Essential Properties and Design Principles of UWB Antennas

Gangula Sravanthi, Assistant Professor, Dept. Ece, Sri Indu College Of Engineering And Technology

Kadamanchi Sravani, Assistant Professor, Dept. Ece, Sri Indu College Of Engineering And Technology

.Anusha, Assistant Professor, Dept. Ece, Sri Indu College Of Engineering And Technology

Abstract

Fundamental standards for ultra-wide-band (UWB) radiation are exhibited and examined right now. The conversation begins with a portrayal of the impact of recieving wires on UWB transmission. The parameters describing radio wires in time and in recurrence area are determined. Since the quantity of conceivable reception apparatus structures is about boundless, the emphasis will be on a characterization as indicated by various radiation standards. For every one of these instruments, the run of the mill points of interest and drawbacks are talked about, and a model radio wire and its attributes are displayed. For a remote architect, the issue to illuminate is the correct structure of a reception apparatus with the ideal radiation qualities. The ultimate result of this paper is that there exist quantities of UWB radio wires, however not every one of them is appropriate for any application, particularly in perspective on radar and correspondence frameworks prerequisites.

KEYWORDS | Ultra-wide-band (UWB); UWB antenna characterization; UWB link; UWB transfer functions

I. Introduction

Typically, narrow-band antennas and propagation are described in the frequency domain. Usually the characteristic parameters are assumed to be constant over a few percent band width. For ultra-wide-band (UWB) systems, the frequency-dependent characteristics of the antennas and the frequency-dependent behavior of the channel have to be considered. On the other hand, UWB systems are often realized in an impulse-based technology, and therefore the time-domain effects and properties have to be known as well [1]. Hence there is a demand for both a frequency-domain representation and a time-domain representation of the system description. In the following, these characterizations in the frequency domain and in the time domain are presented. All parameters are uniformly
used in the whole paper but may not be necessarily compliant with the denotation presented in the cited literature. The coordinate system throughout this paper is as shown in Fig. 1.

A. UWB Frequency-Domain Signal Link Characterization

For the frequency-domain description, it is assumed that the transmit antenna is excited with a continuous wave signal with the frequency f . The relevant parameters for the frequency-domain link description are:

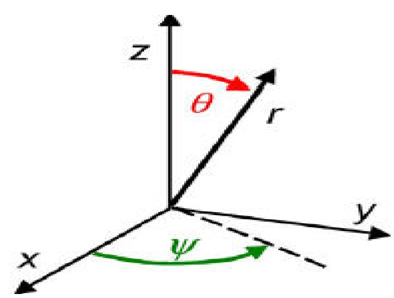

Fig. 1. Coordinate system for UWB link and antenna characterization.

description of a free space UWBpropagation link is given by (2)

$$\frac{U_{Rx}(f)}{\sqrt{Z_{C,Rx}}} = \mathbf{H}^{T}_{Rx}(f, \theta_{Rx}, \psi_{Rx}) \cdot \frac{e^{j\omega r_{TxRx}/c_0}}{2\pi r_{TxRx} c_0} \cdot \mathbf{H}_{Tx}(f, \theta_{Tx}, \psi_{Tx}) \cdot j\omega \frac{U_{Tx}(f)}{\sqrt{Z_{C,Tx}}}. \quad (2)$$

Two orthogonal polarizations are included in the Tx and Rx transfer functions, as noted above. While in narrowband
systems the radiation angles and influence only the polarization, amplitude, and the phase of the signal, they influence additionally the entire frequency-dependent signal characteristics in UWB systems.

For UWB links in rich scattering environments, e.g., indoor, the influence of the channel can be described by a frequency-dependent polari metric channel transfer matrix [3].

B. Time-Domain Signal Link Characterization

For the time-domain description, it is assumed that the transmit antenna is excited with a impulse. The elements
of the UWB time domain link characterization are:

- amplitude of transmit signal uTxðtÞ in [V];
- amplitude of receive signal uRxðtÞ in [V];
- impulse response of the transmit antenna hTxðt; Tx; TxÞ in [m/ns];
- impulse response of the receive antenna hRxðt; Rx; RxÞ in [m/ns];
- radiated field strength eTxðt; r; Tx; TxÞ;
- distance between Tx-Rx antennas rTxRx in [m].

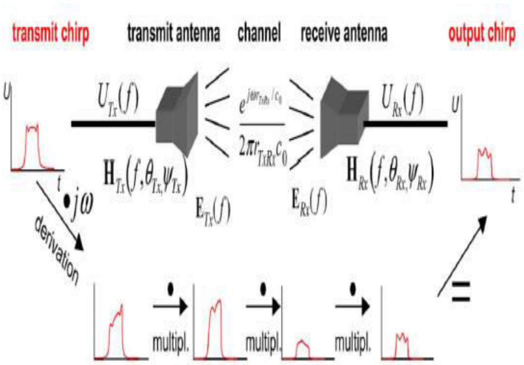

Fig. 2. Frequency-domain system link level characterization.

II. Uwb Definitions And Antenna Parameters

The desired operating frequencies are given by:

- U.S. FCC regulation [6] as 3.1 to 10.6 GHz;
- European regulation [7] (2007j131jEC) as 6.0 t 8.5 GHz;
- special allocations, e.g., ground penetrating radar or wall radar;

but not limited to these. A general definition of UWB is stated with the relative bandwidth

$$2(f_H - f_L)/(f_H + f_L) > 0.2 \qquad (5)$$

A. Antenna Characterization Parameters

In contrast to classic narrow-band antenna theory, where the antenna characteristics are regarded for only a small bandwidth, the characterization of antennas over an ultra wide frequency range requires new specific quantities and representations [1], [8]. In this section, both time domain and frequency-domain representations are regarded.
Depending on the application, the relevant ones have to be selected. In general, the Fourier transforms forward and backward are the operations to switch from frequency domain to time domain, and vice versa. An impulse fed to an UWB antenna is subject to:

- differentiation;
- dispersion (energy storage);
- radiation;
- losses (dielectric/ohmic).
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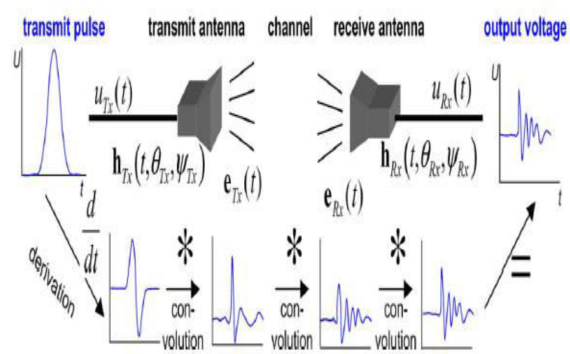

Fig. 3. UWB system link level characterization in time domain.

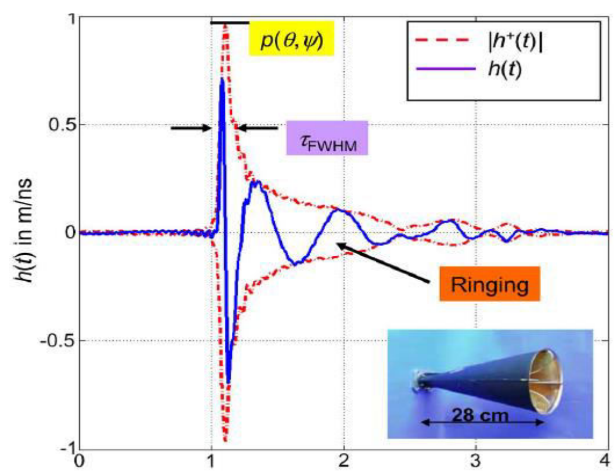

Fig. 4. Characterization of the antenna time-domain transient response (here: horn antenna).

calculated by the Hilbert transform H commonly used in signal processing.

$$h^{+}(t) = (h(t) + j\mathcal{H}\{h(t)\}). \qquad (6)$$

1) Peak Value of the Envelope: The peak value pð; Þ of the analytic envelope is a measure for the maximal
value [h+(t)] of the strongest peak of the antenna's time-domain transient response envelope. It is mathematically defined as

$$p(\theta, \psi) = \max_t |h^{+}(t, \theta, \psi)| \text{ in } \frac{\text{n}}{\text{n}}$$

2) Envelope Width: The envelope width describes the broadening of the radiated impulse and is defined as the width of the magnitude of the analytic envelope [h+(t)] at half maximum (FWHM). Analytically, it is defined as

$$\tau_{\text{FWHM}} = t_1 \big|_{|h^{+}(t_1)|=p/2} - t_2 \big|_{t_1<t_2, |h^{+}(}$$

III. UWB ANTENNA PRINCIPLES

The radiation of guided waves has been discussed intensively in the past. It is the common understanding that the key mechanism for radiation is charge acceleration [10], [11]. The question to answer for UWB is: what kind of structures facilitates the charge acceleration over a very wide bandwidth? The ultra wide bandwidth radiation is based on a few principles:

- traveling-wave structures;
- frequency-independent antennas (angular constant
- structures);
- self-complementary antennas;
- multiple resonance antennas;
- electrically small antennas.

In most cases the radiation starts where the electric field connects 180 out-of-phase currents with half a wavelength spacing. Many antennas radiate by a combination of two or more of the above principles and can
therefore not be simply classified. In the following, the relationships between the radiation principles and the properties of the antennas are discussed. Each explanation of the radiation phenomenon is supported by an example of an antenna.

A. Traveling-Wave Antennas

Traveling-wave antennas offer for the guided wave a smooth, almost not recognizable transition with the fields
accelerated to free-space propagation speed co. Typical antennas are tapered wave guide antennas [12]Vfor example, the horn antenna (see Fig. 4) or the Vivaldi antenna (see Fig. 6). Other radiating traveling-wave structures are, e.g., the slotted waveguide or the dielectric rod antenna. Here the focus will be on the Vivaldi antenna as an example, for which different feed structures like microstrip line, slot line, and antipodal can be applied.

Fig. 6. Aperture coupled Vivaldi antenna. (Left) Top view; (right) bottom view with feed line. Substrate size 75 _ 78 mm2.

Mathematical function that provides a smooth transition, can be used and optimized, regarding the input reflection
coefficient and the radiation characteristics. A typical structure is shown in Fig. 6, etched on a dielectric substrate. The Vivaldi is fed at the narrow side of the slot. For UWB, the major tasks are the wide-band frequency independent
feed and slot-line terminations. The feed shown here is designed with a Marchland balun network with aperture coupling. Non resonant aperture coupling is usually a good choice for UWB feed structures. This allows also for an impedance matching in a wide range. A stub, and the slot line by a circular shaped cavity, terminate the micro strip feed line. The antenna can be designed relatively compact. The propagation velocity v on the structure changes from the slot-line wave velocity vsl to c0 at the end of the taper.

B. Frequency-Independent Antennas

Rumsey investigated the fundamentals of frequency independent antennas in the 1960s [13]. He observed that
a scaled version of a radiating structure must exhibit the same characteristics like the original one, when

fed with a signal whose wavelength is scaled by the same factor. As a consequence, if the shape of an antenna is invariant to physical scaling, its radiating behavior is expected to be independent of frequency. The typical realization is an angular constant structure, which is described only by

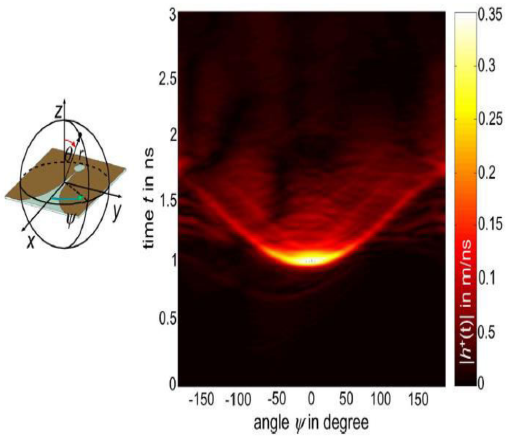

Fig. 7. Measured impulse response [h+(t,∅)]Þj of the Vivaldi antenna of Fig. 6 in E-plane versus frequency.

A planar example of the biconical antenna is the bowtie antenna. The antenna structure consists of two triangular metal sheets (see Fig. 9). They are usually fed by a symmetric line (twin line), which is matched to the feed point impedance. In the case of an asymmetric feed line (like coaxial or micro strip lines), a balun transformer is needed. The bowtie antenna has for the FCC UWB frequency band reasonable dimensions. The application of aperture feed and further optimizations allow very compact design.

The aperture coupled bowtie antenna consists of two triangular radiating patches, of which one serves as a ground plane for the tapered micro strip feed line that ends with a broadband stub (see Fig. 9). The feeding structure couples the energy from an asymmetric micro strip line to the radiating bowtie elements through the aperture formed

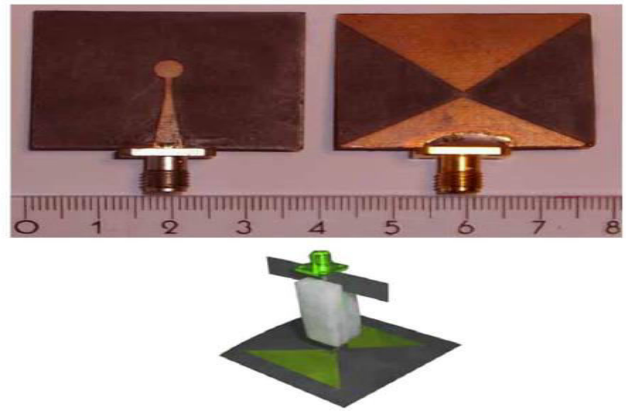

Fig. 9. (Left) Aperture coupled bowtie antenna; bottomviewwith feed line. (Right) Top view; symmetric fed bowtie antenna with balun.

Table 1 UWB Parameters of the Vivaldi Antenna of Fig. 6 in Main Beam Direction

Parameter	Value
p_{max} in m/ns	0.35
τ_{FWHM} in ps	135
$\overline{G}$ in dBi	5.7
G_{max} in dBi	7.8
$\tau_{r=0,22}$ in ps	150

IV. UWB ANTENNA SYSTEM ASPECTS

In practice from a system point of view, two cases for UWB have to be distinguished:

- multiple narrow bands, e.g., OFDM (ECMA-368 Standard);
- pulsed operation (IEEE 802.15.4a).

The first case can usually be treated like the well-known narrow-band operations. The relevant criteria are well covered by the frequency-dependent transfer function Hðf; ; Þ. Antennas for these applications can be all earlier discussed types, especially also the Log-Per antenna. The second case needs a closer look. If in a pulsed operation for radar or communications the full FCC bandwidth from 3.1 to 10.6 GHz, i.e., 7.5 GHz, is covered for example, with the derivative of the Gaussian pulse with FWHM ¼ 88 psVthen the transient behavior, the impulse response Þ of the antenna, has to be taken into account. In this case, the impulse distortion in the time domain and in the spatial domain has to be examined for compatibility.

An adverse behavior of the impulse response, with the following problems:

- low peak magnitude pð; Þ;
- very wide pulse width FWHM;
- long ringing r
- has influence on the system characteristics, for example, on:
- the received signal strength uRxðtÞ, ðS=NÞ;
- the data rate in communications;
- /the resolution in radar.

These adverse effects set requirements for the antennas but also for the other UWB hardware front-end elements like amplifiers, filters, equalizers, detectors, and so on. These requirements restrict the potential antennas to small antennas or traveling wave antennas. Candidates are:

- Mono cone antenna;
- bowtie antenna;

Peak value p in m/ns	0.35	0.13	0.10	0.13	0.23
τ_{FWHM} in ps	135	140	290	805	75
$\tau_{r=0.22}$ in ps	150	185	850	605	130

Fig. 25. Comparison of characteristic parameters of the presented UWB antennas.

- Vivaldi antenna;
- horn antenna.

All antennas with resonances or spurious surface currents are bad candidates and should be disregarded for time-domain operation. Among them is definitely the Log-Per antenna. For certain cases where circular polarization is required, further restrictions hold. A logarithmic spiral antenna, e.g., can only radiate circular polarization if the pulse duration is longer than the equivalent circumference of the active radiating zone. For 88 ps pulses, this equivalent circumference should be less than 2.6 cm, which may contradict the radiation requirement.

These statements make clear that for UWB in extension to research at the component level, also research on the system level has to be performed.

V. CONCLUSION

Ultra-wide-band as an emerging technology requires for the antenna characterization a thorough knowledge of the behavior in time domain, in frequency domain, and, in certain cases, in the spatial domain. It has been shown that for ultra-wide-band, certain antenna classes can be defined according to their radiating characteristics. In Fig. 25, typical, relevant data of the discussed UWB antennas are compared.

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