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A Telematics System using In-Vehicle UWB Communications

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1. Introduction

Owing to the rapid evolution in wireless and cellular communications usage, and the resulting huge demand, new communications technologies are needed to support the cost effective growth of mobile telephony and the tremendous increase in Internet data traffic in new applications such as Telematics. New wireless communication technologies are therefore needed for the delivery of enhanced applications, for example telematics services to motorway users. This is targeted towards transforming wireless techniques to operate on: fast moving vehicles with high impairments encountered at high data rates; small cellular cells which are key to high data rate operation; and, more frequent cell handovers dictated by speed and small cell size. This scenario can make use of data from inductive loops for traffic (vehicular and data) monitoring, prediction, grooming and control.

Central base stations driving distributed antenna units will facilitate this new bandwidth provision and Radio-over-Fibre (RoF) is a technology proposed to achieve transparent data distribution. The replacement of coaxial cables with optical fibres is desirable. Fibre transmission offers sufficient bandwidth with reduced loss over long distances and decreased electromagnetic interference. Low loss Single Mode Fibre (SMF) is commonly deployed outdoors while Multimode Fibre (MMF), with higher losses, is often pre-installed in buildings. Unfortunately MMF is not of a quality that lends itself to broadband Radio-over-Fibre.

Two data transmission approaches meet the data rate requirements criteria, (i) high performance Worldwide Interoperability for Microwave Access (WiMAX) approaches that use an unlicensed spectrum band (5.470-5.725 GHz) for the motorway-to-vehicle communication and (ii) the Ultra Wide Band (UWB) communications standard for communication exchange from the vehicle to the in-vehicle applications. UWB in the unlicensed lower band (3.168-4.752 GHz) offers multipath immunity.

WiMAX technology, based on the IEEE 802.16m standard, is of great interest to Intelligent Transport Systems (ITS) due to the expected need for the delivery of peak rates of up to 1 Gbit/s at fixed speeds and 100Mbit/s to mobile users over micro-cells. Theoretically, antennas are reciprocal, which means they are able to transmit and receive electromagnetic waves with similar properties. Antennas play a key role in wireless communications; the antenna performance is crucial to efficient electromagnetic propagation. Cost-effective while

efficient antenna units have been assessed (Garcia et al., 2008) for Intelligent Transport Systems (ITS) in a highway scenario. The antennas designed and tested served the WiMAX standard over full-duplex bi-directional optical links.

UWB technology is of global interest in modern communication systems due to its potential to deliver high speed data rate transmissions with excellent immunity to multipath interference at low power consumption, low cost (Elmirghani et al., 2006) and simple hardware configuration. The deployment of UWB inside vehicles can provide mobility and connectivity to a host of passenger devices while significantly reducing the costs associated with wiring. Vehicle chasses may contain large steel plates and antennas over ground planes are favoured for ceiling mounts (Garcia et al., 2009).

Key potential applications include advanced ultra-high speed cellular communications to vehicles, emergency services, ramp entry and variable speed control, and roadside assistance notification. The systems can also provide live traffic information and triple play services on in-car traffic information terminals or bespoke terminals.

In this work the following topics are discussed. First, a Telematics system, based on a published patent GB2436909 is presented. In essence, WiMAX is used here in highways to provide communication services to moving vehicles incorporating an in-vehicle UWB network of 480 Mbps. Second, a detailed motorway-to-vehicle wireless communication system using recent developments in RoF systems is introduced. This utilizes centralized base stations driving a host of antenna units along a highway through Single Mode Fibre (SMF). Third, a UWB wireless propagation analysis in an in-vehicle scenario is analysed. The analysis is performed in the lower unlicensed band (3.168-4.752 GHz) of the allocated Federal Communications Commission (FCC) spectrum that has an assigned band from 3.1 to 10.6 GHz (FCC, 2002). Finally, the design of a UWB antenna for an in-vehicle application is described.

2. The telematics system

An attractive nature of a Telematics system is its capability to revolutionise transport using the latest wireless communication technologies including computer networking and communications infrastructure for delivering enhanced services to motorway users, Fig. 1. This provides the users with live traffic information and multi-play services on in-car traffic information terminals or bespoke systems.

The introduced Telematics system utilises RoF as a technology to achieve the modulated carrier distribution. RoF brings the opportunity to simplify typical Base Station (BS) deployments by making them part of the system backbone while being able to transmit over long distances. In addition, among the advantages of using optical fibres are: bandwidth, security, lack of interference and an extreme reduction in maintenance costs that is achieved by centralisation.

The RoF term is used when light is modulated using a radio frequency (RF) information carrying signal and is transmitted over optical fibre. The electromagnetic spectrum that can in theory be used to modulate the light is typically of several GHz bandwidth for the semiconductor lasers and several MHz for light emitting diodes (LEDs). Microwaves are commonly used due to their reasonable coverage, high data rates and capacity using moderate cells with low frequency reuse.

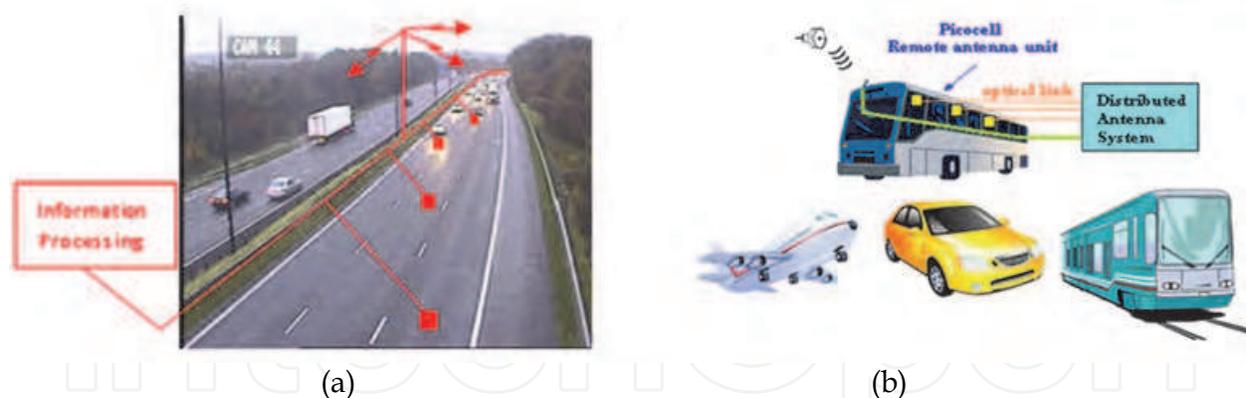


Fig. 1. A highway communication infrastructure (a) and an in-vehicle femtocell (b)

High capacity, Quality of Service (QoS) and data transfer communications are in demand. Methods to meet these demands include techniques that range from the use of smaller radius cells and the use of sectorisation, to the most recent use of multiple antennas in spatial and/or frequency diversity configurations. For these systems it is desirable to have easy integration and small package antenna units. Multiple Input Multiple Output (MIMO) Antennas composed of three 120° sectors exploiting frequency diversity gain have been reported in (Garcia et al., 2008). In the same way, wireless systems devices for the vehicle to road intercommunication are usually of small profile. A tri-sector configuration antenna to meet this demand has been reported in (Garcia et al., 2010).

Low cost RoF distribution deployed in-vehicles is of great interest, Fig. 1b. Unlike coaxial, fibre lines are capable of providing electromagnetic interference free transmissions over the distance. Centralisation of transceivers to a system backbone might complement with lower engineering costs, both in deployment and maintenance.

Antennas play a key role in wireless transceivers as they are the last step to radiating energy into the space. Miniature antennas are required for the in-vehicle application; the prototypes will have to ensure a good system performance and be platform tolerant.

In the next section, the motorway-to-vehicle wireless communication system, the in-vehicle wireless communication system including a UWB in-car wireless channel analysis, and finally the design of an UWB antenna for in-vehicle applications are introduced.

2.1 Motorway-to-vehicle communication system

In Telematics applications, an autonomous data collection and processing systems can exploit recent advances in UWB, Worldwide Interoperability for Microwave Access (WiMAX) and radio fibre technologies to provide data and multimedia services for vehicles along sophisticated highways (Kerner et al., 2005). Traffic prediction systems are receiving increased attention and are being evaluated and adopted in a variety of contexts (Gunter & Grosmann, 2005). Communication between vehicles and vehicle to infrastructure has also been explored using a range of technologies (Lee & Williams, 2000). Refined highways hold sophisticated telematics infrastructure that includes fibre, inductive loops buried, routers, switches and digital video cameras with number plate recognition systems among others.

An example of a highway sensing and communication infrastructure is depicted in Fig. 1.

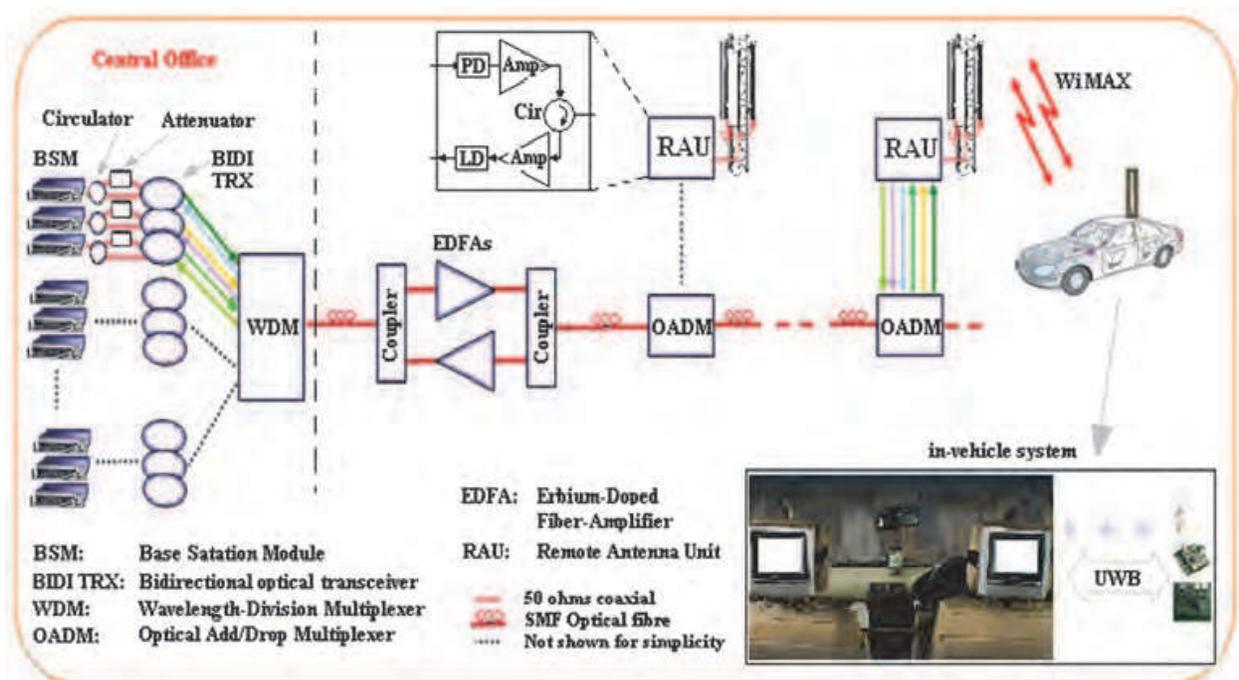


Fig. 2. The Telematics system architecture

The motorway-to-vehicle wireless communication system is realised using various components of the system architecture in Fig. 2, the RoF architecture.

In essence, the system architecture comprises a (virtual) central office (CO) which consists of base station modules (BSM), circulators, attenuators, bidirectional optical transceivers (BIDI TRX) and wavelength division multiplexers (WDM). Erbium-doped fibre amplifiers (EDFAs) provide bi-directional amplification to compensate for losses due to long runs of the single mode fibre (SMF). Optical add drop multiplexers (OADM) provide interfaces between the fibre and the remote antenna units (RAUs).

The functional view of the RoF system is now detailed. The system employs a high performance unlicensed 5.470-5.725 GHz WiMAX band directly modulated over a bi-directional SMF link using remote units composed of three sector antennas (Garcia et al., 2008) which aims to achieve a better capacity and coverage performance over micro-cells, and is intended to support around 100 Mbps. The radio frequency (RF) signals are directly modulated using a distributed feedback laser (DFL) contained in the BIDI TRX. The signal generated is carried over the downlink SMF to a remote RAU site which converts this optical signal to an RF signal by positive-intrinsic-negative photodiode with a transimpedance amplifier (PIN-TIA) receiver with high sensitivity. For uplink transmission, the wireless signal received from an RAU is amplified, converted into an optical form by a DFB laser (chosen as an ideal device for SMF and long haul communications), and transported uplink by the SMF to the CO where another PIN-TIA receiver in BIDI TRX demodulates the optical signal into the RF.

2.2 In-vehicle communication system

UWB technology has gained huge interest globally due to its potential to deliver high data rate and spatial capacity, with multipath immunity (Das et al., 2006; Way, 1989) and low power, low cost design. The deployment of this wireless technology in vehicles will provide

mobility and connectivity to a host of passenger devices while reducing significantly the costs associated with wiring.

In addition, large vehicles can benefit from the use of low cost optical fibre communications. A RoF system can be used as part of a distributed antenna system (DAS), (with centralised control) which supports the deployment of femtocellular access networks at 480Mbps within airplanes, buses, coaches, cars, lorries, trains, trams and other transport vehicles. Such a system can assist in the minimisation of radio frequency (RF) inference when compared to coaxial cable links, simplifies the infrastructure and reduces engineering cost. A high-level block diagram for the in-car system is depicted in Fig. 3.

Next, a study of a UWB system over RoF in an in-vehicle scenario is described in Section 2.2.1. Experimental results of the radio propagation within the car in a realistic environment validate the system and are described in Section 2.2.2.

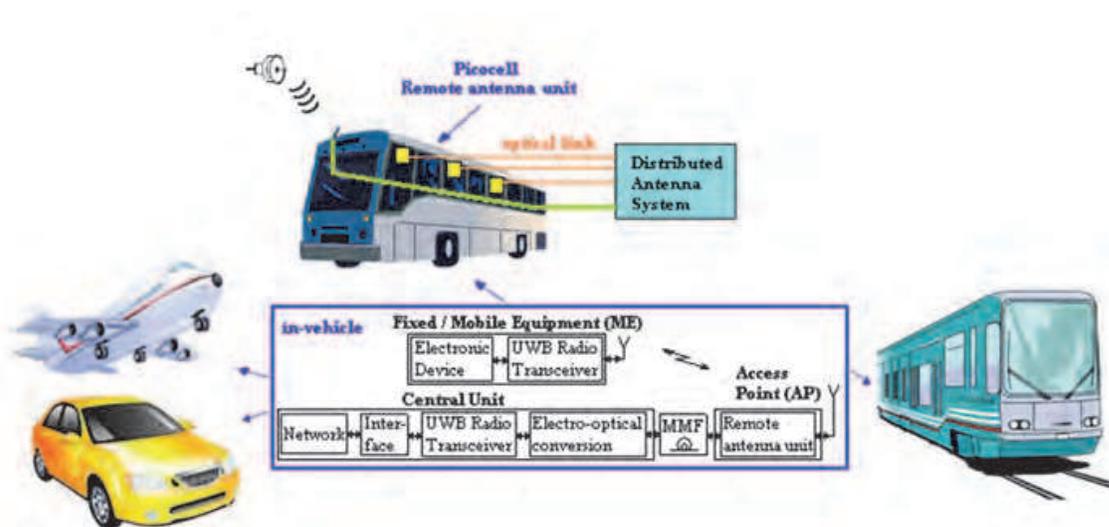


Fig. 3. The in-vehicle distributed antenna system

2.2.1 UWB RoF transmission in-vehicle

A feasibility study of an IEEE 802.15.3a UWB system based on Multi-Band Orthogonal Frequency Division Multiplexing (MB-OFDM) transmitted over RoF inside a vehicle is described. The in-vehicle system set-up includes a DV9110 Development Kit (DVK) from Wisair Ltd and a Renault Extra Van that was used as a base for the experiments. Two UWB transceivers were placed in the vehicle; one was used as an Access Point (AP) and the other as fixed/Mobile Equipment (ME). Each transceiver had an integrated monopole antenna of 2 dBi gain. The transceiver emits a short pulse of output power $80\mu\text{W}$ (Power Spectral Density PSD of -42 dBm/MHz max) containing the WiMedia/MBOA Group 1 sub-band (3.168–4.752 GHz) and using a modulated signal MB-OFDM quadrature phase shift keying (QPSK) at a varying physical data rate between 53.3 Mbps and 480 Mbps.

The in-vehicle system design is depicted in Fig. 4 which shows the UWB RoF architecture.

A UWB radio at the central unit was directly modulated over an optical signal using a Vertical Cavity Surface Emitting Laser (VCSEL) and then distributed over a MultiMode Fibre (MMF) to a remote antenna unit where the transmitted modulated optical signal was demodulated back to radio using a PhotoDetector (PD) and then propagated by the antenna

into the space. A multimode fibre network was used for the UWB radio distribution due to the large bandwidth, low loss and the ability of centralisation at a relatively low cost (Garcia et al., 2005).

Results using Agilent ADS software demonstrate the feasibility of the RoF system. A waveform generator was used to transmit/receive through the system. It used a signal spectrum at 1 MHz narrow resolution bandwidth (RBW) filter within a Federal Communications Commission (FCC) mask. The transmitted and received signals are depicted in Fig. 5. They overlapped and showed good agreement.

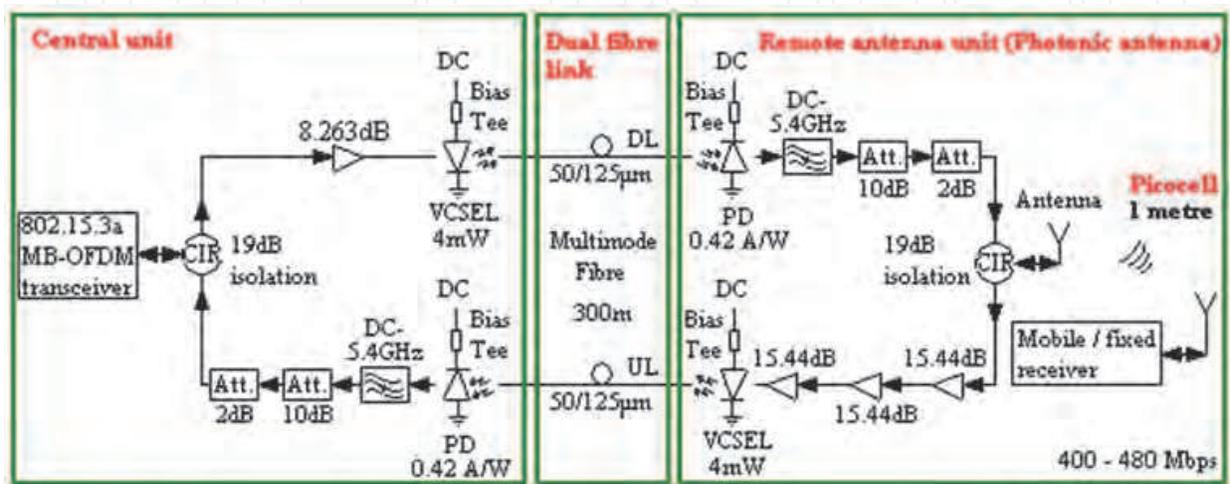


Fig. 4. The complete UWB RoF femtocell

The measured output power was -41.3dBm ; this agreed with the maximum UWB Effective Isotropic Radiated Power (EIRP) allowance and the receiver sensitivity was -79.55dBm . The system Transmit (Tx) power budget was measured near 0dBm after compensating for a power penalty (attributed to optical and RF devices losses) of 8.26dB .

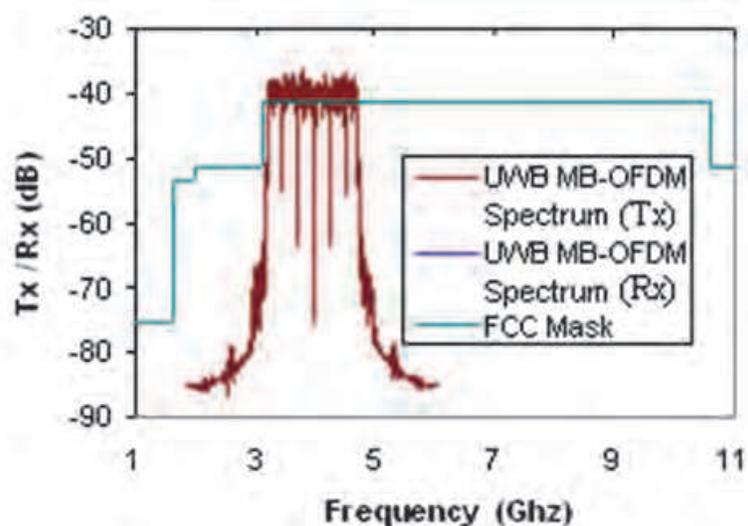


Fig. 5. Transmitted/received UWB MB-OFDM signal

A Bit Error Rate (BER) test evaluated the performance of the system. The transmitter produced OFDM UWB symbols that a receiver was capable of analysing; with/without

multipath over an in-door channel. The resulting test for the down link is depicted in Fig. 6, where an irrelevant BER difference between a referenced transmitter and the UWB RoF full-duplex system is observed.

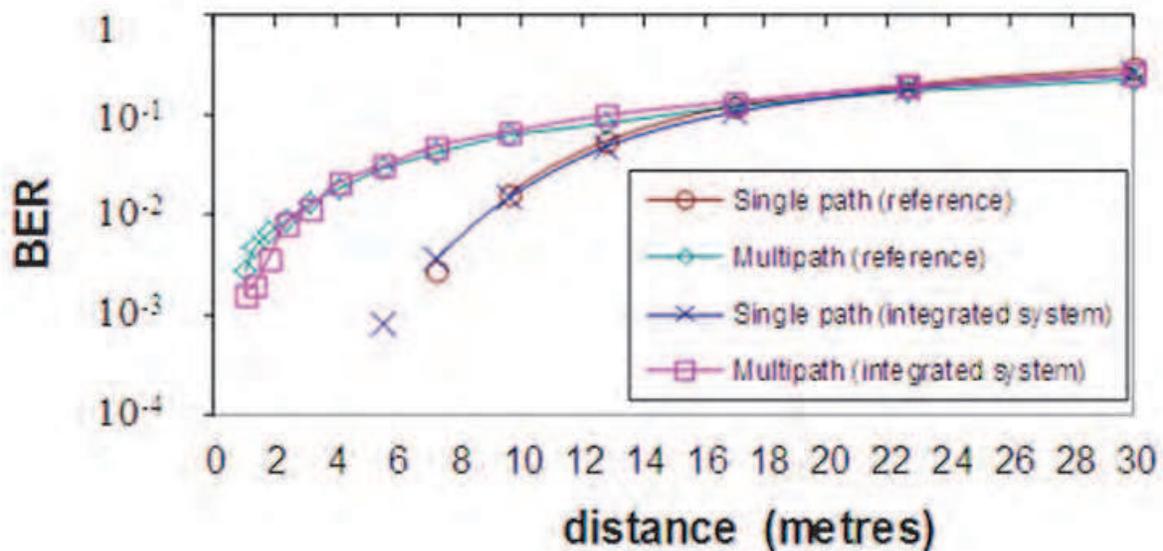


Fig. 6. The system Bit Error Rate (BER)

The results show the feasibility of the RoF system; this would allow extending UWB radio signals over hundreds of meters distances, well enough for in-vehicle applications.

2.2.2 UWB in-car wireless propagation

Based on the MultiBand technique, the multiband UWB (MB-UWB) splits the spectrum into sub-bands and uses conventional narrow band techniques, such as Orthogonal Frequency-Division Multiplexing (OFDM), to transmit the information in each sub-band (Elmirghani et al., 2006).

In this section, the propagation of a MB-UWB wireless system is studied within the in-car environment.

Using the same wireless set-up as in Section 2.2.1 without the optical fibre distribution, each transceiver was connected to a laptop for control and datalogging.

The cell size which is limited by the in-vehicle dimension was 0.9 metres in radius. The access point was set in the middle of the ceiling of the car as the preferred location in vehicles (Garcia et al., 2009); this ensures good power distribution and minimises field exposure to occupants.

The maximum channel path loss (where the antennas are considered as part of the channel) was measured at 33.53dB at 3.8GHz and the antenna mismatch or de-tuning is best at about 4cm away from the metallic in-car ceiling. A -91.30dBm noise floor was observed and an Access Point (AP) UWB Development Kit (DVK) power of -43.42dBm (1MHz resolution bandwidth, RBW) was employed.

Several channel analysis have been reported in (Garcia et al., 2009), this includes a rich multipath in this application, high reflections, path delay changes in open and closed environments with a possible Doppler dispersion, and the Inter-Symbol Interference (ISI) for moving vehicles. A Bit Error Rate (BER) measurement was made to validate the system.

The BER was set up having the Access Point (AP) and Mobile Equipment (ME) intercommunicating reciprocally with each other. To predict the maximum achievable data rate at the allowed BER, packets of certain known length were sent over the in-car channel from the AP to the ME when the vehicle was stationary and then at different vehicle velocities using the driver closed environment scenario. The received data is analysed and recorded as BER in Figs. 7a and 7b respectively. Throughputs (capacity) for the same set up are shown in Figs. 8a and 8b. Although there are fluctuations in the BER performance, an average of 2.5×10^{-4} is obtained while the vehicle is stationary and BERs up to 3.2×10^{-2} are measured at a speed of 120km/h.

The vehicle in motion (system closed) affects the BER results. The ISI mainly arising from high reflections within the small car metallic chamber is conjectured to be aggravated by the antenna instability due to the mobile vehicle vibration and interaction through the restricted window area. This is translated into a collection of received variations in the amplitudes and phases of differently delayed waves caused by further fading and multipath. The interference of direct path and the reflected waves results in higher BERs.

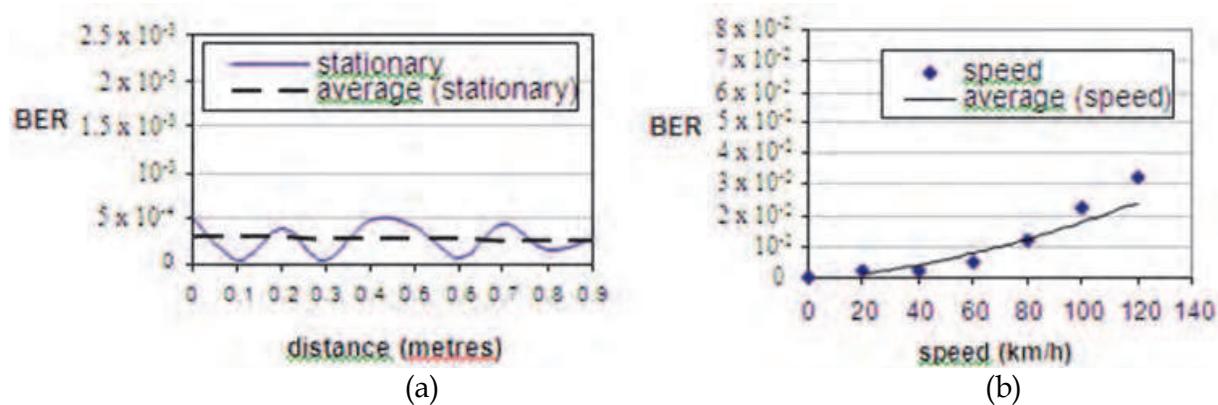


Fig. 7. BER as a function of distance (a) and BER as a function of mobility (b).

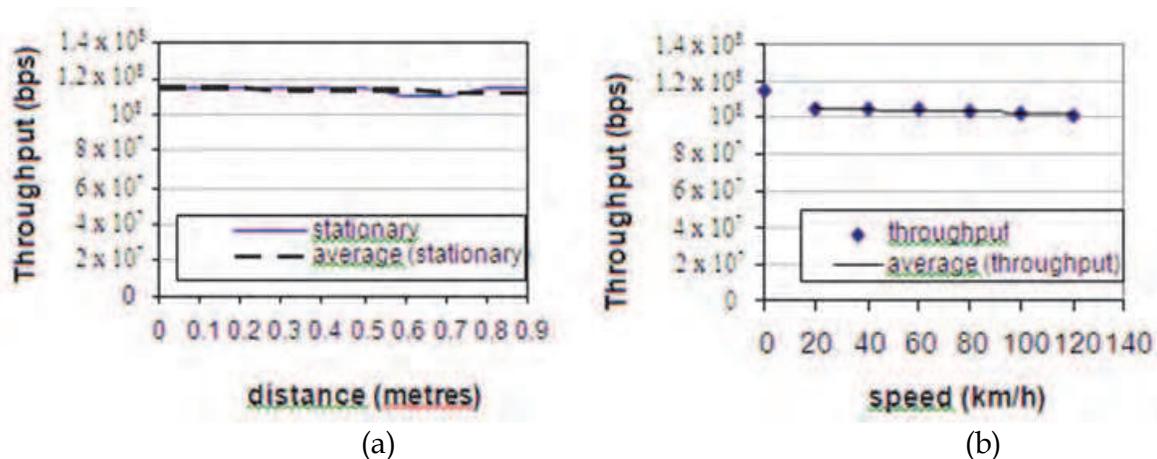


Fig. 8. Capacity vs. distance (a) and Capacity vs. mobility (b).

An average of 115Mbps throughput is measured when stationary and up to 102Mbps at a speed of 120km/h. The vehicle in motion affects the BER results due to the antenna instability that is created while in motion. There was high multipath in-vehicle, and this, in

the moving vehicle, resulted in ISI and caused higher BER measured at higher speeds. In the same way, a lower data rate was achieved in motion.

3. UWB Antenna for in-vehicle applications

Planar Inverted-F Antennas (PIFAs) are well suited for integration inside vehicles. Their chasses may contain large steel plates and antennas over ground planes are favoured for ceiling mounts (Garcia et al., 2009). A UWB PIFA incorporating two shorting posts with coupling gaps is presented. The antenna operates at the lower UWB band (3.168-4.752 GHz) with a 3.57:1 VSWR and has a tailored impedance bandwidth and roll-off comparable to a standard frontend Band Pass Filter (BPF). To bring down unit cost, there has been a drive to simplify the hardware of UWB systems (Mohammad & Ismail 2008) and hardware could be further reduced by the adoption of the UWB PIFA proposed here, because the commonly deployed front-end BPFs would not be required. For the antenna to be implemented in car, the antenna performance was verified when in close proximity to a large conducting plate. Additionally, the elimination of the BPF with its associated insertion loss can offer power savings from the vehicle's battery especially when stationary.

Fig. 9 depicts the geometry of the UWB PIFA antenna. It consists of two planes, an etched upper layer (A) and a bottom ground (B) separated by an air substrate ($\epsilon_r \approx 1$).

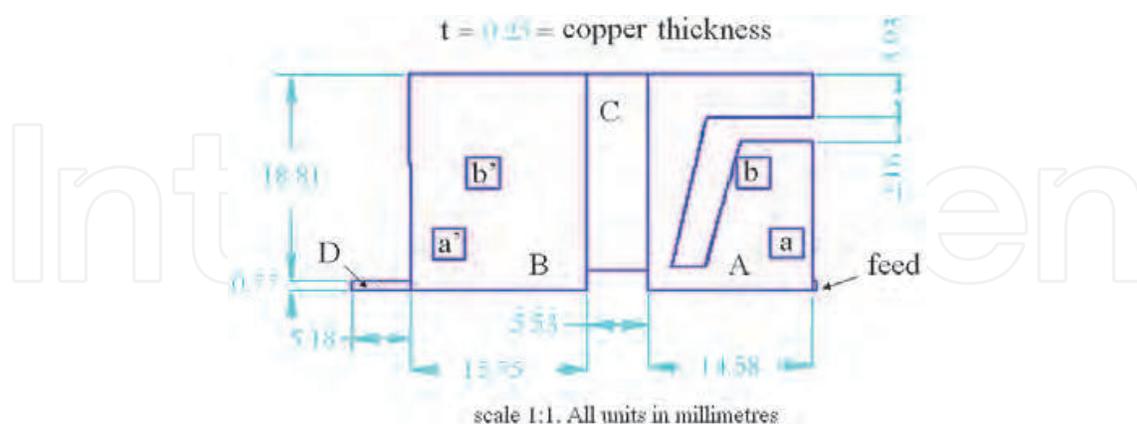
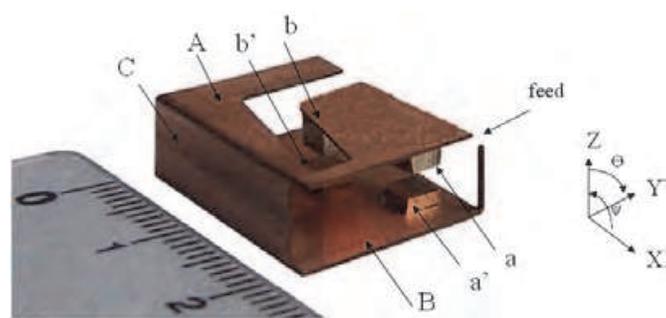


Fig. 9. Geometry of the UWB PIFA

The A and B planes are capacitively coupled via the two pairs of pins (a & a' and b & b'). The dimensions of both posts a & b are $2.9 \times 2.9 \times 2.9 \text{ mm}^3$ while posts a' & b' are $2.9 \times 2.9 \times 1.45 \text{ mm}^3$. Coupling between planes A and B is achieved across the gaps in the posts.

The antenna is fed at the upper plane A using the inner core (0.51 mm) of a 50Ω rigid coax cable with a total diameter of 2.16mm and 62mm length. The outer shield of the cable is

attached to a grounding strip, D, electrically connected to B. The total volume of the antenna is $19.58 \times 15.75 \times 5.53 \text{ mm}^3$. The maximum dimension is smaller than 0.21λ at the lowest frequency of operation.

A simulated parametric study of the capacitive gap is reported in (Garcia et al., 2010b) where decreasing the gap between a and a' (or b and b') tended to improve the band-notch depth and impedance roll-off. Therefore, adjusting the gap capacitance of the electrically unconnected shorting posts allows a BPF like characteristic to be defined. An optimum length value of $a = b = 2.9 \text{ mm}$ and, $a' = b' = 1.45 \text{ mm}$ was found to give a band-notch at 5.5GHz, a return loss (RL) of -5dB, roll-off of 0.18 and 0.03 dB/MHz and a -5dB S11 fractional bandwidth of 40%. The optimal value of the gap corresponds to 1.18mm.

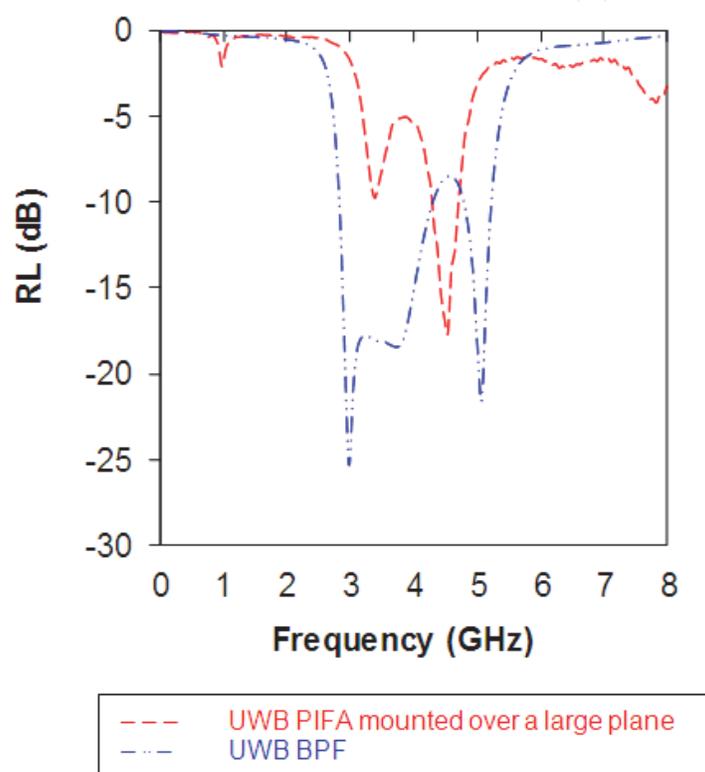


Fig. 10. The UWB PIFA antenna

The reflection coefficient of the UWB antenna is shown in Fig. 10 compared to a standard frontend BPF (RFlambda, n.d.). Compared to the commercially available BPF (2441MHz pass-band rejection and 2dB insertion loss; roll-offs of 0.050dB/MHz and 0.031dB/MHz for the lower and upper bands respectively), the UWB antenna has a lower 1108MHz pass-band rejection and improves the roll-offs to 0.024dB/MHz and 0.030dB/MHz.

An antenna having a VSWR of 3.57 (5dB RL) can be calculated to present an equivalent mismatch loss of 1.65dB (Kraus & Marhefka, 2001). Therefore, if the BPF and its associated mismatch loss of 2dB was removed, then there will still be an overall reduction in loss of 0.8dB.

The measured 5dB return loss bandwidth of the proposed PIFA is 42.15% for the 3.168-4.860 GHz FCC UWB. To investigate the effect of attaching the antenna to a large conducting plate in a car chassis, a larger ground plane of dimensions $510 \times 800 \times 0.75 \text{ mm}^3$ was placed $\frac{1}{4}$ wavelength below the PIFA. Fig. 10 shows the S11 response.

The far-field radiation patterns of the antenna including the large plane in polar form (measured at 4.752 GHz) are depicted in Fig. 11. The patterns are essentially directional, presenting a 120° half power beam-width (HPBW) and 1.53/1 front-to-back ratio in the H-azimuth plane and similar value for the E-elevation. A gain of 7.11dBi was measured with the E plane present.

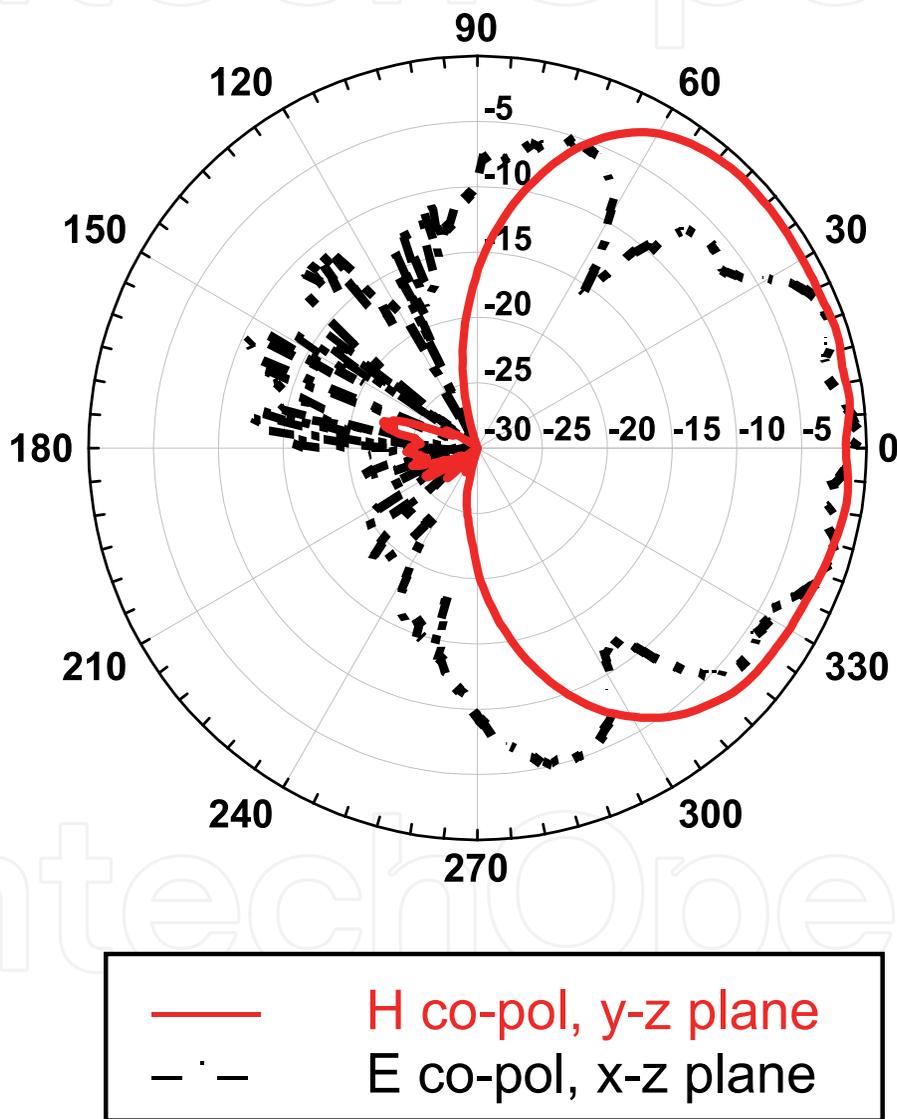


Fig. 11. Radiation patterns of the antenna including the large ground plane

4. Conclusion

This chapter has introduced new techniques and methodologies to support the cost effective growth of mobile telephony and the tremendous increase in Internet data traffic in Telematics for the delivery of enhanced services to highways users.

A Telematics system has been described based on a high performance WiMAX spectrum using an unlicensed band (5.470-5.725 GHz) and recent developments in RoF systems as a base for the delivery of wireless communications to motorway-to-vehicle applications. This approach results in a relative low cost deployment and maintenance, extends the radio over long distances and delivers peak rates of at least 1 Gbit/s to fixed users and 100Mbit/s to mobile users over micro-cells.

Cost-effective while efficient narrow band tri-sector antenna units have been assessed for Intelligent Transport Systems (ITS) in the presented highway scenario. The antennas served the WiMAX standard over full-duplex bi-directional optical links (Garcia et al., 2008). These antennas seem to be reasonably proficient for use in ITS due to their potential higher gains and reduced spatial limitations. The low VSWR performance achieved by the use of these narrow band antennas can improve the system link budget, which is translated into a relatively higher coverage/throughput.

The Robustness to multipath interference offered by the unlicensed lower band (3.168-4.752 GHz) UWB communication is to be exploited for in-vehicle communications. Within this work a promising low cost RoF link to extend the UWB radio over relatively long distances (i.e.: trains, trams and airplanes) has been introduced. The transmission was assessed using a relatively inexpensive multimode RoF link. The transmission network was capable of providing high data rates of 400-480Mbps at picocells of about a metre radius with inconsiderable SNR degradation performance over fibre links of several hundred of meters.

In addition, a wireless propagation of UWB radio inside a vehicle is analysed. The analysis of the UWB radio channel in-vehicles demonstrates that UWB is a very suitable and promising technology for transmission networks able to provide high data rates of 400Mbps within cars. Path loss was not of a significant level due to the short ranges that are encountered within cars. However, the main attenuation might perhaps be due to shadowing effects. High data rates were achieved in closed environment scenarios (Garcia et al., 2009). As many new cars include air conditioning, it is not unreasonable to expect the environment to be closed for the majority of the time.

A UWB antenna design example for an in-vehicle application has been introduced. The results indicate that the presented antenna works satisfactorily in the unlicensed UWB band and that the antenna element can be mounted on a large ground plane without degrading its performance. Owing to the low volume of the design it can be easily integrated inside vehicles in close proximity to the body.

5. Acknowledgment

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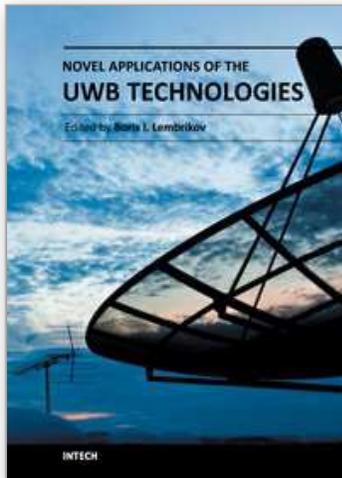
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Ultra wideband (UWB) communication systems are characterized by high data rates, low cost, multipath immunity, and low power transmission. In 2002, the Federal Communication Commission (FCC) legalized low power UWB emission between 3.1 GHz and 10.6 GHz for indoor communication devices stimulating rapid development of UWB technologies and applications. The proposed book *Novel Applications of the UWB Technologies* consists of 5 parts and 20 chapters concerning the general problems of UWB communication systems, and novel UWB applications in personal area networks (PANs), medicine, radars and localization systems. The book will be interesting for engineers and researchers occupied in the field of UWB technology.

How to reference

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