Impulse Radio (IR) transmitters, that generated a UWB signal from DC to 6 GHz, including a digital control/modulation circuitry to emulate time hopping (TH) and pulse position modulation (PPM), a Digital to Analog Converter (DAC) that converts the digital pseudo-random sequence into an analog signal, which feeds a Voltage Control Oscillator (VCO), followed by a variable gain power amplifier, and a step recovery diode (SRD) based pulse generator. Details on pulse shape and spectrum can be found in [6]. A UWB antenna, was integrated to radiate the signal. This is the first version of UWB transmitters developed in ACORDE.

D. Others

Additional equipment required to perform the measurements is presented in Table I:

Table I .- Equipment required

Spectrum Analyser	Agilent HPE 4408
Vector Network Analyser	Agilent N3383A
Others	Power Supply / RF Cables
	GSM Antenna
	Laptop (Matlab® software)
	Combiner
	Variable Attenuators

III. GSM/DCS Measurement Campaign

Two types of measurements were carried out, conducted and radiated. In conducted measurements there is a perfect control and monitory on both the UWB power at the mobile receiver (I_{UWB}) and the RxLevel. Conducted measurements were carried out at different RxLevels (Table II). Radiated measurements reflect a more realistic environment, and the set-up test characteristics are summarised in Table III.

Table II .- Conducted Measurements

GSM-900	No UWB Interference
	RxLevel=-105 dBm
	RxLevel=-100 dBm
	RxLevel=-90 dBm
DCS-1800	No UWB Interference
	RxLevel=-105 dBm
	RxLevel=-100 dBm
	RxLevel=-95 dBm
	RxLevel=-90 dBm

Table III .- Radiated Measurements

Indoor	GSM-900
Outdoor	GSM-900
	DCS-1800

A. Conducted Measurements

In conducted measurements, the GSM/DCS handset was isolated, avoiding the effect of co-channel interference. Therefore, measurements could be developed for low GSM/DCS receiver signal levels, even at sensitivity, and knowing that degradation is due to the presence of UWB interference. In other words, there was a stable behaviour of the GSM/DCS system in the conducted case.

The UWB transmitters output was connected to a variable attenuator, varying the UWB power in 1 dB steps. Without attenuator, UWB transmitters were configured to transmit –60 dBm in the chosen GSM channel, (200 KHz bandwidth). The same calibration corresponds to –70 dBm in the DCS channel.

Attenuators losses (together with cables, combiners..) were measured with the Vector Network Analyser, in order to quantify the exact UWB interference power level introduced to the handset. The GSM/DCS downlink signal was combined with the UWB interference, monitoring and capturing communication parameters (BER, RxLev). UWB interference was gradually increased until communication was lost.

1) Behaviour in absence of UWB interference

In both conducted and radiated campaigns the initial phase was the characterization of the handset's behaviour and performance in absence of interference, as a reference situation to quantify afterwards the degradation introduced by UWB.

Sensitivity, which is defined as the minimum received signal level to assure a BER not exceeding 0.2% , is obtained at this stage. Other reference levels were considered, to achieve 1 and 2% BER (Table IV). In an isolated situation (conducted), the sensitivity measured was slightly lower that the theoretical reference sensitivity [7]. In a real situation with co-channel interference this sensitivity is degraded, as will be demonstrated later.

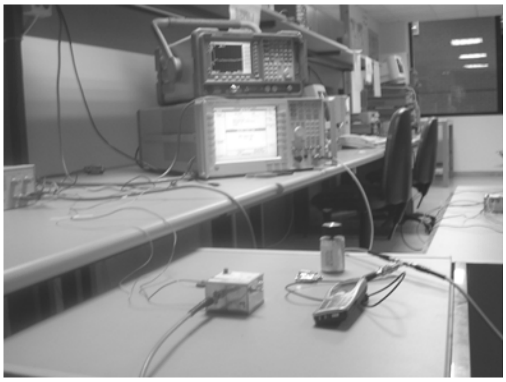

Fig 1.- Conducted measurements test bench

Table IV .- Measured Receiver Thresholds

	Sensitivity [dBm]	
BER	GSM-900	DCS-1800
0.2 %	-105.4	-101.5
1 %	-108.0	-104.1
2 %	-109.2	-105.3

2) GSM-900: presence of UWB interference

At the handset's sensitivity level (–105 dBm RxLevel), the average BER in absence of interference is 0.2%, and, theoretically, the introduction of UWB interference will increase this BER level above the maximum acceptable. During the measurements it was proved that, at such level, and in order not to notice its effect, UWB interference, must be at least 15.3 dB below the GSM carrier level. When raising the

RxLevel (–100dBm and –90dBm), the protection ratio was reduced, because there was a certain margin for other sources of degradation other than thermal noise (Table V).

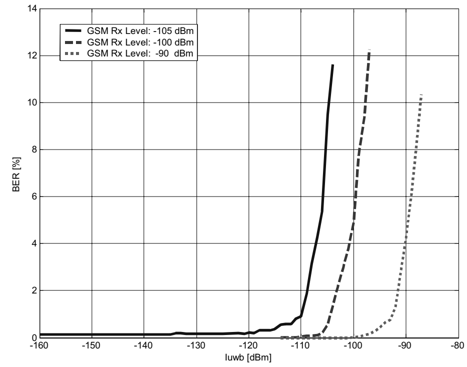

Fig 2.- Summary UWB interference level vs. BER; GSM

3) DCS-1800: presence of UWB interference

No C/I_{UWB} could be obtained at –105 dBm RxLevels for 0.2% and 1% BER, because it was below the sensitivity level for these values. In the 2% BER, -105 dBm RxLevel is very close to the corresponding minimum level, and, for that reason, the protection ratio, 6.8dB, was higher than the values measured in the remaining levels.

At –100 dBm, 1.5 dB above sensitivity, the protection ratio (0.2% BER) was 8.6 dB, value which was reduced down to 7.9 dB for higher RxLevels. In the case of 1% and 2% BER, the value of –100 dBm RxLevel is high enough as to avoid the effect of thermal noise, and maintain the C/I_{UWB} protection ratio measured at higher RxLevels. (Table VI)

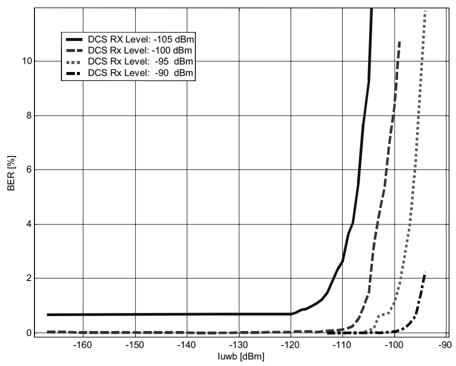

Fig 3.- Summary UWB interference level vs. BER; DCS

Figures 2 and 3 represent the BER vs in-band UWB interference for GSM and DCS respectively. As the carrier level increases, the system can accept a higher interference level maintaining its performance requirements. The C/I_{UWB} ratios obtained are summarised in Tables V and VI.

B. Radiated Measurements

It was first tried to develop the measurements for low RxLevels, close to the receiver's sensitivity, but this was discarded the network is not stable in time. At these levels it is not possible to quantify which of the variations respond to deviations in the variable co-channel interference of the GSM/DCS network, or due to UWB emissions. It was tested that, as expected, there is a more stabilised behaviour in absence of GSM/DCS network activity (nights, weekends..), and abrupt behaviour in a normal day operation. In order to avoid these influences, measurements were developed at higher RxLevels, where all degradation was assigned to UWB.

Table V .- GSM-900 Conducted C/I protection ratios

	GSM-900 BER C/I_{UWB} [dB]		
RxLevel	0.2 %	1%	2%
-105	15.3	4.8	3.9
-100	6.0	4.4	3.2
-90	6.6	2.3	1.5

Table VI .-DCS-1800 Conducted Protection Ratios

	DCS-1800 BER C/I_{UWB} [dB]		
RxLevel	0.2 %	1%	2%
-105	--	--	6.8
-100	8.6	5.7	4.6
-95	8.9	5.2	3.7
-90	7.9	5.4	4.2

In radiated measurements, UWB interference power level was fixed, and the GSM/DCS RxLevel reduced in variable steps, by controlling the BS transmitted power. The reference RxLevel was monitored in absence of interferers. There was a perfect control on the RxLevel at the mobile handset, but not on the UWB interference level, that presented some variations due to the inherent characteristics of wireless propagation.

The BS transmitted initially at a high power level, and gradually reduced in steps according to the RxLevel, until reference BER was obtained (0.2,1,2%). This new 'degraded sensitivity' was compared to the original sensitivity, being degradation (D) the difference between them. A GSM/DCS antenna was placed in the future location of the GSM/DCS handset, in order to measure UWB power in the receiver's channel with a spectrum analyser. It was also estimated from the degradation measured (1), where N_0 is thermal noise.

$$I_{UWB} = 10\log\left(\left(10^{D/10} \cdot 10^{N_0/10}\right) - \left(10^{N_0/10}\right)\right) \quad (1)$$

In the aggregation cases, I_{UWB} was also estimated as the summation of power levels introduced by the individual transmitters, in order to verify the Gaussian behaviour of UWB aggregation. Based on these C and I_{UWB} levels, C/I_{UWB} ratios were obtained employing the three methodologies (measured, estimated through degradation and estimated as summation of individual power levels).

1) Indoor Aggregated Measurements

GSM-900 indoor aggregated measurements were developed during a weekend, in order approach a stable GSM network behaviour. The configuration chosen for this aggregated measurements consisted on 8 UWB transmitters (labelled A to G), located in a 20 cm circumference, surrounding a GSM/DCS handset (Figure 4). The degradation introduced by each transmitter was characterised individually, and afterwards, the number of active devices was increased, one by one, until all the eight transmitters were active.

In order to make measurements reproducible, and due to the physical limitations imposed by the analog potentiometer controlling the transmitter's output power, the UWB devices were calibrated at their maximum available output power, that presented slight variations from one transmitter to another. This was not a shortcoming, as far as the power generated by each device was characterised.

Fig 4.- Indoor aggregated measurements setup

In Figure 5, the protection ratios vs. obtained BER with each individual transmitter is presented, whereas Figure 6 presents the same parameters for different combinations of active transmitters. Regarding the sensitivity in absence of interference, the value is close to the conducted one, because measurements were developed in an environment with no GSM/DCS activity. The obtained C/I_{UWB} are also very similar to the conducted ones, being 6.5 dB for 0.2 % BER in all possible combinations of active transmitters (Table VII).

Table VII .- GSM-900 Indoor Aggregated C/I_{UWB}

	$C/I_{UWB\ min}$		
Active Transmitters	**0.2 %**	**1%**	**2%**
A	6.5	4.9	3.5
B	6.5	4.8	3.7
C	6.5	3.2	2.4
D	6.5	4.7	4.1
E	6.5	4.0	2.3
F	6.5	2.0	0.7
G	6.5	2.3	1.3
H	6.5	4.3	3.9
A,B	6.5	4.5	3.3
A,B,C,	6.5	4.3	3.4
A,B,C,D	6.5	3.6	1.9
A,B,C,D,E	6.5	3.5	1.7
A,B,C,D,E,F	6.5	3.6	2.9
A,B,C,D,E,F,G	6.5	3.5	2.1
A,B,C,D,E,F,G,H	6.5	3.9	2.6

2) Outdoor Aggregated Measurements

The configuration was the same as indoors. The aggregation was measured with the eight transmitters active. Close to the outdoor environment there was a populated area, with high GSM/DCS network activity. That is the reason for the great difference in GSM/DCS sensitivity compared to the previous isolated conducted and indoor environments. In fact, this a clear example of a real situation in which GSM/DCS handsets operate.

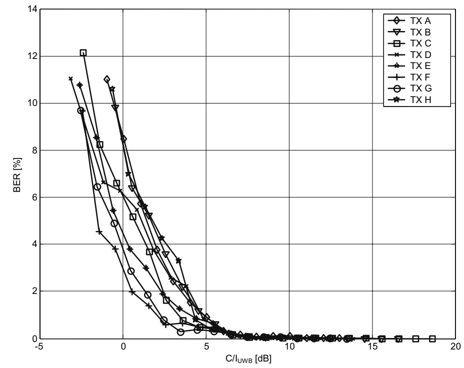

Fig 5.- C/I_{UWB} [dB] vs BER[%]: Individual transmitters

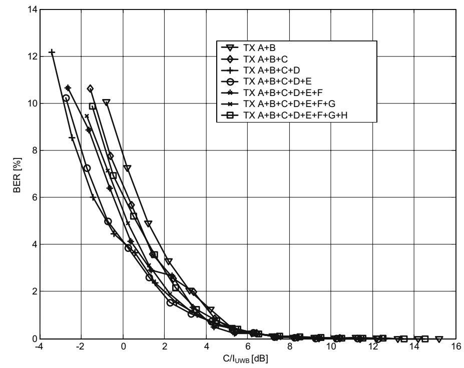

Fig 6.- C/I_{UWB} [dB] vs BER [%]: Combinations of active transmitter

The C/I_{UWB} protection ratios for GSM and DCS are similar to the conducted and indoor ones, as presented in the following tables.

Table VIII .- GSM Outdoor Aggregated Measurements

	BER		
	0.2 %	1 %	2 %
Sensitivity - No UWB [dBm]	-87.6	-93.1	-95
Degradation [dB]	36.8	42.7	44.9
C/I_{UWB} min [dB]	**7.0**	**4.2**	**2.9**

Table IX .- DCS Outdoor Aggregated Measurements

	BER		
	0.2 %	1 %	2 %
Sensitivity - No UWB [dBm]	-87.2	-90.6	-92.4
Degradation [dB]	32.6	34.3	34.3
C/I_{UWB} min [dB]	**8.6**	**6.9**	**5.1**

IV. RESULTS

1) On UWB Aggregation:

UWB aggregation effects on GSM/DCS handsets behaves like AWGN (Table X). The power levels measured and estimated through degradation, were close to the power levels obtained through the summation of individual contributions. The slight differences were due to the variability in transmitted power of the UWB transmitters, as well as some variations due to the wireless nature of the network.

Table X .- Indoor UWB Interference in GSM channel

Active Transmitters	Measured [dBm]	Estimated (Degradation) [dBm]	Estimated (Summation) [dBm]	Δ_{max} [dB]
A,B,C,	-70.6	-69.4	-70.0	0.7
A,B,C,D	-68.9	-67.5	-68.3	1.4
A,B,C,D,E	-67.6	-66.2	-67.1	1.4
A,B,C,D,E,F	-66.4	-66.3	-66.4	0.1
A,B,C,D,E,F,G	-65.6	-65.2	-65.8	0.6
A,B,C,D,E,F,G,H	-64.8	-65.5	-64.9	0.7

2) On the protection ratios and PSD limits

First of all, the sensitivity levels measured in an isolated environment, with no co-channel interference, were similar to the theoretical reference sensitivity values. In such situations there is no margin for other types of interference, like the unavoidable co-channel interference in GSM networks, neither UWB interference, if this sensitivity value is not to be degraded.

However, in a real environment, the measured sensitivity was higher than the reference values, and therefore higher external interference power levels below the internal GSM/DCS network interference not noticed.

As a result of the measurement campaign, C/I_{UWB} ratios were obtained. These can be applied for GSM/DCS carrier levels at least 1 dB above the real sensitivity.

Table XI .- C/I_{UWB} Overall Protection Ratio

	0.2 %	1%	2%
GSM	**7 dB**	**5 dB**	**4.5 dB**
DCS	**9 dB**	**7 dB**	**5.5 dB**

The next step was the calculation of maximum acceptable PSD mask. The maximum PSD can be calculated for a RxLevel 1 dB above the theoretical sensitivity, with one UWB transmitter located at a given distance. However, it was proved that, in a loaded GSM/DCS environment, its sensitivity is well above the reference sensitivity. The maximum acceptable PSD was calculated also for this minimum RxLevel measured in a real GSM/DCS activity situation. The maximum PSDs obtained from such levels and three separation distances (20cm, 36cm and 1m) are presented in table XII:

Table XII .- Maximum Acceptable PSD

	Maximum PSD [dBm/MHz]					
	20 cm		**36 cm**		**1m**	
	Worst case	Real Sens.	Worst case	Real Sens.	Worst case	Real Sens.
GSM	-86	-70	**-81**	**-65**	- 72	-57
DCS	-78	-65	**-73**	**-60**	-65	-52

V. CONCLUSIONS

Through conducted and radiated measurement campaigns, we have concluded that a C/I_{UWB} protection ration of 7 dB is required in order to protect GSM-900 handset devices from IR-UWB interferers, and 9 dB for the DCS-1800. Under such premises, the handset did not suffer undue interference from UWB devices. Two sets of maximum acceptable PSD are presented, one based on an unlikely worst case situation and the second one a real measured situation, with GSM/DCS activity and, therefore, co-channel interference. The difference between both approaches can be as high as 16 dB.

On one hand, it is not reasonable to define UWB limitation at levels these handsets do not generally work even in absence of UWB interference. On the other hand, defining the limits based on the second criteria may be argued to be not protective enough. It is suggested to adopt a trade-off solution between both situations.

VI. FUTURE WORK

Future work is required in the definition of operating conditions under which GSM/DCS receivers should be protected from UWB, and whether the adoption of worst case situation or more realistic solutions. Operation conditions include the separation distance, realistic and, at the same time, restrictive enough receiver signal levels at which protection must be assured, protection criteria (0.2% BER is one possibility, although others may be faced), amongst others. Additional studies and tests are being developed with UMTS receivers.

Future work is also required in the scope of the regulatory bodies, such as the ECC TG3 measurements group, as well as in the development of market available UWB transceivers.

VII. ACKNOWLEDGEMENTS

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