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AN "F-GAIN" ANTENNA FOR UWB-RFID

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Abstract—This paper presents an UWB antenna concept adapted for a potential application of RFID in a severe multi-paths environment for European regulation (UWB-LDR 6–8.5 GHz). The UWB provides theoretically the signal integrity and designing the UWB antenna is compatible with low size, cost and low complexity consideration. Under the hypothesis of using the same antenna at both transmitting or receiving states, the $1/f^2$ effect of free space attenuation can be minimised by a pre-emphasis included in the antenna design, that is to say an "f-gain" antennas at both transmitting (Tx) and receiving (Rx) parts. As a result, the printed antennas described are neither constant aperture nor constant gain type.

1. INTRODUCTION ABOUT UWB ANTENNAS

Wireless communications systems have, for several years now, focused on the Ultra Wide Band [1–3], an old spread spectrum concept. From an antenna point of view, the Ultra Wide Band (UWB) concept can covers different applications such as [10] Ground Penetrating Radars (GPR), Multi-narrowband continuous-wave transmission (for multi-radio) and impule radio. The latter can operate in a 3.1 to 10.6 GHz frequency band [1] according to Federal Communications Commission regulations and in a 6 to 8.5 GHz for the European regulation (UWB Low Data Rate applications).

The UWB principle is to spread in frequency the information with a very low power level. As shown by the Figure 1, anybody should take care about the fact that widening the bandwidth of the signal

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$$C(B)_{B\to\infty} = B_{B\to\infty}\log_2\left(1+\frac{p}{B_{B\to\infty}N_0}\right) = \left(\frac{p}{N_0}\right)\log_2(e)$$

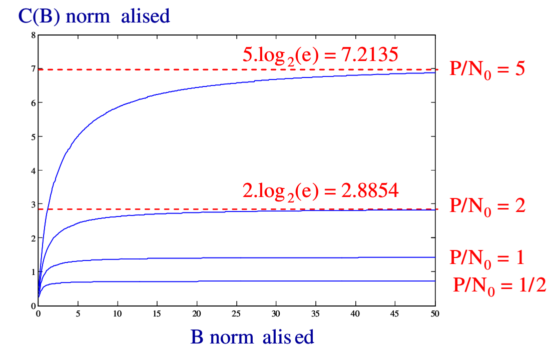

Figure 1. Shannon's law of capacity for UWB case.

cannot increases the capacity to infinity due to Shannon's law. The advantage of UWB is only based on the spreading of the information and provides theoretically immunity to selective fading (ex. multi-paths channel). There are different manners to spread the information in a UWB transmission. i) first is the multi-band OFDM (Orthogonal Frequency Division Multiplex) technique that corresponds to a multi-carriers transmission cases providing high data rate transfer possibility but at short range due to the principle of low power emission. The drawback is clearly the constant power emission of the system that penalises the lifetime of battery assisted systems. ii) Second are the traditional pulsed systems that provide low consumption and long range possibilities. The time precision needed for the wideband pulse enables interesting possibilities of localisation. The data rate transfer is very low in this case. iii) Third is the principle of sub-band occupation by wider or modulated pulses compared to ii). The advantage could be to keep a low consumption and increasing the data rate transfer. Multiplexing is possible but needs a bank of Tx/Rx chains. These approaches are summarised in Figure 2.

In UWB, the goal is to transmit very low power pulses in order to achieve high data rate without disturbing other neighbouring wireless communications that share part of the UWB band. Antennas dedicated to such applications are not supposed to be multi-harmonic but they are required to be really non-dispersive and wideband. Furthermore, phase transfer response must be linear with respect to frequency, see Figure 3, and ideally for any direction of emission.

Also the shape of the radiation pattern (DDR) has to be conserved in function of the frequency, and in function of the polarisation

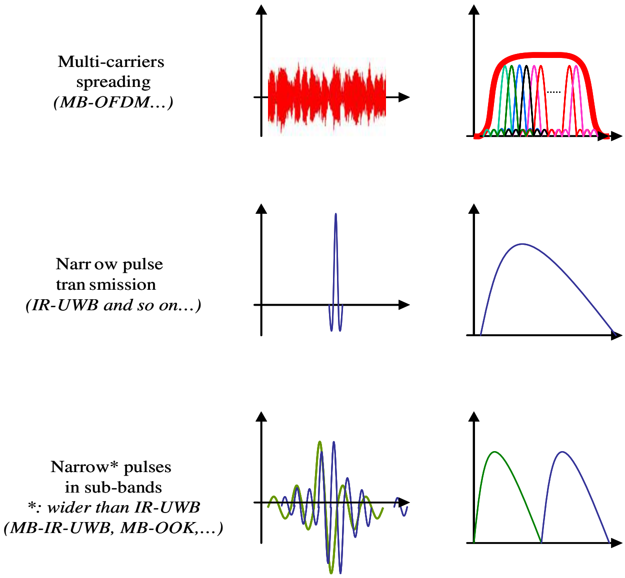

Figure 2. Different principles for UWB (time and frequency representation).

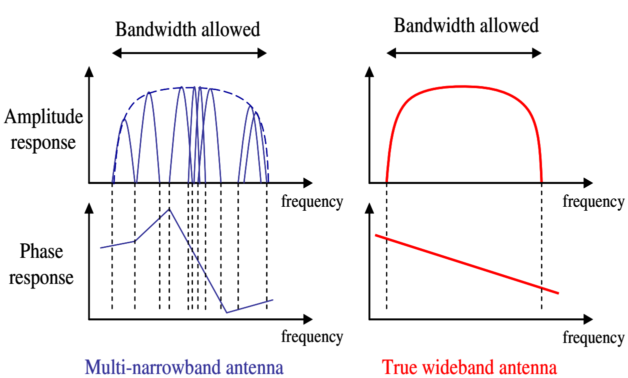

Figure 3. Difference between multi-band and wideband antennas.

at the same time, to avoid an amplitude compression effect, see Figure 4. The dispersion that can be observed on radiated pulses reveals the antenna time behaviour. Integration and production of UWB mobile transceivers imply an additional task that consists in building a minimum-size low-cost antenna. These considerations lead to avoid volumetric structures (i.e., bi-conical, 3D monopoles or horns).

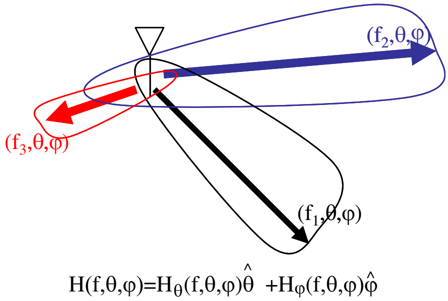

Figure 4. Compression effect for a UWB antenna.

However studying the latter as possible UWB antennas is essential to find design rules for other technologies. Micro-strip antenna shapes, for example, are often inspired by projection of 3D existing antennas [4–11].

To conclude this part: UWB is a spectrum spreading technique that provides interesting immunity to multi-paths effects and the design of UWB antennas is a careful task needing considerations about the dispersion and the frequency behaviour of the radiation pattern (also, the antenna is of course to be wideband matched).

2. RFID-UWB, THE RUWBIS PROJECT

2.1. UWB for RFIDs

The radio frequency identification (RFID) has been known in the industry for several years and constitutes again a research field with considerable increase nowadays [13, 14, 16]. Indeed, the growing popularity of RFID labels in several industrial applications such as containers traceability, people identification, public transport, allowed a wider deployment of this technology. RFID mass development supports costs reduction making this technology competitive compared to traditional identification and traceability techniques. Several frequency bands are authorized by the European regulation for RFID applications: 125 kHz, 13,56 MHz, 868 MHz and 2,45 GHz. The encountered propagation phenomena vary with the frequency band. The correct identification operation depends on several factors such as: antennas performance, propagation conditions, feeding techniques, environment as well as the materials on which the tag is located.

Typically, an RFID system consists of a part usually called base station/reader whose main role is to identify an element called label or tag/transponder, see Figure 5. One of the most widespread labels

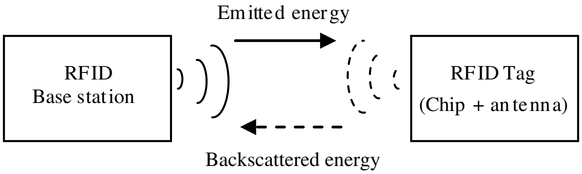

Figure 5. RFID principle.

at the present time is the passive tag which does not have its own feeding circuit. A passive tag is made up of an antenna and an integrated circuit called chip. There are two types of "RFID link" between the base station and the tag: i) inductive coupling (near-field) based on mutual induction for proximity identification that often need no battery for the tag and ii) radiation (far field) needing a Tx/Rx system and so a battery assisted tag.

The environment influence is to study in the case of non-proximity (ii) radiation Tx/RX RFID systems. The narrowband traditional RFID operates in wide areas where propagation channel is not sensitive to selective fading or other destructives effects. This type of RFID employs directive narrowband antennas and is used for "RF pointing" identification and not in logistic mass identification. In a multi-paths environment, traditional radiating RFID is not able to recover information due to the fading effect on the continuous wave.

As mentioned in previous part UWB provides theoretical immunity against multi-paths. Using UWB for RFID could be a benefit in a considered scenario. This is the idea of the project RUWBIS.

2.2. Ruwbis

RUWBIS is the concatenation of Radio Frequency UWB Identification in Sensors Networks. Also the title is very ambitious; the first step is to consider the use of UWB transmission for RFID applications. RUWBIS is applicable in scenario where multi-paths fading effects are the major penalty. Targeted application is the metallic containers identification (and possible localisation in a second step) on the boat where the traceability is lost due to the severe multi-paths environment. The project is to provide a cheap Tx/Rx system on each container that can communicate with others ones and so recovering the composition of the overall merchandise. In fact this is an important logistic problem because containers location are randomised to avoid "selective stealing" in harbours.

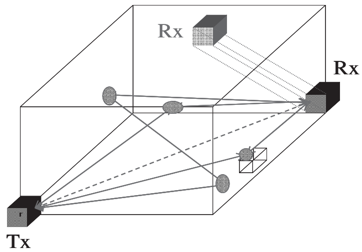

Figure 6. RFID-UWB application case.

Figure 6 illustrates the problem of non visibility between two containers inside the cargo boat and the variation of the channel response if the location is different for one of the two. While reflections are metallic, the multi-paths effect is highly present in this environment. RUWBIS project actual considerations are to build a dedicated UWB antenna for an RFID application. The UWB frequency band we interested first is the European standard 6–8.5 GHz.

3. DESIGN CONSIDERATION FOR THE ANTENNA

The design of the UWB antenna is oriented in printed small one for size and cost considerations. Designing an UWB antenna for a system implies to consider all electrical variations of PA and LNA circuit in frequency and also antennas impedances and spatial distortions that can occurs due to Tx/Rx directions. For simplicity, it is well suited to consider the same antenna for the Tx and the Rx part. Figure 7 summarises the designs constraints for the UWB Tx/Rx antenna.

We will now review UWB design principles necessary for our antenna. History begins with the work of Maxwell followed by Bose, Marconi, Amstrong and Carter with biconical 3D antennas. It goes on with horns and spherical fat structures with interesting wideband properties (Lindenbald, Schelkunoff, Friis, Kings and Kraus). In 1940, arguing that the stored reactive energy is reduced in bulbous antenna due to smaller current concentration in thick structures, Kings claims that “fatter is better” for the design of such antennas. Then, a lot of work has been done on volumetric curve based or tapered antenna (Schekulnoff, Friis, Marié and Stöhr). A great contribution, concerning the frequency independence of some structures (based only on angles), has been added by Rumsey [12]. This was the introduction of spiral and log-periodic antennas, although the latter are dispersive due to phase centre translation in frequency. Nowadays, modern UWB antennas

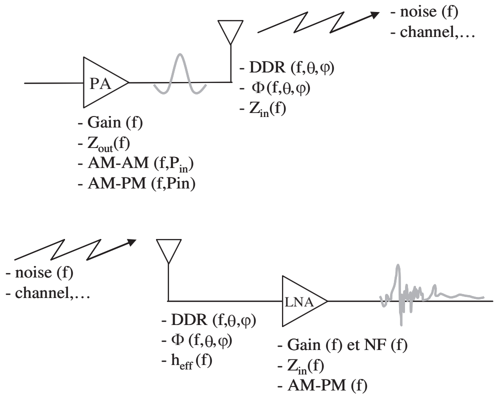

Figure 7. Schematic of the design considerations.

have to account for several considerations: matching properties (which leads to tapered profiles), minimum reactive power and, hence, resonance (which leads to thick or bulbous structures), low cost and small size (which leads to printed antennas). Several technologies, already proposed for lower frequency band applications [1, 2], can be used to realise wideband antennas. Interesting states of the art about the latter are given in [1, 5, 8, 10]. The diversity of proposed solutions is very important. The most important constraint is to build a non-resonant structure, which generally implies wide bent surfaces of conductor printed on substrates [15]. Travelling wave structures are also preferred because they allow avoiding geometric resonances. This is due to the success of the Vivaldi antenna [8] despite its directional radiation pattern.

Considering practical realisation requirements (size and cost), the printed antenna is very popular for UWB. The geometry is first designed for a wide radiation pattern and, then, optimized for frequency matching. References [5, 6] present slot antennas and monopoles that are matched in a second step by a modification of the geometric parameters. It seems that thick printed structures offer the wideband behaviour necessary for UWB in a first step, bent shapes being chosen to radiate with large beam-width. The second step is to consider both matching and dispersion [17, 18]. Lots of improvements were proposed in order to adapt the UWB antenna to the transmission system constraint [19, 20]. In [10], the author suggests to take care about the free space attenuation applied in a wideband signal transmission. In frequency we have a $1/f^2$ transfer function that distorted the amplitude of the spectrum. One solution is to combine a constant gain antenna with a constant aperture antenna. This possibility enables a theoretical cancellation of the $1/f^2$ but differentiates the Tx and Rx antenna. Another interesting possibility based on the constraint that the antenna is the same for Tx and Rx is reported in Figure 8.

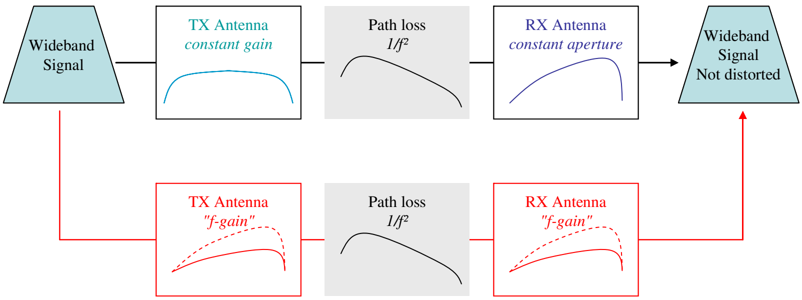

Figure 8. Combination of antenna types to cancel the $1/f^2$.

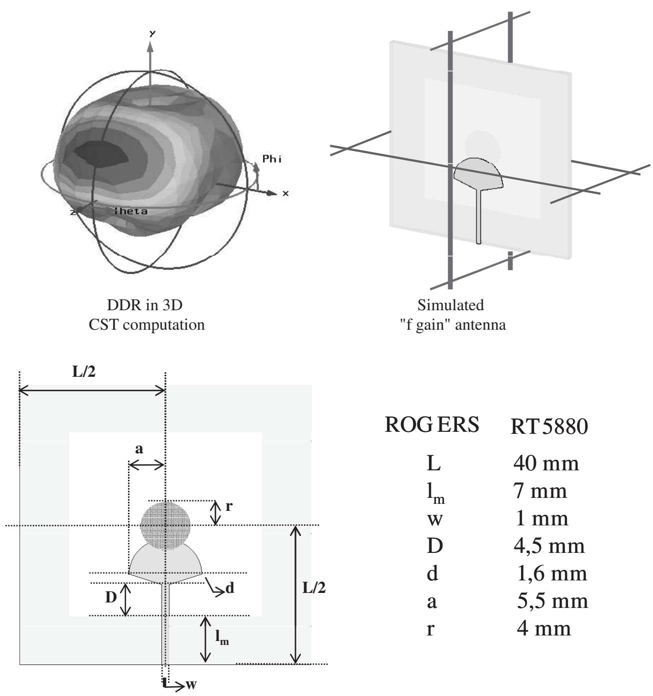

Figure 9. Simulated antenna, geometry and its radiation pattern (7 GHz).

This solution is to build an antenna neither constant aperture nor constant gain but with a "f-gain" frequency dependence. If we use the same antenna at both Tx and Rx, the $1/f^2$ factor is cancelled as well. This enables the communication system to use only one antenna with a switch/duplexer. Applying the consideration developed above, we focused on a modified taper with bending of the edge to avoid a sharpened peak, source of resonance. The ground plane was opened to enable a bi-directional radiation pattern and a disc is added to wide the 3-dB aperture. The antenna area is about $4 \times 4\,\text{cm}^2$. This antenna, its geometry and 3D radiation pattern at 7 GHz are reported on Figure 9. The ground plane optimisation is the one of the major fagtor for setting the gain dependency (targeted in $1/f$). As a matter of fact, the importance of the ground plane made the type of the antenna evolving between a constant aperture type or a constant gain type.

The degrees of freedom for optimisation of ours structure are high if we can modify the width and height of the feed line, the angle of the taper and the position of the added disc. We first considered the matching of the antenna to reach $-12\,\text{dB}$ in simulation for the return loss, see Figure 10. The return loss is evaluated by the $|S_{11}|$ as the antenna is supposed to radiate (no coupling effect in the near-field).

We also simulated the transfer function between two identical antennas in the best line of sight case, see Figure 11. The "Tx wideband pulse" is the Gaussian pulse computed by CST (time EM domain simulation).

In time domain simulation, pulses are seen to be distorted non-significantly, resulting in fidelity factors of 92% and 96% (maximum inter-correlation factor). These results are showing a good advantage

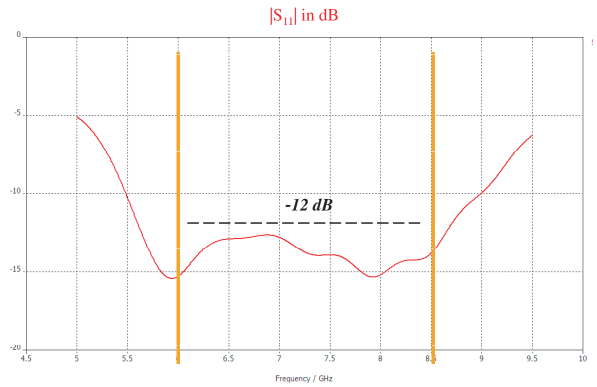

Figure 10. Return loss simulation (S_{11} without near-field effect).

of these antennas when using them in an impulse based transmission system, with a correlation receiver (impulse radio UWB scenario). This is a good appreciation for the f gain wanted property of our antenna.

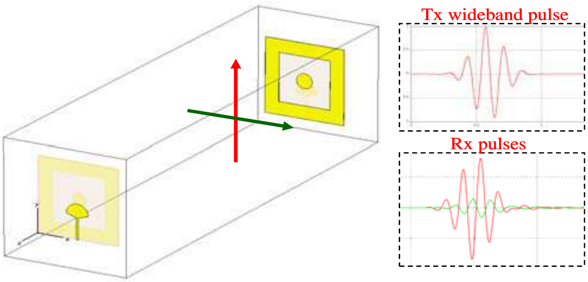

Figure 11. Simulation of two antennas in lign of sight. Rx pulses are reported for co-(red) and cross (green) polarization.

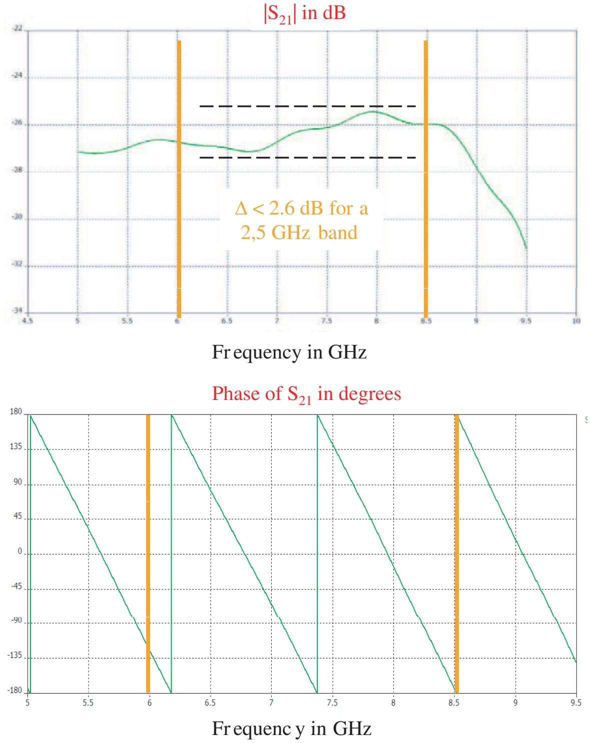

Figure 12. S_{21} energy transfer coefficient in lign of sight.

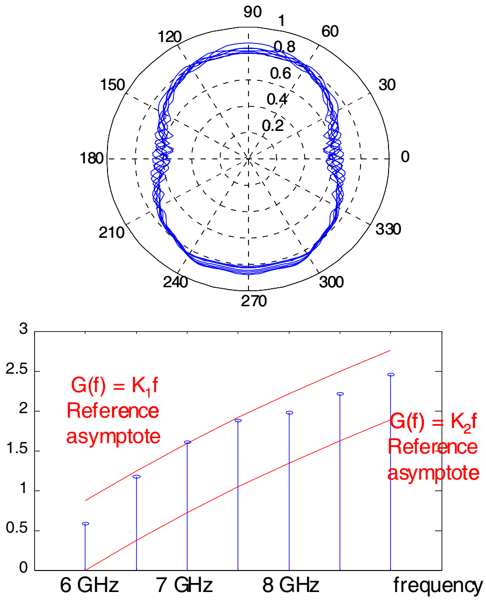

Figure 13. Directivity in the horizontal plane and main gain variation in frequency in the 90° direction (correspond to 0°, line of sight)

The S_{21} parameter confirms this property by providing less than 2.6 dB variation on the 6 to 8.5 GHz bandwidth considered, see Figure 12. Figure 12 also illustrate the low phase distortion (linear) profile.

Plotting of the mean gain on a localised solid angle tends to demonstrate the f-gain property of the radiation pattern. In the context of an UWB transmission, this antenna seems to be interestingly suited. Figure 13 illustrates the f-gain variation of the antenna for the main direction considered, with a shift of 90°, which is in the horizontal plane at 90° (see the 2D projection of Figure 13). This direction corresponds to the 0° of the 3D DDR in Figure 9. Adding reference asymptotes K_1 and K_2 helps to consider qualitatively the linear variation in function of the frequency.

4. PERSPECTIVES

The antenna presented can be suitable for the UWB RFID project RUWBIS. The "F-gain" property enables to use the same antenna at Tx and Rx and to cancel theoretically the $1/f^2$ free space propagation effect. As the antenna is supposed to be used in multi-paths propagation channel, the transmission coefficient is the main point to optimise. Our perspectives are to build and measure the antenna characteristics thanks to the spherical measures platform SESAME at Supélec that provides 3-D radiation pattern.

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