

RECOMMENDATION ITU-R SM.1754

Measurement techniques of ultra-wideband transmissions

(Question ITU-R 227/1)

(2006)

Scope

Taking into account that there are two general measurement approaches (time domain and frequency domain) this Recommendation gives the appropriate techniques to be applied when measuring UWB transmissions.

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 UWB technology may be integrated into many wireless applications such as short-range indoor and outdoor communications, radar imaging, medical imaging, asset tracking, surveillance, vehicular radar and intelligent transportation;
- d) that a UWB transmission may be a sequence of short-duration pulses;
- e) that UWB transmissions may appear as noise-like, which may add to the difficulty of their measurement;
- f) that the measurements of UWB transmissions are different from those of conventional radiocommunication systems;
- g) that proper measurements and assessments of power spectral density are key issues to be addressed for any radiation,

noting

- a) that terms and definitions for UWB technology and devices are given in Recommendation ITU-R SM.1755;
- b) that there are two general measurement approaches, time domain and frequency domain, with each having a particular set of advantages and disadvantages,

recommends

- 1** that techniques described in Annex 1 to this Recommendation should be considered when measuring UWB transmissions.

Annex 1

Measurement techniques of ultra-wideband transmissions

1 Introduction

There are multiple techniques for generating UWB signals with various data modulation and randomization schemes. This Annex describes frequency-domain and time-domain measurement techniques of power spectral density for UWB transmissions and for all types of UWB signals.

In this Annex, the term “emission” is used in a general sense in the context of measurement, and not with the meaning defined in Article 1 of the Radio Regulations.

1.1 Frequency-domain versus time-domain measurement approaches

There are two general approaches for measuring the spectral characteristics associated with UWB emissions, each involving a particular set of advantages and disadvantages.

One approach involves the measurement of a UWB signal’s temporal (time domain) characteristics. Digital signal processing (e.g. Fast Fourier Transform (FFT)) is then applied to transform the measured temporal parameters to their frequency domain representation. Once the UWB signal has been properly represented in the frequency domain, compliance with bandwidth requirements, emission limits, and other applicable regulations can be determined. The temporal measurement approach is often referred to as a “full-bandwidth” measurement, since theoretically it yields a characterization of the UWB signal across the full bandwidth. The second approach involves a direct measurement of the UWB spectral characteristics in the frequency domain. This approach, called “swept spectral measurement”, is often referred to as a “bandwidth-limited” measurement, since the bandwidth capabilities of most existing test equipment are considerably less than the full bandwidth of the UWB signal.

The temporal measurement approach requires a modern digital storage oscilloscope containing a high-speed digitizer with a real-time bandwidth greater than the upper UWB frequency, and FFT processing to calculate the frequency spectrum of the signal. Post-processing software can include many standard radio-frequency (RF) measurements such as root-mean-square (rms) average power.

The swept spectral measurement approach involves the use of a spectrum analyser, vector signal analyser, or similar measurement instrument to detect the UWB signal characteristics in the frequency domain. Conventional test equipment may be insufficiently sensitive to enable detection of UWB signals at very low levels in specific frequency bands.

1.2 Normal test signals for data

This applies to the equipment under test (EUT) with an external modulation connector. The test data that should be used as an input into EUT for measurement of UWB transmissions should be similar to the data transmitted in the actual operation.

In the case of measurements for UWB communication devices, actual data patterns for the fixed part of control signals and frame structures should be used. However, pseudo-random data patterns may be used for the message part of the signal because the message part may be assumed to be a bit stream that is a random sequence.

1.3 General UWB measurement system

The measurement of radiated electromagnetic emissions requires the use of a measurement system that comprises a receiving antenna and a test receiver (e.g. a spectrum analyser). When low power signals are involved, a low-noise amplifier (LNA) with a sufficient bandwidth may be needed between the antenna and the test receiver, improving the effective sensitivity of the measurement system.

1.4 Measurement environment

The low transmission levels from UWB devices make it desirable to perform the measurement in an anechoic or a semi-anechoic chamber. Measurements made in an anechoic chamber should correlate to a measurement made in a semi-anechoic chamber. This is usually accomplished by adjusting for the effect of the ground screen in a semi-anechoic environment or an open area test site (OATS). The measure of a device's effective isotropic radiated power (e.i.r.p.) should be independent of which type of test environment is used.

For frequencies above 1 000 MHz, there is no need for a propagation correction factor since ground reflection is not significant.

1.4.1 Radiated measurement procedure below 1 000 MHz¹

When the reflection from the ground screen cannot be eliminated, the following procedure can be used:

- The UWB emission is examined in small segments, such that reflections, gains and losses do not vary significantly over the segment.
- For table-top sized devices, place the unit on a non-conducting surface at a height of 0.8 m.
- Use conventional device rotation and elevation searches to maximize reception of the emission.
- Take a measurement.
- Factor in gains and losses, as well as considering the ground screen contribution.
- Take sufficient measurements both in azimuth and elevation to ascertain that the maximum emission value has been recorded.
- Repeat at each frequency of interest.

1.4.2 Radiated measurement procedure above 1 000 MHz

Above 1 000 MHz, in a semi-anechoic chamber, the floor between the device and the receiving antenna is treated with RF absorber to remove the ground screen influence. A scan of the search antenna over 1 to 4 m should show a maximum emission near the height at which the device has been positioned, if the floor has been properly treated. Note that for a free-space measurement there is no requirement to maintain a device height of 0.8 m. The device may be positioned at any height that maximally mitigates reflections from the floor. A highly directive receiving antenna assists in reducing the effect of the ground screen reflection. The measurement is recorded without correction for the ground reflection.

¹ One administration recognizes 960 MHz as the measurement detector breakpoint in order to maintain consistency with its emissions mask which defines an emissions limit breakpoint to coincide with the edge of a worldwide aeronautical radionavigation band.

For table-top sized devices, the following procedure can be used:

- Place the unit on a non-conducting surface at an appropriate height.
 - The floor between the search antenna and the device should be treated with material to absorb RF energy suitable for the frequency range being measured.
 - Vary the height of the search antenna to verify that reflections from the floor have been minimized. It may be necessary to alter the height of the device to achieve the lowest reflections from the floor. The main lobe of the search antenna should not receive a floor reflection. The search antenna height should remain fixed throughout the measurement.
 - Take a measurement.
 - Factor in the gains and losses. The ground screen contribution has been eliminated by the addition of absorber in the reflected path.
 - Take sufficient measurements both in azimuth and elevation to ensure that the maximum value has been recorded.
- g) Repeat for each frequency of interest.

1.5 Measurement variations for ground penetrating radar devices and wall imaging radar devices

The emissions of concern from ground penetrating radar (GPR) and wall imaging radar (WIR) devices are not those radiated directly from the antenna. Since the direct emissions penetrate a substrate where they are rapidly attenuated, they pose little risk of interference to radiocommunication services. Instead, only the indirect (i.e. scattered and/or leaked) emissions are of concern. In order to measure these emissions, a method should be used to isolate the direct emissions from the indirect emissions. Two methods to accomplish this isolation are described below.

One method is to place the GPR/WIR directly over a bed of sand of at least 50 cm in depth. The area of the sand-bed should be adequate to accommodate the GPR/WIR transducer (antenna). Measurements are then performed at an adequate number of radials and antenna height steps to determine the maximum radiated emission level. If this methodology precludes the use of a ground screen, the measured data should be further adjusted to account for the ground screen contribution.

Another method is to place the GPR device at a height of 80 cm on a non-conducting support with the emitter directed downwards. If the GPR emissions are expected to have components below 500 MHz, a layer of ferrite tile should be placed directly on the floor below the GPR. Pyramidal or wedge-shaped RF absorbers not less than 60 cm in height are placed directly below the GPR. Some sections of absorber may be inverted and placed over other absorbers to form a solid block.

Care should be taken not to place any RF absorber between the device and the search antenna, as this would prevent energy not directed downwards from reflecting from the ground screen. The placement of the absorber should not be disturbed when the device is rotated. This arrangement prevents energy directed downward from consideration in the measurement.

A search in azimuth and elevation for indirect emissions may now be performed.

1.6 Equipment under test orientation

The UWB EUT should be oriented with respect to the measurement system so as to ensure the reception of the maximum radiated signal. Determining this orientation can be made easier by using a non-conductive turntable or other form of positioning system to systematically search for the orientation that provides the maximum response within the measurement system. Regardless of how

the orientation is determined, a sufficient number of radials should be considered to determine the radial at which the maximum response is captured by the measurement system.

1.7 Measurement distance

A separation distance of 3 m is normally used. In some cases, it may not be possible to measure UWB transmissions without amplification and/or moving to one metre or less separation between the receiving antenna and the UWB device, taking care to maintain the far field condition.

1.8 Measurement antennas

Measurement antennas are typically optimized over specific frequency ranges. When measuring the complete spectrum of UWB transmissions, several measurement antennas are required, each optimized over a distinct frequency range.

1.9 Measurement receiver and detectors

The measurement apparatus may be one of the following: a spectrum analyser, an electromagnetic interference (EMI) test receiver, a vector signal analyser, or an oscilloscope. In the following sections, these alternatives are described generically as a measurement receiver.

A UWB transmission can exhibit different characteristics depending upon the reference receiver bandwidth. For example, a pulse-generated UWB transmission can appear as a CW-line spectrum if the receiver bandwidth is greater than the pulse repetition frequency (PRF). If the receiver bandwidth is less than the PRF then the same transmission can appear noise-like. In addition, if baseband modulation techniques are used (e.g. pulse position modulation), the spectral lines may be “smeared” within the reference bandwidth, creating a noise-like response. In the case of a line spectrum, the quasi-peak power or peak power spectral density is of particular interest. A noise-like spectrum is best defined in terms of the average power spectral density. Due to possible receiver bandwidth dependent variations, the measurement of a UWB spectrum requires the use of several signal detectors.

Three signal detectors are recommended for measuring UWB transmissions. For measuring signal characteristics in the radio-frequency spectrum below 1 000 MHz, a quasi-peak detector specified in CISPR-16-1-1 is recommended. An r.m.s. average detector is recommended for measuring the r.m.s. average UWB radiated signal amplitude in the frequency spectrum above 1 000 MHz. A peak detector is recommended for determining the peak power associated with UWB transmissions in the spectrum above 1 000 MHz.

1.10 Measurement system sensitivity

The radiated emissions from a UWB device are often too weak to overcome the noise of a conventional spectrum analyser. For example, noise level of spectrum analyser is equivalent to an e.i.r.p. density of -47 dBm/MHz at one GHz, and -25 dBm/MHz at 26 GHz. Therefore, it becomes necessary to utilize an LNA at the output of the measurement antenna to reduce the effective noise figure of the overall measurement system.

This increased sensitivity of the measurement system can render it particularly vulnerable to ambient environmental signals. If strong ambient signals are present within the measurement environment, an appropriate RF filter should be placed ahead of the LNA to provide the pre-selection necessary to prevent amplifier overload, while permitting signals in the frequency range of interest to propagate through the measurement system. The insertion loss associated with this filter should be minimal and should also be considered when determining the overall sensitivity of the measurement system.

When the analyser sensitivity is insufficient, radiometric measurements described in § 2.6 is one of the effective methods.

1.11 Example test sequence

The spectral characterization of a UWB device should begin with a peak-detected radiated measurement in a one MHz resolution bandwidth (RBW) since the results obtained from this measurement could preclude the need for subsequent quasi-peak or r.m.s. average measurements in certain frequency regions². For example, if the data collected from this peak-power measurement shows that the radiated emissions levels are equal to, or less than, the applicable quasi-peak and r.m.s. average limit, then this data may be adequate. This is based on the fact that both the quasi-peak and the r.m.s. average levels are always less than, or equal to, the peak signal level.

After the -10 dB bandwidth is measured according to § 2.1, the maximum power and associated frequency observed in each frequency span should be compared to the applicable limit. In those cases where a peak emission exceeds the applicable quasi-peak and r.m.s. average limit, further investigation in subsequent quasi-peak and r.m.s. average tests is required. The data collected from this measurement should be adjusted as previously discussed to remove any measurement system influence on the detected peak levels. Once the data is adjusted, a plot of the complete spectral envelope is produced by combining the segmented data sets.

2 Frequency-domain measurements

This approach involves a direct measurement of the UWB spectral characteristics in the frequency domain. This approach is often referred to as a “bandwidth-limited” measurement, since the bandwidth capabilities of most existing test equipment is considerably less than the full bandwidth of the UWB signal.

2.1 Determination of -10 dB bandwidth

The frequency at which the maximum power level measured in a one MHz segment with the peak detector is designated f_M . The peak power measurements should be made using a spectrum analyser with a one MHz resolution bandwidth and a video bandwidth of one MHz or greater. The analyser should be set to peak detection using the maximum-hold trace mode. The one MHz segments, above and below f_M , where the peak power falls 10 dB, are designated f_H and f_L , respectively.

For the lowest frequency bound f_L , the emission is searched from a frequency lower than f_M that has, by inspection, a peak power much lower than 10 dB less than the power at f_M and increased towards f_M until the peak power indicates 10 dB less than the power at f_M . The frequency of that segment is recorded.

This process is repeated for the highest frequency bound f_H , beginning at a frequency higher than f_M that has, by inspection, a peak power much lower than 10 dB below the power at f_M . The frequency of that segment is recorded.

The two recorded frequencies represent the highest f_H and lowest f_L bounds of the UWB transmission, and the -10 dB bandwidth B_{-10} is defined as $f_H - f_L$.

² This measurement of peak power should not be confused with the peak power spectral density measurement as described in § 2.7.

2.2 A preliminary measurement method using a reverberation chamber

A reverberation chamber (see CISPR 16-1-4 and IEC61000-4-21 for its structure and operations) can be used for a preliminary measurement to find f_M and an approximate shape of the spectrum of a UWB transmission. After that, the precise measurement should be performed on an OATS or in a semi- or fully anechoic chamber at the frequency.

The mode-tuned operation may be preferred for the reverberation chamber. A spectrum analyser is set to the frequency sweep mode and the peak detector. The sweep time and the RBW of the analyser are set to the same values as described in § 2.1.

2.3 CISPR quasi-peak measurements

Quasi-peak measurements are made using a quasi-peak detector with RBW that conforms to CISPR 16-1-1 requirements.

2.4 Average power measurement using a spectrum analyser

The average power spectral density (PSD) for a UWB transmissions is the r.m.s. average power, referenced to an ideal Gaussian bandwidth. For measurement speed, accuracy and reproducibility; the PSD should be directly measured using a swept technique with an r.m.s. average detector and an RBW equal to the reference bandwidth. Note that the RBWs of most modern spectrum analysers closely approximate the ideal Gaussian filter characteristics³. The r.m.s. average PSD is often expressed in units of dBm/MHz (i.e. in a one MHz bandwidth).

2.4.1 Average equivalent isotropic radiated power (e.i.r.p.) spectral density

UWB equivalent isotropic radiated power (e.i.r.p.) spectral density is the product of the power spectral density supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna. It is the highest signal strength measured in any direction and at any frequency from the UWB device, as measured in accordance with the procedures specified in § 2.4.2, 2.4.3 and 2.4.4 of this Recommendation.

2.4.2 Average measurements using an r.m.s. detector

This procedure is valid only for spectrum analysers with an r.m.s. average detector. The measurement set-up for the r.m.s. average measurement is the same as previously described with respect to the EUT orientation and the measurement system.

Measurement set-up

- Set the RBW of the spectrum analyser to 1 MHz.
- Set the video bandwidth (VBW) to be at least 1 MHz (a VBW of 3 MHz is desirable)⁴.
- Set the frequency span to examine the spectrum across a convenient frequency segment (e.g. 600 MHz).
- Set the detector to r.m.s.
- Set the sweep time so that there is no more than a one ms integration period in each measurement bin.

³ Typically, r.m.s. results have less than 0.3 dB error from that obtained using an ideal Gaussian filter.

⁴ This requirement is needed as the VBW filtering on most spectrum analysers occurs on a log power scale rather than a linear power scale.