

Ultra-Wideband And Radar Co-Existence

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Abstract

This paper presents the results from a study into Ultra-Wideband (UWB) systems and Radar co-existence. An overview of UWB technology is presented and a series of models for UWB interference with Radar systems are developed. The models are backed up with experimental data and used to quantify the potential reduction in Radar performance that may occur with the predicted proliferation of UWB devices. Results are presented for typical scenarios and the mitigation options discussed.

Keywords: Ultra Wideband, UWB, Radar Interference

Introduction

In February 2002, the FCC gave approval for the limited use of Ultra Wideband (UWB) devices. This enables the re-use of existing spectrum at very low power levels for short-range communications and location applications. Although the FCC imposed restrictions on UWB occupancy of the GPS band, UWB systems will overlap some primary Radar bands and could cause Radar de-sensitisation due to an overall increase in noise level in the environment. It is likely that Europe and the rest of the world will follow by approving UWB in the next two years.

The primary aim of this study was to investigate how high densities of UWB transmitters in urban environments would affect the performance of Radar systems. The study has analysed the UWB signal structure and investigated how multiple UWB signals aggregate at a Radar receiver. Interference models have been developed and combined with measured propagation data and typical Radar parameters to quantify the reduction in Radar performance that may be expected with the predicted proliferation of UWB devices in the near future.

UWB Systems

UWB is unique as a radio technology in that it can be used as a communications technology, a Radar technology and as a range measurement and location technology. UWB radio technology uses extremely low transmit powers, spread over a wide bandwidth. The receiver integrates the power across the whole bandwidth to recover the signal from the noise.

An UWB system is defined as one in which the fractional bandwidth is equal to or greater than 0.20 or has a UWB bandwidth equal to or greater than 500 MHz, regardless of the fractional bandwidth. UWB bandwidth is defined as the frequency band bounded by the points that are 10 dB below the highest radiated emission, as based on the complete transmission system including the antenna. The upper boundary is designated f_H and the lower boundary is designated f_L . The fractional bandwidth equals $2(f_H - f_L) / (f_H + f_L)$.

The current regulatory environment for UWB would favour the use of the 3.1GHz to 10.6GHz band of frequencies. This is based upon the USA's FCC regulations for UWB [1].

The large bandwidth used, indirectly means that high bit rates are possible. However, these regulations impose extremely strict limits on the maximum transmitted power (EIRP -41.3dBm). Even accounting for the UWB receiver's ability to integrate the received signal power across the whole bandwidth, the maximum range of an UWB link at typical bit rates is likely to be in the tens of meters.

At the time of writing the IEEE have yet to agree upon a standard format for UWB transmissions (IEEE 802.15.3a), although two competing formats have been proposed. These are the Motorola-XtremeSpectrum led UWB proposal (using direct-sequence CDMA) and the Multiband OFDM Alliance (MBOA) proposal.

Roke Manor Research Ltd (RMR) has developed its own proprietary UWB solution that uses a form of CDMA.



Figure 1: RMR UWB Hardware

The technique used in our UWB testbed retains the capabilities of communications, Radar and range/position measurement.



Figure 2: RMR UWB Antennas

RMR has also developed an UWB antenna solution that offers an even 360-degree beam pattern with good gain and impedance

matching characteristics over the 3.1GHz to 10.6GHz range.

The anticipated mass use of UWB systems will be for home and office computing as a wireless replacement for USB2.0 operating at 480Mb/s. This will mean that whilst in homes that have PCs there may be many UWB devices, these peripheral connecting radio links are not likely to be continuously transmitting. We have assumed for our interference models that there will be an average of one active transmitter per household. With an average city density of 40 houses per hectare this gives a transmitter density of 0.004/m².

Interference Models

Analysis of the UWB signal structure has demonstrated that it is valid to assume that UWB signals sum as Gaussian white noise, [2], [3] if the condition $f_{PRF}/B > 5$ is met, where f_{PRF} is the composite Pulse Repetition Frequency (PRF) of all of the UWB transmitters under consideration and B is the victim Radar receiver bandwidth. With a typical victim Radar receiver bandwidth of up to a few tens of MHz and UWB pulse repetition rates for a single transmitter of 50MHz (average pulse spacing of 20ns) this condition is met for even small numbers of UWB transmitters.

Based upon this analysis, a series of models for UWB interference with Radar have been developed by studying the propagation of signals through an urban environment and aggregation of the signals at a Radar receiver.

Consider a ground-based or naval Radar receiver located a distance, RI , from the edge of a city. It is assumed that UWB transmitters are uniformly distributed throughout the city. UWB signals propagate from an area, dA , within the city to the victim Radar receiver at distance r . When propagating through the urban environment, the signals are attenuated as $1/r^\gamma$. When propagating through free-

space, the signals are attenuated as $1/r^2$.

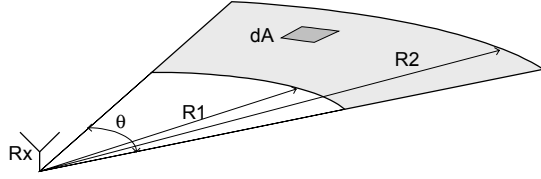


Figure 3: Ground Based Radar Interference Model

The UWB interference power density at the victim Radar receiver is given by

$$\rho = \int_0^{\theta} \int_{R_1}^{R_2} \frac{P}{4\pi L \left(R1 + (r - R1)^{\frac{\gamma}{2}} \right)^2} r dr d\theta$$

and it can be shown that the maximum predicted Radar range is

$$R_{MAX}^4 = \frac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 k \left[T_s + \frac{P_{UWB} \theta G \lambda^2}{(4\pi)^2 L k} \int_{R_1}^{R_2} \frac{r}{\left(R1 + (r - R1)^{\frac{\gamma}{2}} \right)^2} dr \right] B \left(\frac{S}{N} \right)_{min}}$$

This formulation can be extended to a scenario where the Radar is located within an urban environment, such as an Air Traffic Control Radar.

A similar derivation can be performed for the airborne Radar scenario (based upon [4]). It is assumed that an area of UWB transmitters is located beneath the aircraft and that interference from the UWB transmitters enters through the antenna side lobes.

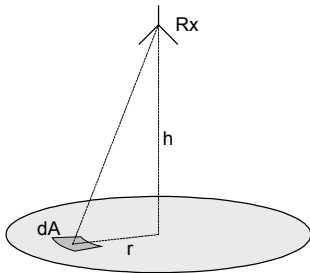


Figure 4: Airborne Radar Interference Model

As signals propagate from the UWB transmitter through the buildings and rooftops, they are attenuated as $1/r^\gamma$. When propagating through free-space, the signals are attenuated as $1/r^2$.

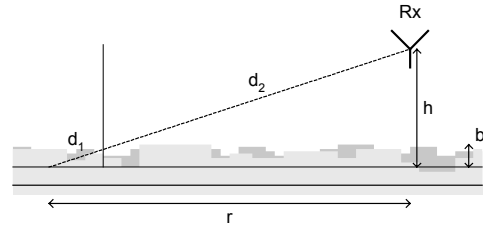


Figure 5: UWB Tx to Airborne Radar Propagation

For this scenario, the UWB interference power density at the victim Radar receiver is given by

$$\rho = \int_0^{R} \int_0^{2\pi} \frac{P}{4\pi L \left(\left(\frac{bs}{h} \right)^{\frac{\gamma}{2}} + s - \frac{bs}{h} \right)^2} r dr d\theta$$

where

$$s = \sqrt{r^2 + h^2}$$

Therefore, the maximum predicted Radar range is

$$R_{MAX}^4 = \frac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 k \left[T_s + \frac{P_{UWB} G_{sidelobes} \lambda^2}{8\pi L} \int_0^R \frac{r}{\left(\left(\frac{bs}{h} \right)^{\frac{\gamma}{2}} + s \left(1 - \frac{b}{h} \right) \right)^2} dr \right] B \left(\frac{S}{N} \right)_{min}}$$

These Radar performance prediction models were incorporated into a simulation developed in MATLAB. This was used to investigate the levels of interference for varying UWB transmitter density, city areas and typical Radar parameters.

The simulations demonstrated that the level of interference and reduction in Radar performance is critically dependent upon attenuation of the UWB signals as they propagate through the urban environment and the path loss exponent value, γ . To address this, trials were performed to determine realistic values for γ experimentally.

Trials And Data Gathering

Trials were designed to validate the path loss model and determine the path loss exponent, γ .

The trials equipment consisted of a fixed transmitter and a portable receiver. The transmitter consisted of a signal generator and power amplifier transmitting via an Ultra-Wideband antenna. CW transmissions were used with a maximum power of +20dBm. A similar antenna and a spectrum analyser were used as the receiver and this was moved to a number of measurement locations around the RMR site. Narrow band measurements were made at a series of spot frequencies over the UWB band.

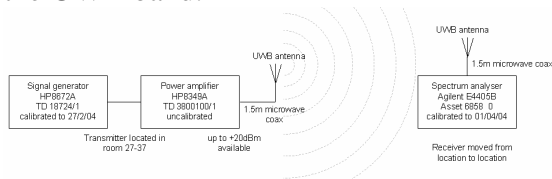


Figure 6: Trials Equipment

The measurement locations are shown in Figure 7; the measurements covered the same building, adjacent buildings and remote locations outside the main office blocks.

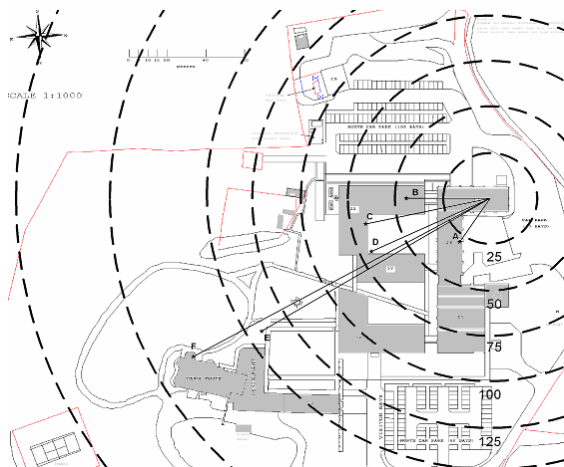


Figure 7: Measurement Locations

The path loss was measured at spot frequencies of 3-10 GHz every 1GHz.

Location	A Old Building	B New Building g1	C New Building g2	D Outdoor s 1	E Outdoor s 2	F Manor House
Range (m)	29	44	67	69	140	178
f (GHz)	Rel loss (dB)	Rel loss (dB)	Rel loss (dB)	Rel loss (dB)	Rel loss (dB)	Rel loss (dB)
3	98	105	138	122	139	139
4	101	114	149	131	142	-
5	110	99	149	134	143	-
6	120	110	150	137	144	-
7	123	127	148	139	-	-
8	108	113	146	133	139	-
9	104	118	145	124	139	-
10	102	119	146	125	-	147

Table 1: Measured Results

The path loss formula was then fitted to the results with the reference distance fixed at 1 metre. The results are shown in Table 2.

f (GHz)	γ
3	4.4
4	4.7
5	4.5
6	4.7
7	5.0
8	4.3
9	4.2
10	4.2

Table 2: Measured Path Loss Exponent

The average exponent was found to be 4.5 with a standard deviation of 0.3. This has to be qualified by stating that it pertains to a relatively small data-set and measurements at other locations (possibly offsite) may differ as the buildings construction at RMR may not be typical for all urban situations. The path loss exponent may seem high is consistent with results appearing in the literature for urban measurements. Several large surveys have been reported on as well as smaller trials, Figure 8 shows one such large dataset (AT&T) for residential in-building propagation that reported an exponent of 3.1.

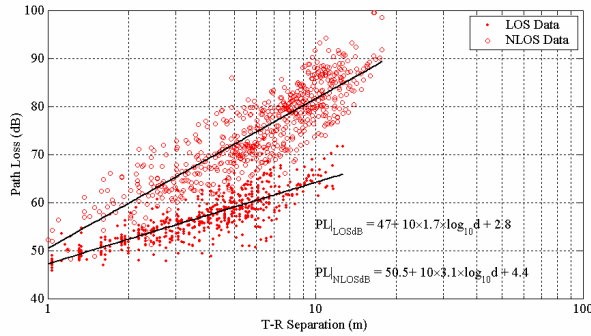


Figure 8: AT&T Measured Data

Other surveys have mostly reported values of between 3 and 5 with a few exceptions. The exponent is consistently high and in broad agreement with the measurements at RMR so further trials are not justified.

Results From Modelling

Extensive simulations were performed with the measured urban path-loss exponent value of 4.0 to investigate the interference levels for a variety of scenarios and Radar parameters. Three typical results are presented here.

For the naval scenario, it assumed that a ship Radar is located off a coastline. The maximum Radar range for detection of a target with a Radar cross section of 2m^2 is plotted against the extent of the city in Figure 9 (left). It can be seen that the UWB interference does reduce maximum Radar range to a small extent. The Radar located 10km from the coastline is affected less than the Radar 1km off the coastline. Interference from transmitters located a distance greater than 100m into the city has negligible impact upon the Radar. This is due to the high path loss exponent for signals propagating within the city. Figure 9 (right) plots the relative levels of Radar system noise temperature and effective interference noise temperature. It is clear that the effective interference noise temperature is significantly less than the system noise temperature and that the noise does not “build-up” indefinitely.

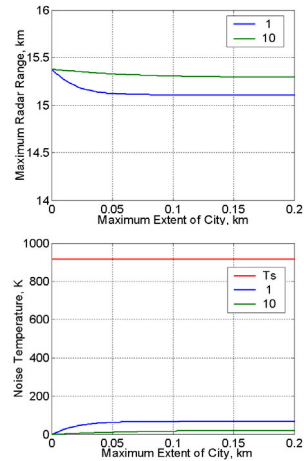


Figure 9: Naval Radar Results

The urban scenario shows similar results to the naval scenario. The Radar is in the centre of an urban environment, with a gap of 100m or 500m between the Radar and the edge of the city. It is assumed that the main beam of the Radar is squinted upwards and that interference enters through the sidelobes of the victim Radar receiver antenna. It can be seen (Figure 10) that the Radar located 500m from the edge of the city is affected less than the Radar located 100m from the edge of the city. Interference is only received from UWB transmitters located within the first 30-40m of the city. The interference noise does not build up indefinitely.

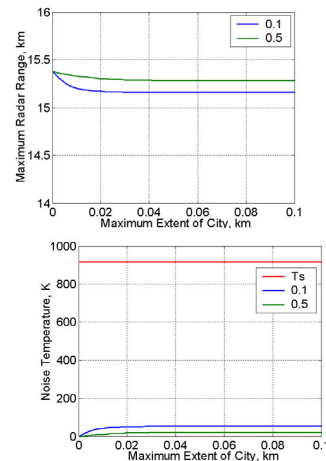


Figure 10: Urban Radar Results

For the airborne scenario, the aircraft is located above a city of a certain radius. Interference enters through the sidelobes of the victim Radar receiver antenna and we consider the levels of interference as the

city radius increases. Results for aircraft at altitudes of 1km and 10km are plotted in Figure 11. The aircraft at 1km above the city is affected by UWB transmitters located within a radius of 20km beneath it. Beyond that radius, signals are attenuated to such an extent that interference is negligible. The aircraft 10km above the city is affected by UWB transmitters within a radius of up to 50km beneath it. A city of radius 50km would contain over 31million UWB transmitters based upon the parameters used for this work, and so would be an extreme case. However, even for this extreme case, for both aircraft altitudes the maximum Radar range is reduced by less than 0.2dB.

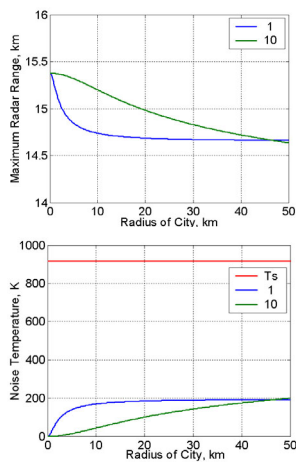


Figure 11: Airborne Radar Results

The three example results presented above are specific to certain sets of parameters, but are typical of the results gathered in this work. The simulations indicate that for most realistic scenarios UWB interference will be negligible. However, it is possible to construct “hot-spot” scenarios where a very high density of UWB transmitters within the main beam of a nearby Radar will cause a problem.

Mitigation Options

This work has shown that in all realistic scenarios the aggregation of UWB signals is noise-like. This means that mitigation

against UWB interferers by signal processing methods in the victim receiver is not possible. Instead, the options would be to lobby for a decrease in the UWB transmission power regulatory limits, or to RF screen the areas where the UWB devices are used.

However, this work has also demonstrated that in realistic scenarios of UWB usage, the aggregated UWB signal strength does not reach levels that would cause any significant degradation in performance of victim receivers. It is therefore our recommendation that the FCC’s EIRP limit of -41.3dBm is sufficient to provide protection to current spectrum users.

In rare and extreme cases where very high concentrations of UWB devices are present or safety of life may be at stake then a localised ban or screening measures should be used. For example, the use of UWB devices by passengers on board commercial airliners could be prohibited. Also, airport departure lounge areas could incorporate radio-absorbing materials in the walls to mitigate for the potential presence of large numbers of UWB devices.

Conclusions

This work has concluded that large numbers of UWB signals will appear as Gaussian white noise to a victim Radar receiver. Interference models have been developed for naval, urban and airborne Radars and have been used to quantify the likely impact of UWB interference on Radar systems. A measurement campaign has been performed to investigate the propagation of UWB signals within the urban environment.

Based upon the propagation measurements and typical Radar parameters, simulations have demonstrated that for most realistic scenarios UWB interference should not pose a significant problem and mitigation should not be necessary. However, in certain “hot-spot” scenarios interference

may become an issue, but due to the noise-like nature of the UWB signals mitigation options are likely to be limited to screening measures or a localised ban on UWB devices.

This work does not necessarily apply to other signal structures (for example WLAN) where the noise-like properties of UWB signals may not apply. Considering the potential growth of such systems, it is recommended that these be investigated in further work.

Acknowledgements

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References

- [1] FCC, 2002, Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, ET Docket 98-153, FCC 02-48 First Report and Order Federal Communications Commission
- [2] R. J. Fontana, 2002, An Insight Into UWB Interference From A Shot Noise Perspective, IEEE Conference on Ultra Wideband Systems and Technologies
- [3] A. Papoulis, 1965, Probability, Random Variables and Stochastic Processes, McGraw-Hill
- [4] W.C.Lynch, K.Rahardja, S.Gehring, 1998, "An Analysis of Noise Aggregation from Multiple Distributed RF Emitters", Interval Research Corporation

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