RECOMMENDATION ITU-R SM.1755-0*

# Characteristics of ultra-wideband technology

(2006)

**Scope**

Information on technical and operational characteristics of ultra-wideband (UWB) devices is needed to study the impact of these devices on other radiocommunication services. This Recommendation is giving the list of terms and definitions as well as general characteristics of UWB technology.

**Keywords**

Ultra-wideband, short-range, modulation, radiocommunication services

The ITU Radiocommunication Assembly,

*considering*

a) that intentional transmissions from devices using ultra-wideband (UWB) technology may extend over a very large frequency range;

b) that devices using UWB technology are being developed with transmissions that span numerous radiocommunication service allocations;

c) that devices using UWB technology may therefore impact, simultaneously, many systems operating within a number of radiocommunication services, including those which are used internationally;

d) that UWB technology may be integrated into many applications such as short-range indoor and outdoor communications, radar imaging, medical imaging, asset tracking, surveillance, vehicular radar and intelligent transportation;

e) that it may be difficult to distinguish UWB transmissions from emissions or unintentional radiations in equipment that also contains other technologies, where different limits may apply;

f) that applications using UWB technology may benefit sectors such as public protection, construction, engineering, science, medical, consumer applications, information technology, multimedia entertainment and transportation;

g) that devices using UWB technology for certain applications may result in their high density deployment in some environments where stations of radiocommunication services have already been or will be deployed;

h) that the spectrum requirements and operational restrictions for devices using UWB technology may vary according to their application;

j) that devices using UWB technology normally operate on a non-protected, non-interference basis;

k) that information on the technical and operational characteristics of devices using UWB technology and applications is needed to study the impact of devices using UWB technology on radiocommunication services; and

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* Radiocommunication Study Group 1 made editorial amendments to this Recommendation in the years 2018 and 2019 in accordance with Resolution ITU-R 1.

l) that information on the terms and definitions associated with UWB technology, and devices using UWB technology, is needed,

*recommends*

**1** that the terms, definitions and abbreviations contained in Annex 1 should be used in describing UWB technology and devices using UWB technology;

**2** that the general characteristics contained in Annex 2 should be used to characterize UWB technology;

**3** that the technical and operational characteristics contained in Annex 3 should be considered in studies relating to the impact of devices using UWB technology (those devices that are not presently recognized as operating under allocations to radiocommunication services) on radiocommunication systems;

**4** that the following Notes will be considered as part of this Recommendation.

NOTE 1 – Administrations authorizing or licensing devices using UWB technology should ensure, pursuant to the provisions of the Radio Regulations, that these devices, will not cause interference to and will not claim protection from, or place constraints, on the radiocommunication services of other administrations as defined in the Radio Regulations and operating in accordance with those Regulations.

NOTE 2 – Upon receipt of a notice of interference to the radiocommunication services referred to in Note 1 above from devices using UWB technology, administrations should take immediate action(s) to eliminate such interference.

# Annex 1

## UWB terms, definitions and abbreviations

### 1 UWB terms and definitions

In describing UWB technologies and devices, the following terms have the definitions indicated:

*Ultra-wideband technology (UWB)*: 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]

*UWB transmission*: radiation generated using UWB technology.

*Activity factor*: the fraction of time during which a device using UWB technology is transmitting.[2]

*Impulse*: a surge of unidirectional polarity that is often used to excite a UWB band-limiting filter whose output, when radiated, is a UWB pulse.

*Pulse*: a radiated short transient UWB signal whose time duration is nominally the reciprocal of its –10 dB bandwidth.

*Radar imaging device*: a device used to obtain images of obstructed objects. This includes in-wall and through-wall detection, ground penetrating radar, medical imaging, construction and home repair imaging, mining, and surveillance devices.

*Ground penetrating radar (GPR) device*: a radar imaging device that operates typically when in contact with or within close proximity to the ground for the purpose of detecting or mapping subsurface structures. While primarily used for examining "underground", the term "ground" can be expanded to mean any lossy dielectric material.

*Wall radar imaging device*: a sensor that is designed to examine and map the interior of walls. The wall is usually made of a concrete structure or similar dense impermeable material that absorbs much of the impinging radio-wave energy. Typical applications include reinforced concrete building walls, retaining walls, tunnel liners, the wall of a mine, the side of a bridge, or another physical structure that is dense enough and thick enough to dissipate and absorb most of the signal strength transmitted by the imaging device.

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[1] The –10 dB bandwidth $B_{-10}$ and –10 dB fractional bandwidth $\mu_{-10}$ are calculated as follows:

$$B_{-10} = f_H - f_L$$

$$\mu_{-10} = B_{-10}/f_C$$

where:

$f_H$: highest frequency at which the power spectral density of the UWB transmission is –10 dB relative to $f_M$

where:

$f_M$: frequency of maximum UWB transmission

$f_L$: lowest frequency at which the power spectral density of the UWB transmission is –10 dB relative to $f_M$,

$f_C = (f_H + f_L)/2$: centre frequency of the –10 dB bandwidth.

The fractional bandwidth may be expressed as a percentage.

[2] For multiple devices, see § 3 of Annex 3.

*Through-wall radar imaging device*: a sensor used to transmit energy through an opaque structure such as a wall or a ceiling to detect the movement or location of persons or objects that are located on the other side. These devices are deliberately designed to maximize energy transfer through an opaque structure. This category may include products such as stud locators that are designed to locate objects behind walls that are not sufficiently thick or dense enough to absorb the transmitted signal, such as gypsum, plaster or similar walls.

*UWB communication device*: a short-range communication device to transmit and/or receive information between devices.

*UWB measurement device*: a device used to measure distance or position.

*Medical imaging device*: a sensor used to detect the location or movement of objects inside the body of a human or an animal.

*Location sensing and tracking*: a network of sensors installed at precisely surveyed locations to measure the location of a remote device using UWB technology.

*Vehicular radar device*: a radar device mounted on land transportation vehicles to detect the location and movement of persons or objects near a vehicle.

*Multi-functional device*: a device that enables multiple UWB applications, such as radar imaging, vehicular radar, location sensing and tracking, and communication functions, using a common platform.

NOTE 1 – The terms necessary bandwidth, occupied bandwidth, unwanted emissions, out-of-band domain and spurious domain, as defined in Article 1 of the Radio Regulations, are generally not relevant to UWB transmissions.

## 2 Abbreviations related to UWB

| | |
|---|---|
| BPM | Bi-phase modulation |
| DS-CDMA | Direct sequence-code division multiple access |
| DSSS | Direct sequence spread spectrum |
| GPR | Ground penetrating radar |
| MB-OFDM | Multiband OFDM |
| OFDM | Orthogonal frequency division multiplexing |
| OOK | On-off keying |
| AM | Pulse amplitude modulation |
| PPM | Pulse position modulation |
| PRF | Pulse repetition frequency |
| PSD | Power spectral density |
| RBW | Resolution bandwidth |
| SRR | Short-range radar |
| UWB | Ultra-wideband |
| WPAN | Wireless personal area network |

# Annex 2

## General characteristics of UWB technology

### 1 Potential high-density use

UWB technology can potentially be integrated into many applications that could offer benefits to the public, consumers, businesses, and industries. For example, UWB could be integrated into applications for improved public safety through the use of vehicular radar devices for collision avoidance, airbag activation and road sensors, short-range high data rate communication devices, tagging devices, liquid level detectors and sensors, surveillance devices, location determination devices, and as a replacement for wired high data rate connections over short distances. Though most devices using UWB technology would operate at very low power, the many potential UWB applications could result in high density of devices using UWB technology in certain environments such as office and business cores.

### 2 High data rate

Devices using UWB technology may operate at very low power levels and can support applications involving multiple users at high data rates (e.g. short-range wireless personal area networks (WPANs) at data rates greater than 100 Mbit/s).

### 3 Secure communications

UWB signals are potentially more covert and potentially harder to detect than non-UWB radiocommunication signals. This is because UWB signals occupy a large bandwidth, can be made noise-like, and can communicate with a unique randomizing timing code at millions of bits/s. Each bit is typically represented by a large number of pulses of very low amplitude typically below the noise level. These features result in secure transmissions with low probability of detection (LPD) and low probability of interception (LPI).

### 4 Robust communications

Devices using UWB technology are generally designed to have large processing gain, a measure of a device’s robustness against interference.

### 5 Communication system capacity

The theoretical system capacity of any communication system, including a UWB system, may be calculated from the Shannon relation:

$$C = B \log_2 \left( 1 + \frac{\int_B P_d(f)\,\mathrm{d}f}{\int_B N_0\,\mathrm{d}f} \right) \qquad (1)$$

where:

$C$: channel capacity (bit/s)

$B$: channel bandwidth (Hz)

$P_d(f)$: signal power spectral density (W/Hz (or dBm/Hz))

$N_0$: noise power spectral density (W/Hz (or dBm/Hz)).

The Shannon relation shows that the theoretical channel capacity of a UWB communication system is very large because of its bandwidth, even though its power spectral density is very low and restricted in amplitude.

## 6 UWB power spectra

UWB signals generated by basic pulse position modulation have numerous spectral peaks. Randomization is used to make the signal more noise-like. The shape of the power spectral density of an emitted UWB signal is usually controlled by an appropriate choice of the pulse shape, modulation technique, timing jitter, and pseudo-noise code sequences used for randomization of the UWB pulses. The spectral shape of a UWB transmission is additionally defined by components such as antennas.

### 6.1 Requirement for a large bandwidth

UWB transmissions spread over a very large frequency bandwidth in comparison with non-UWB transmissions. Among the challenges is finding a suitable spectrum and a way to introduce UWB applications without causing interference into radiocommunication services.

### 6.2 Pulse shaping

Pulse shaping enables control of the frequency content of the UWB transmission, which can reduce interference into radiocommunication systems. It is fundamental that pulse shapes for UWB communications must have a zero-mean because an antenna cannot radiate signals at zero frequency. Creative designs of pulse shapes and a variety of modulation options can be incorporated in UWB communication system designs.

### 6.3 UWB modulations

For UWB pulses, information can be coded using pulse position modulation (i.e. binary or *M*-ary PPM), PAM (i.e. binary or *M*-ary PAM), bi-phase modulation of pulse polarity (i.e. BPM), modulation by a doublet of a positive pulse followed by a negative pulse or vice versa, and pulse on-off keying (OOK). Furthermore, combinations of these modulations can be used. As an example, a hybrid bi-phase and PPM modulation scheme has been shown to eliminate discrete components of the UWB PSD.

UWB signal transmission involves pulse shaping, spreading, modulation, and randomization. Appropriate hybrid modulation and randomization of a UWB signal makes its spectrum appear like additive white Gaussian noise. The choice of the UWB modulation scheme impacts the power spectral density of the radiated signal and consequently its impact on radiocommunication services. In particular, the impact of the discrete components of the PSD can be mitigated or they can be eliminated.

#### 6.3.1 Pulse position modulation (PPM)

PPM is a UWB modulation technique by which data are represented by time shifts from a reference time. Binary PPM has been a popular early choice and appears relatively early in the literature on UWB communications. PPM modulated UWB signals may have discrete spectra that carry no information, and may cause interference. This can be greatly mitigated by randomizing the positions of the pulses using pseudo-noise sequences, which whitens the spectrum significantly.

This randomization for PPM has often been called time hopping (TH). Another way to reduce the interference from PPM UWB signals is to increase the period of the pulse train. This decreases the frequency of occurrence of discrete components of the PSD.

One form of a pulse position modulation is multiband impulse (MB-I) UWB which comprises a method whereby the spectrum is divided into sub-bands. Impulses of very short duration are sent in frequency and time-hopped sequences over several sub-bands. Polarity or bi-phase modulation of data is used with the time-frequency hopped impulses. A multidimensional modulation space may be employed by filling out a matrix of time and frequency with impulses. Complex and efficient (with respect to $E_b/N_0$) coherently detected modulations are also possible. The noise-like quality of the signal results from the time-frequency hopping.

### 6.3.2 Bi-phase modulation (BPM)

For a binary phase modulation, a specific pulse shape and its negative are used to represent a zero and a one. BPM yields an advantage of 3 to 6 dB over PPM in multipath-free environments. It also has a peak power to average power ratio of less than 3 (compared to a sine wave with a ratio of 2).

### 6.3.3 Pulse amplitude modulation (PAM)

PAM is a technique that varies the amplitude of the transmitted pulses based on the data to be transmitted. In PAM modulated devices a set of amplitudes is selected to represent the data to be transmitted. A pulse of any shape with a mean of zero may have its amplitude modulated with ±1 variations (binary signalling) or *M* variation (*M*-ary PAM). PAM signals may be demodulated with non-coherent techniques.

### 6.3.4 On-off keying (OOK) modulation

OOK is a special case of PAM UWB modulation wherein the presence or absence of a pulse within a time slot represents a one or a zero.

### 6.3.5 Chirp modulated UWB

In chirp modulation, the carrier frequency is swept over a very wide band during a given pulse interval. The sweep pattern, which encodes the data, may be linear or non-linear according to the device requirements.

### 6.3.6 Modulation by a pair of opposite polarity doublets

A doublet consisting of a positive pulse followed by a negative pulse, or vice versa, provides another form of modulation. An advantage of this type of modulation is that the choice of separation between pulses in a doublet and the time separation between doublets enables the frequency spectrum to be shaped to mitigate interference.

### 6.3.7 Direct sequence and direct sequence code-division multiple access (DS-CDMA) UWB

Direct sequence ultra-wideband (DS-UWB) uses high-duty cycle polarity coded sequences of pulses to encode data at rates in the order of hundreds of megabits to beyond a gigabit per second or more. For a fixed pulse rate, multiple pulses are used to represent a single bit, thus trading energy per bit for data rate. The UWB bandwidth of DS-UWB is a function of the sub-nanosecond pulse duration of each chip. The UWB signal is noise-like with a low probability of detection and low probability of interception. The design of a good spreading code for DS-UWB is critical for good performance in a multipath environment. In DS-CDMA multiple users can share the same spectrum simultaneously by using suitable codes.

### 6.4 Multiband modulation and multi-user techniques

#### 6.4.1 Multiband orthogonal frequency division multiplexing (MB-OFDM)

MB-OFDM structures the spectrum into several sub-bands. The data is transmitted across the bands using a time-frequency code (TFC). Within each sub-band an OFDM modulation scheme is used to convey information.

#### 6.4.2 Frequency hopping for multiband (FH-UWB)

In FH-UWB the signal is distributed into one of several frequency bands for a short-time period. This hopping between bands is done according to a pre-assigned pattern (uniform or non-uniform).

A multiband system can be based on the principle of transmitting different symbols in different bands in a periodic sequence, very similar to frequency hopping. Various modes of operation can be implemented by modifying the hopping rate, symbol and number of bands.

#### 6.4.3 Time division multiple frequency modulation for multiband

Time division multiple frequency modulation is a modulation scheme similar to frequency hopping since it uses multibands but different because the relationship between bands. Its main advantage is that it allows one to increase the number of bits per symbol and, consequently, to reduce the symbol rate. This reduces the effect of intersymbol-interference caused by delay spread.

#### 6.4.4 Cross-band flexible multiple access for multiband

A cross-band flexible UWB multiple access scheme for multi-piconet wireless PANs uses specially designed encoding and decoding matrices to obtain resilience against multi-user interference (MUI), accommodate various spreading alternatives, enable full multipath diversity and effect scalable spectral efficiency (from low, to medium and to high-data rates).

## 7 Common signalling mode (CSM)

A CSM is a candidate method by which devices using different UWB technologies may coordinate their activity and potentially mitigate their impact on systems operating within radiocommunication services.

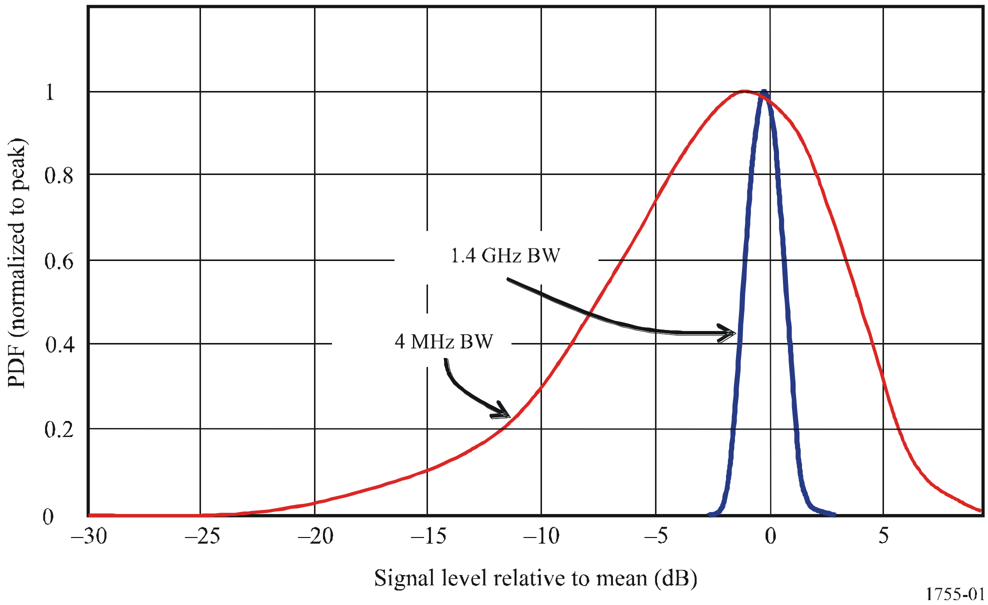
## 8 Multipath effects

A wide transmission bandwidth (BW) is needed to overcome multipath fading in an indoor environment. In this environment, the delay spread between different multipath reflections will be small, and the coherence bandwidth of the channel will therefore be large. UWB communication devices are therefore resistant to multipath fading in an indoor environment, because they have a wide transmission bandwidth and closely spaced multipath components can therefore be resolved in the receiver.

Figure 1 compares the signal statistics of multipath fading for signals with bandwidths of 4 MHz and 1.4 GHz. The wider bandwidth signal exhibits a lower probability of a deep fade relative to the mean signal level.

FIGURE 1

**Probability density function of a 0.7 ns UWB pulse (1.4 GHz BW) and of a 4 MHz wide narrow-band signal**




During propagation a sub-nanosecond pulse is dispersed, which may result in Rayleigh fading in the frequency domain. However, each of these reflections is an independent signal so a RAKE receiver can then be used to coherently add the energy in each of the pulses that are received from each of the multipath components to provide a gain over single path reception.

## 9 Imaging and location capabilities

UWB transmissions can penetrate walls and obstacles and provide high accuracy location determination. These properties can also be useful in applications to detect movement of persons and objects. For example, radar imaging applications can be used by law enforcement, rescue and fire organizations to detect persons hidden behind walls or under debris in situations such as hostage rescues, fires, collapsed buildings or avalanches. UWB can be used at hospitals and clinics for a variety of medical applications to obtain images of organs within the body of a person or an animal. UWB can also be used in applications:

– to locate objects such as mineral deposits, metallic or non-metallic pipes, electrical cables in walls, and plastic land mines;
– to measure ice thickness of frozen lakes and runway conditions at airports;
– in forensic and archaeological studies; and
– to find flaws in bridges and highways.

# Annex 3

## Technical and operational characteristics of devices using UWB technology

### 1 Operational characteristics

UWB technology can be integrated into many applications. Some UWB devices may support more than one application. Examples of the broad categories of UWB applications and their operational characteristics are given in Table 1.

TABLE 1

**Operational characteristics of applications**

| UWB application | Operational characteristics |
|---|---|
| **1 Radar imaging** | – Mostly occasional use by professionals in limited numbers<br>– Use is limited to specific locations or geographic areas |
| Ground penetrating radar | – Occasional use by professionals at infrequent intervals and specific sites<br>– A specific application may have a limited number of devices that operate in mobile continuous use on roadways<br>– Transmission is directed towards the ground |
| In-wall radar imaging | – Occasional use at infrequent intervals<br>– Professional users: typically engineers, designers, and professional of the construction industry<br>– Transmission is directed toward a wall<br>– Devices are operated typically in direct contact with the wall to maximize measurement resolution and sensitivity |
| Through–wall radar imaging | – Device is transportable<br>– Used by trained personal: normally police, emergency teams, security and military<br>– Occasional use at infrequent intervals<br>– Deployed in limited numbers<br>– Transmission is directed towards a wall<br>– Devices may operate at some distance from the wall to maximize operation safety in case of hostile action |

TABLE 1 (*end*)

| UWB application | Operational characteristics |
|---|---|
| Medical imaging | – May be used for a variety of health applications for imaging inside the body of a person or an animal<br>– Indoor stationary occasional use by trained personnel<br>– Transmission is directed towards a body |
| **2 Surveillance** | – Operate as "security fences" by establishing a stationary RF perimeter field and detecting the intrusion of persons or objects in that field<br>– Continuous outdoor and indoor use in a stationary manner |
| **3 Vehicular radar** | – Mobile usage<br>– High-density use may occur on highways and major roads<br>– Terrestrial transportation use only<br>– Transmission is generally in a horizontal direction |
| **4 Measurement** | – Stationary indoor/outdoor use |
| **5 Location sensing and tracking** | – Typically fixed infrastructure; mostly stationary use<br>– Transmitters always under positive control |
| **6 Communication** | – High-density use may occur in certain indoor environments such as office buildings<br>– Some applications have occasional use such as an UWB wireless mouse; others will operate at a higher percentage of time, such as a video link<br>– Outdoor use may also occur |

## 1.1 Operational characteristics of ground penetrating radars

Table 2 includes examples of operational characteristics of some UWB ground penetrating radar (GPR) devices currently available in the market.

TABLE 2

**Operational characteristics of some UWB GPR devices**

| | Device A, D, E and F | Device B and C |
|---|---|---|
| Operation and control | Remote or computer triggered | Remote or computer triggered |
| Operational height | Ground coupled<br>$R \approx 0$ m | Ground coupled<br>$R \approx 0$ m plus occasional off surface to < 1 m |
| Deployment mode | Normally down looking | Normally down looking with some wall usage |
| User type | Normally consultant, professional, or researcher | Normally consultant, professional, or researcher |
| Usage mode | Occasional use at specific locations | Occasional use at specific locations |

# 2 Technical characteristics of UWB devices

## 2.1 Communications devices and measurement systems

The characteristics given in Table 3 provide examples of three existing communication devices.

TABLE 3

**Characteristics of some UWB communications devices**

| | Device G | Device H | Device I |
|---|---|---|---|
| Maximum average e.i.r.p. (dBm/1 MHz) | –41.3 | –41.3 | –41.3 |
| Lower frequency at –20 dB and –10 dB (GHz) | 3.1, 3.6 | ≥ 3.1<br>(–10 dB down) | 3.1, 3.6 |
| Upper frequency at –10 dB and –20 dB (GHz) | 9.6, 10.1 | ≤ 10.6<br>(–10 dB down) | 9.6, 10.1 |
| Antenna pattern | Omni | Omni | Omni |
| Pulse rate (Mpulse/s) | > 500 | ≥ 1 | > 1 000 |
| Bit rate (Mbit/s) | ≤ 100 | ≤ 40 | ≤ 500 |
| Range (m) | ~10 | < 100 | 4-10 |
| Maximum average e.i.r.p. (dBm/1 kHz) in 960-1 610 MHz | ≤ –90 | ≤ –85.3 | ≤ –90 |
| Maximum average e.i.r.p. (dBm/1 MHz) in 960-1 610 MHz | < –90 | ≤ –75.3 | ≤ –90 |
| Maximum average e.i.r.p. (dBm/1 MHz) in 1 610-3 100 MHz | < –63.3 | ≤ –53.3 | ≤ –63.3 |

Device G is intended for applications within offices or homes with transmission of data up to a data rate of 100 Mbit/s. It is also intended for operation between hand-held devices that may be outside and that do not employ a fixed infrastructure. Such applications include links among personal digital assistants or laptop computers. Within a wireless LAN, it may carry multiple digital video signals among components of a video system such as between a video camera and a computer, between a cable set-top box and a television, or between a high-end plasma display and a DVD player.

Device H is a multipurpose device intended for use indoors for industrial, commercial, and consumer applications where communications, precision positioning or radar sensing is required. The device can be configured to operate over a range of data rates. The operating range depends upon the data rate.

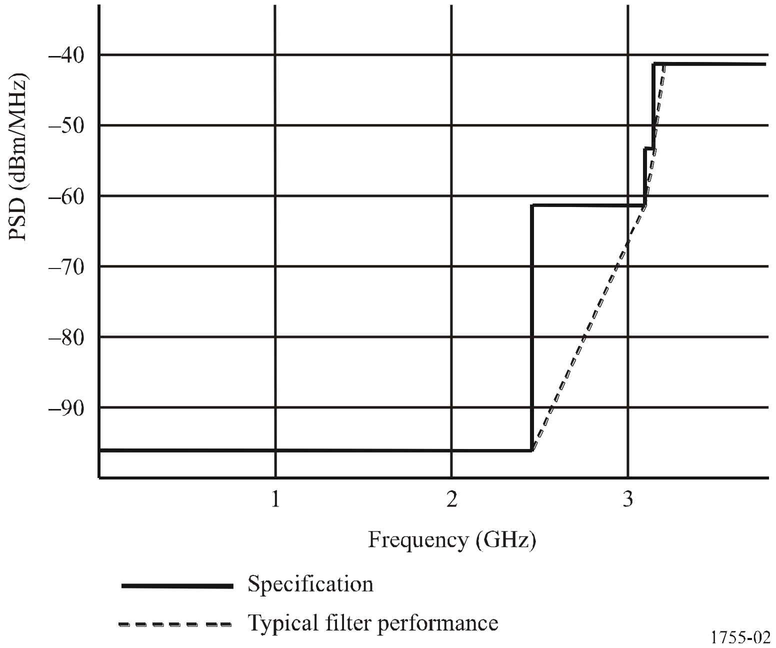
Device I is intended for operation within office or home applications for transmission of data at a rate up to 500 Mbit/s. These higher data rate devices are intended to provide wireless connectivity for many of the same applications as Device G, but also serve to provide a wireless cable replacement for high-speed wired connections such as USB or IEEE 1394.

Figures 2 and 3 provide examples of the spectrum masks of two other devices.

Device J is intended for office and home applications for transmission of data up to a data rate of 480 Mbits/s. The specifications for this device include requirements for close-in transmitted spectrum mask and a receiver pre-selector filter. The transmit spectrum shaping is performed in the digital domain, and the receiver pre-selector filter is an RF component. As this device is time division duplex, this pre-selector filter can be also used to filter the transmitted signal. Figure 2 shows the combination of the characteristics of these two filters applied to an in-band PSD of –41.3 dBm/MHz.

FIGURE 2

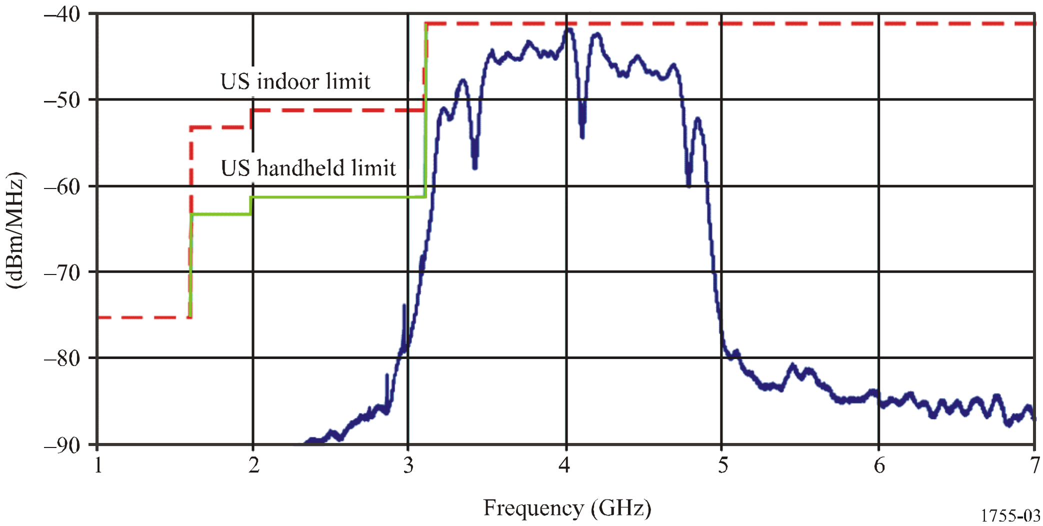
**Calculated spectrum mask of UWB device J**




Device K is also intended for office and home applications for transmission of data up to a data rate of 480 Mbits/s. Figure 3 shows the measured transmitted spectrum of this device.

FIGURE 3

**Measured transmitted spectrum of UWB device K**



### 2.2 Vehicular radar systems

The characteristics given in Table 4 provide an example of existing products. Vehicular radar devices that use UWB technology operate in higher frequency bands than those used by UWB communications devices. These devices are being designed to detect the location and movement of objects near a vehicle, enabling features such as near collision avoidance, improved airbag activation, and suspension devices that better respond to road conditions. Vehicular radars emit an UWB signal over a well-defined frequency range.

TABLE 4

**Example of characteristics of an existing UWB vehicular radar device**

| Parameter | Value |
|---|---|
| Centre frequency (GHz) | ~24.125 |
| Maximum e.i.r.p. density (dBm/1 MHz) | –41.3 |
| –20 dB occupied bandwidth (GHz) | 22.125 to 26.125 |
| Pulse repetition frequency (MHz) | 0.1-5 |
| Maximum peak power (e.i.r.p.) (dBm/50 MHz) | 0 |
| Antenna pattern | Directional |
| Mounting height (m) | ~0.50 |
| Range (m) | ~20 |
| Target separation (cm) | 15-25 |

Impact calculations for vehicular radars should take into account the peak vehicle density, the percentage of the Earth's surface where those densities are achieved, and the market penetration of UWB vehicular radars over time.

### 2.3 GPR systems

GPR devices are used for mapping subsurface structures. While primarily used for examining "underground", the term "ground" can be expanded to mean any lossy dielectric material. GPRs are also referred to as baseband or impulse radars. A summary of the characteristics of the GPR signals and devices is as follows:

– GPR measures *in situ* physical properties (i.e. permittivity, conductivity or permeability) of the subsurface material. These *in situ* properties occurring in frequencies ranging from 1-2 000 MHz are difficult to determine in any other way.

– The objective of GPR measurements is to detect subsurface features. Air launched signals are undesired and as much effort as possible is made to minimize signals which travel through the air and which contaminate the desired measurements.

– GPR devices are part of the geophysical tool set and have been in active use for many years. The small number of units and the general adherence to minimizing air launched transmission have resulted in minimal interference concern.

– When GPR devices are in operation they have a low use duty cycle. It is common to make measurements with an operational duty cycle of 10% to 1% followed by a long period of no usage while moving to the next survey position or planning the next measurement sequence.

– GPRs are used infrequently and the location of usage is constantly changing. These factors further reduce the probability of interference to radiocommunication services.
– GPRs are different from through-wall radar imaging devices. Typical GPR wall applications involve examining the interior of structures such as bridge piers, tunnel liners, and concrete walls. The GPR signals are dissipated in the material. Through-wall radar imaging devices are designed to launch signals into the air on the other side of the wall.
– The peak power spectral density increases as the centre frequency of the GPR decreases but the average power spectral density does not. As frequency decreases, PRF normally decreases and the average power remains roughly constant.
– Lower frequency (geological) GPRs are used in remote geographic areas where there is a lower likelihood of interference with radiocommunication services.
– GPR must use a wide bandwidth signal to achieve adequate resolution.

Table 5 includes examples of technical characteristics of some UWB GPR devices currently available in the market. (See § 1.1 for the operational characteristics of these devices.)

TABLE 5

**Characteristics of some GPR devices using UWB technology**

| | **Device A** | **Device B** | **Device C** | **Device D** | **Device E** | **Device F** |
|---|---|---|---|---|---|---|
| Quasi peak e.i.r.p. (dBm/120 kHz) | –65 | –59 | –59 | –57 | –57 | –55 |
| Average e.i.r.p. (dBm/1 MHz) | N/A | N/A | -68 | N/A | N/A | N/A |
| Lower frequency at –10 dB (MHz) | 120 | 185 | 317 | 19 | 18 | 17 |
| Upper frequency at –10 dB (MHz) | 580 | 840 | 1 437 | 79 | 125 | 202 |
| Antenna pattern | Dipole ground-coupled. Directional downward | Dipole ground-coupled. Directional downward | Dipole ground-coupled. Directional downward | Dipole ground-coupled. Directional downward | Dipole ground-coupled. Directional downward | Dipole ground-coupled. Directional downward |
| Pulse repetition frequency (kHz) | Variable to maximum of 100 | Variable to maximum of 100 | Variable to maximum of 100 | Variable to maximum of 100 | Variable to maximum of 100 | Variable to maximum of 100 |
| Range (m) | 0 to 5 | 0 to 2.5 | 0 to 2 | 0 to 20 | 1 to 10 | 0 to 5 |

## 3 Activity factor of devices using UWB technology

When applying activity factor to deployment scenarios of multiple devices using UWB technology, technology penetration, peak use rate, frequency of use, and other factors related to deployment (including penetration of competing technologies (wireline, infrared, etc.)) should be considered.

### 3.1 Activity factors and technology penetration of 24 GHz vehicular short-range radar (SRR) devices

The SRR activity factors derived in this section are meant to serve as a basis for determining the aggregate interference from a large number of vehicles equipped with SRR devices using UWB technology.

The calculation of the level of this aggregate interference should be based on a deployment model that takes into account the fact that different modes of operation and that not all SRR devices are operating at the same time.

#### 3.1.1 Pulsed devices, pulse gating and activity factor

Pulsed SRR devices cannot operate on a continuous basis because of their inherent operation principle that results in a typical Crest factor[3] of more than 20 dB.

The SRR modes of operation that influence the device activity factor are described in § 3.1.2 through § 3.1.4.

#### 3.1.2 SRR modes of operation

For an SRR, the activity factor includes long switch-off periods (e.g. due to not using all sensors in certain driving situations) as well as short switch-off periods.

Several modes of operation of SRR devices leading to an average power reduction need to be considered in the derivation of the activity factor:

– *SRR switched off:* Depending upon the control device in a vehicle, SRR devices may be turned off automatically when the vehicle is stopped for a duration longer than some preset interval, for example at a traffic light or a railroad crossing. In some vehicles both the engine and the SRR devices may be turned off while in other vehicles the engine may remain on but some or all SRR devices may be turned off.[4]

– *Reduced pulse repetition frequency:* The parking aid and stop-and-go application can run at a reduced PRF because of the low vehicle speed and slowly changing traffic scenario. This reduction in PRF proportionately reduces the average power of the ensemble of SRR devices. The nominal PRF in this context is then the frequency where the SRR device achieves the maximum allowed mean power. Depending on the traffic scenario dynamics some applications will run on a lower PRF or with longer quiescent periods. Both effects reduce the transmitted mean power. This mean power reduction can be expressed as an activity factor.

– *Non-UWB mode:* Most sensors are being designed to also operate in certain driving situations in a non-UWB mode within the 24.00 to 24.25 GHz band. The non-UWB mode can be either a narrow-band mode in this frequency range or a Doppler mode (continuous wave (CW) mode).

  The reason for a non-UWB mode of SRRs is that some vehicular applications or driving situations need either less object separation capability (which results in a much smaller occupied bandwidth) or a longer detection range (which requires higher emission power as might be permitted solely in this band). SRR devices may switch between either a wideband mode or a narrow-band mode. When an SRR device is operating in a non-UWB mode, its emissions are not considered to be UWB transmissions.

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[3] The Crest factor (CF) is defined by: $CF = 10 \log (P_{pk}/P_{rms})$, with $P_{pk}$: peak power and $P_{rms}$: average power.

[4] Some low fuel consumption car models already use this technique.

– *Partial frequency range and multiband UWB operation:* A further reduction in the aggregate mean power of the SRR ensemble is possible when the SRR devices share the available frequency range, each using a different portion of the available frequency band. In this case, interference to radiocommunication services can be mitigated by changing frequency to a different portion of the band.

### 3.1.3 Activity factor typical value estimation for different SRR operation modes

In Table 6 the activity factor for SRR is estimated for the different operation modes used in various driving situations.

TABLE 6

**Calculation of estimated activity factor for all modes of operation**

| Driving situations | Modes of operation | | | | Activity factors from all modes of operation(4) | Occurrence of driving situations in per cent of driving time | Activity factors from all modes of operation weighted by the occurrence of the driving situations |
|---|---|---|---|---|---|---|---|
| | "SRR switched off" mode | "Reduced PRF" mode (PRF reduced from 100% to 10%) | | "Non-UWB" mode | | | |
| | Time SRR switched **on**(1) in per cent of driving time (activity factor No. 1) | Time **full** PRF(2) in per cent of driving time | Activity factor from this mode(3) (activity factor No. 2) | Time UWB mode in per cent of driving time (activity factor No. 3) | | | |
| Highway, moving traffic | 100 | 80 | 82 | 60 | 49.2 | 55.00 | 27.06 |
| Highway, slow traffic | 100 | 100 | 100 | 80 | 80.0 | 10.00 | 8.00 |
| City driving | 70 | 80 | 82 | 70 | 40.2 | 35.00 | 14.06 |
| City, forward parking | 100 | 0 | 10 | 100 | 10.0 | 0.05 | 0.01 |
| City, backward parking | 100 | 0 | 10 | 100 | 10.0 | 0.05 | 0.01 |
| | | | | **Resulting activity factor (%)** | | | **49.1** |

(1) Time SRR switched **on** = 100% – SRR switched **off**.

(2) Time **full** PRF = 100% – Time **reduced** PRF.

(3) Activity factor = (Time full PRF * 100%) + (100% – Time full PRF * 10%).

(4) Product from activity factors Nos. 1 to 3.

NOTE 1 – The numbers in Table 6 are estimates made at the time this Table was prepared. Administrations may wish to undertake their own analysis of these factors when doing their studies.

The calculations show that the use of the different modes of operation result in an aggregate activity factor of around 50% leading to a power reduction of 3 dB.

### 3.1.4 Technology penetration estimation

There will be alternative technologies for some of the functionality supplied by 24 GHz UWB SRR devices, including 79 GHz UWB SRR devices if appropriate, infrared, ultrasonic and closed circuit video devices. A 100% penetration of SRR devices using UWB technology in the 24 GHz band is unrealistic. It is more likely that the eventual penetration will stabilize at a smaller percentage.

Table 7 evaluates the 24 GHz SRR penetration and other competing technologies.

TABLE 7

**Technology penetration estimation for short-range sensors**

| **Technology** | **Technology penetration (%)** | | |
|---|---|---|---|
| | **Europe/2013** | **Europe/2030** | **USA/2030** |
| 24 GHz UWB SRR sensors | 7 | 0 | 40 |
| 79 GHz UWB SRR sensors | 1 | 55 | 0 |
| Narrow-band SRR sensors (e.g. 24.00-24.25 GHz band) | 20 | 10 | 10 |
| Infrared and ultrasonic sensors | 15 | 15 | 15 |
| Camera based sensors | 2 | 10 | 10 |
| Vehicles with no short-range sensors | 55 | 10 | 25 |

NOTE 1 – The numbers in Table 7 above are estimates made in 2005. Administrations may wish to undertake their own analysis of these factors when doing their own studies.

On a long-term basis (2030) it is assumed that the UWB SRR technology would represent a penetration of about 55%. The penetration in the 24 GHz band of SRR UWB technology is assumed to be around 40% if no mandatory limitations are applied by national regulators. It has to be noted that the regulation in Europe authorizes the placing into the market of 24 GHz SRR until 2013 and limits the penetration to 7% of the car fleet.

Even many years after the market introduction of SRRs, a significant number of cars will have no short-range sensors at all. This can be derived from the experience of the introduction of many other automotive technologies. Even if all new cars were to be equipped with such sensors in some years it would take 15 years until the vehicle density approached 100%. This penetration would unrealistically assume that no other automotive safety technologies are developed during this period.

A penetration of 7% or 40% for 24 GHz UWB SRR corresponds to mitigation factors of 11.5 dB and 4 dB respectively.

### 3.2 Activity factor description for location sensing and tracking systems

In a normal deployment in a workplace, e.g. hospital or office, it is expected that the density of active transmitters will be about one active device per 200 $m^2$. Wide area deployment utilizes a cellular architecture, with UWB transmitters in different cells using different UWB channels. If two UWB transmitters are being managed by the same cell, the system will ensure that they are not active simultaneously by use of time-resource sharing.

A typical operational UWB location tag will emit a signal for a period, followed by a period in which it does not transmit. The non-transmit period is dependent on its activity rate, which can be changed according to the type of application. For example, a tag carried by a person might transmit once a second (i.e. duty cycle of 24 ms every second or 2.4%) and a tag placed on an item of equipment might transmit only once every 10 s (i.e. a duty cycle of 0.24%). There will be a maximum rate at which a tag is allowed to transmit, resulting in a maximum duty cycle.

For equipment that does not move very often (e.g. once a week) the duty cycle is typically very much smaller than the above figures.

### 3.3 Activity factor of communication devices using UWB technology

In this section, activity factors for communication devices that use UWB technology are derived. Several simulation scenarios were considered:

– The aggregation of emitted power from a large number of transmitters into victim receivers (ground or satellite based).

– The concentration of power from a "hot spot" into a victim receiver.

– The interference generated from individual transmitters in a cluster into nearby victim receivers.

– The market penetration of devices using UWB technology versus competing technologies (wireline, infrared, etc.).

It is necessary to determine the aggregate activity or "on-air" time of devices using UWB technology to study the effect of a large number of devices on affected radiocommunication services. Where interference from the nearest device using UWB technology is predominant (rather than aggregate effects), the use of average activity factors is not appropriate in interference studies. For these studies, sufficient information needs to be included to effectively model the behaviour.

The aggregate activity factors below were derived using the following assumptions:

– UWB e.i.r.p. density of –41.3 dBm/MHz is assumed.

– Devices using UWB technology did not use an outdoor infrastructure.

– There were no outdoor surveillance devices taken into consideration as part of the outdoor evaluation.

– The analyses were for WPAN and similar high data rate applications.

– Under all scenarios considered, streaming video applications dominate UWB applications to a level greater than 95%.

A peak value of the aggregate activity factor for multiple devices using UWB technology was derived considering the highest estimated rate of UWB market penetration, peak use rate, frequency of use, and other factors related to deployment including market population growth and market share of alternative technologies.

Anticipating the future activity factor is very challenging as it requires prediction of future adoption of the technology which is in turn subject to variables such as competitive technologies. For this reason, the activity factor is stated as a range with the principal assumptions listed above.

#### 3.3.1 Activity factor for indoor communication devices

– 1-5% activity factor, averaged over the complete population.

– Factors which may increase the activity factor:

  – Increased population of un-coded or minimally coded video. This range of 1-5% assumes that a minimal amount of minimally coded video is employed. If uncoded video becomes more predominant, the activity factor would increase.

  – Increased market penetration of devices using UWB technology used for video transmission.

– Factors which may decrease the activity factor:
  – Increases in efficiency of the compression technologies used – advanced compression technologies entering the market, such as MPEG-4 and DVM have the potential to reduce the activity factor.
  – Lower market penetration of devices using UWB technology used for video transmission.

### 3.3.2 Activity factor for outdoor communication devices

The outdoor aggregate activity factor is significantly lower than the indoor factor primarily because of the unavailability of high data rate streaming video sources for outdoor applications. UWB is primarily employed outdoors for file transfer and low data rate streaming.

– 0.01-0.02% activity factor, averaged over the complete population.
– The outdoor activity factor may increase or decrease based upon the penetration of UWB into handheld devices.

## 3.4 Activity factors of other types of devices using ultra-wideband technology

Table 8 shows the activity factor for a device using UWB technology for various applications.

TABLE 8

| **UWB application** | **Typical activity factor (%)** |
|---|---|
| Ground penetrating radar | < 1 |
| Medical imaging systems | < 1 |
| Other radar imaging systems (wall, through-wall, etc.) | 1 |
| Surveillance systems | 50 |