UWB - ULTRA WIDEBAND CHARACTERISTICS AND THE SALEH-VALENZUELA MODELING

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ABSTRACT

The Article deals with the use of the Saleh Valenzuela (SV) model in the UWB frequency band. It presents the calculation of the SV model parameters for receiving antenna depending on different positions of transmitting antenna. The calculated SV parameters are derived from the real measured external environment. The calculated parameters will be used for concluding the definition of the signal spread in the measured environment.

Keywords: *UWB, Saleh Valenzuela model, SV parameters*

1. INTRODUCTION

1.1. UWB radio technology

The UWB is a widespread spectrum technology transmitting signals in a way which does not interfere with the conventional narrow-band technologies although the carrier wave is used in the same frequency band. This is one of the main positive characteristics of this technology. UWB is the technology for transmitting information spread over a large bandwidth (>500 MHz)[12]. In theory and under the right circumstances this feature allows it to be used and share the spectrum with other technologies at the same time.

FCC (The United States Federal Communication Commission) and ITU-R (International Telecommunication Union) have allocated a wide range of frequencies for Ultra Wideband (UWB) wireless communication system to operate usually in the band from 3.1 to 10.6 GHz, low-power transmission, high-speed links for a variety of applications. High-data-rate wireless communication needs wide bandwidths to transmit information and it may be spread over a wide bandwidth at low power levels. This provides the opportunity to share the spectrum with other technologies.

1.2. Applications

The article deals with the problem of data transmission in the UWB band for the use in commercial sector to replace the startup program "Find a Car in the Parking Lot". The study will contribute to solve the transfer in free space or in the area with multipath signal propagation and as the potential technology for replacing competitive older and slower technology.

Impulse radio UWB (IR-UWB) is a wireless technology used for the fast transition of a very large amount of digital data over a wide frequency spectrum at very low power and over short distances. IR-UWB technology uses very short pulses (few nanoseconds or less) that spread their energy in bandwidth for two main types of applications: high data rate combined with short range (10m) communication or low data rate with medium range.

The UWB is the most frequently used system for short-range indoor applications due to low emission levels allowed. As the duration of UWB pulses is short, it is easy to provide high data rates. Furthermore the OFDM technology could be also used to minimize bandwidth requirements.

1.3. Advantages

UWB has several advantages in comparison with other narrow-band technologies:

- unlicensed bandwidth (no license fees)
- sharing the same frequency spectrum with other systems
- high security
- low average transmission power (lower power requirements- longer battery life)
- greater resistance to jamming (systems have a high processing gain PG)

$$PG = \frac{RF\ Bandwidth}{Data\ Bandvidth}$$

- very short duration of transmitted pulses (nanosecond duration) is the reason why pulses are unlikely to overlap (IR UWB)

1.4. Disadvantages

- short-range communications
- complicated synchronization between the transmitter and the receiver
- complicated channel estimation
- sampling and synchronization are more complicated than in a narrow-band, due to the short duration of UWB pulses(inevitability of fast analog-to-digital converters) (only for IR UWB)

2. THEORETICAL SALEH-VALENZUELA MODEL

One of the most popular models, used to describe multipath spread, consisting of clusters and rays, is the Saleh-Valenzuela (SV) model. The SV model describes the mathematical equation for the complex baseband impulse response. SV model expects the spread of the signal consisting of clusters and rays [see picture 1].

Received signal [2]:

$$r\,(t) = \int_{-\infty}^{\infty} h(t,\tau)\, s(t-\tau) d\tau + n(t) \tag{1}$$

where

τ is the delay
$n(t)$ is the noise
$s\,(t-\tau)$ is the transmitted signal
$h(t,\tau)$ is the possibility time variant

The impulse response h(t) of the channel [3]:

$$h(t) = \sum_{c=1}^{C} \sum_{r=1}^{Rc} a_{cr} \delta(t - T_c - \tau_{cr}) \tag{2}$$

where

C is the number of clusters
R_c MPCs (Multipath cluster´s or “rays”)
T_c is the arrival time of cth cluster
τ_{cr} is the arrival time of the r-th ray within is the cluster
δ is the Dirac delta function (delta)
a_{cr} is the relative weight (or multipath gain coefficient) of ray (c; r)

The Saleh-Valenzuela (SV) model is one of the models, based on the multipath rays arriving to the receiver in groups called clusters. Each ray and cluster has independent fading. The later the rays and clusters arrive, the lower is their power. The arrival times of clusters and rays are described by Poisson distribution [11].

$$P(T_n|T_{n-1}) = \Lambda e^{-\Lambda(T_n - T_{n-1})},\ n > 0 \tag{3}$$

$$P\left(\tau_n\middle|\tau_{n,(m-1)}\right) = \lambda e^{-\lambda(\tau_n - \tau_{n,(m-1)})},\ m > 0 \tag{4}$$

n is the number of the cluster
m is the ray number in the n-th cluster.

The Saleh-Valenzuela Model parameters: $\Gamma, \gamma, \Lambda, \lambda$

Λ is the mean cluster arrival rate
λ is the mean ray arrival rate
Γ is the cluster exponential decay factor
γ is the ray exponential decay factor

σ is the standard deviation of the lognormal distributed path powers

The mean path power gain for path l is determined by:

$$\bar{a}_l^{\,2} = \bar{a}_0^2 \,.\, e^{-\tau_l \gamma}, \tag{5}$$

where

γ is an exponential decay factor
$\bar{a}_0^2$ is the mean path power gain of the first arrival

$$\bar{a}_0^2 = G_T G_R . \left(\frac{\lambda}{4\,\pi}\right)^2 . \frac{1}{d_{ant}^2} . \frac{1}{\lambda_h} \quad , \tag{6}$$

where

λ_h is the echo arrival rate
G_T is the transmit antenna gain
G_R is the receiver antenna gain
d_{ant}^2 is the distance between transmitter and receiver

$$\gamma = \frac{1}{\tau_{rms}} . \frac{\sqrt{2K+1}}{K+1} \tag{7}$$

γ is the exponential decay factor
K is the Ricean factor (for Ricean channel K >>0, τ_{rms}-small, for Rayleigh channel K=0, τ_{rms}-high)
τ_{rms} is the delay spread

$$K_r = \frac{P_{k/max}}{(\sum_k P_k) - P_{k/max}} \tag{8}$$

K_r is the Ricean factor
$P_{k/max}$ is the strongest component of the cluster/

Ray exponential decay factor

$$\gamma = \frac{10}{m_\gamma . ln_{10}} \tag{9}$$

m_γ is the negative slope of the regression line on the dB slope

Cluster exponential decay factor

$$\Gamma = \frac{10}{m_\Gamma . ln_{10}} \tag{10}$$

The SV model is relatively young and general. It contains a considerable number of simplifications. The SV model also assumes that the variance of the lognormal fading is independent from the clusters delay. This does not fully reflect the physical reality. In the fact, the relative variance should be smaller for small delays than for the large ones.

Physical Interpretation of the SV Model

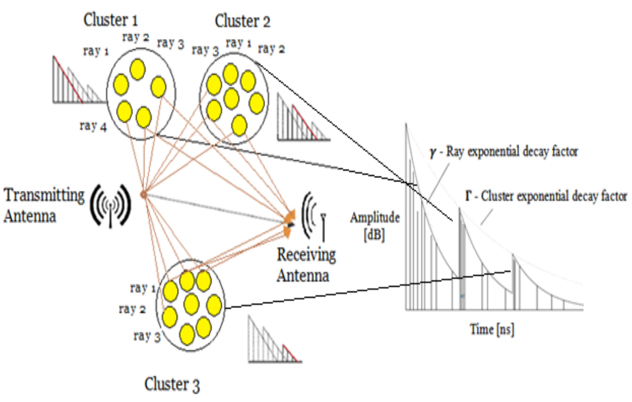

Fig. 1 The physical spread of the signal in channel

3. METHODS

3.1. Measurement

The data, used for calculation of the SV model parameters, were measured by the use of Rohde & Schwarz ZVA67 four ports vector network analyzer. Measurements were performed in outer area with distances from 1 to 7 meters from the transmitting antenna and the receiving antennas.

Because of the wideband nature and using TOA techniques, the UWB technology is suitable technology for positioning applications. The position estimation requires knowledge of the Channel Impulse Response (CIR), which can be acquired in the time domain by excitation the channel with narrow pulses or indirect method using Inverse Fast Fourier Transform (IFFT) to transfer function measured in the frequency domain. CIR in the time domain has many advantages, for example very fast measurement of the channel response. The disadvantage is extremely fast sampling. Due to the availability of measuring equipment (Rohde & Schwarz - vector analyzer) was used for the time domain measurement the indirect measurement method.

The measuring method and setup deals with the data processing, including the conversion of the measured channel transfer functions in the frequency domain into the time domain. Detection of the first three rays, the first three clusters and calculation of the transmitting (TX) antenna position was used the Time-of-Arrival (TOA) technique. Measurement of the UWB channels for car positioning was carried out by transmitting antenna in the range from 1 to 7 meters at the distance from the receiving antenna. The height of the transmitting antenna was set to 115 cm. The receiving antennas were placed on the car roof and in back mirrors. Antenna types were carried out as a small mono-cone antenna with an omnidirectional pattern. The data were measured by three antennas specified in table 1, 2, 3. The positioning of antennas is visible in the picture Fig. 7, 8, 9. The environment in which the measurement was performed was a crowded ground parking mall.

Depending on the location of the transmitting and receiving antennas, there were received signals for clear Line of Sight (LOS) and also Non clear Line of Sight (NLOS) scenarios. Each receiving antenna provides scattering parameters, which correspond to the complex channel transfer functions. Data were measured in the frequency domain with the R&S four port vector network analyzer in the frequency band 2 - 10 GHz. There were chosen 801 frequency points in the frequency band with a 10 MHz frequency step. The bandwidth of the IF band-pass filter was set to 10 Hz. The calculations do not include the correction methods or statistical techniques to repair or filter interference. Therefore, the results may be different from the theoretical values.

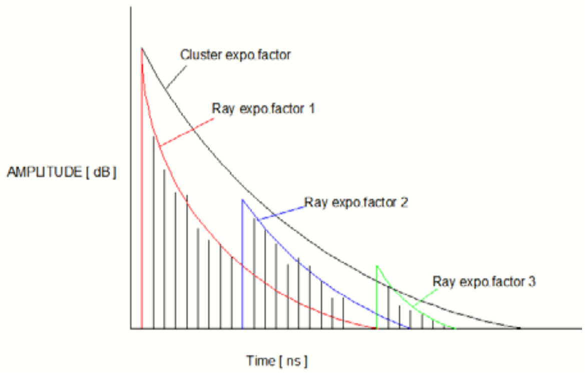

Fig. 2 SV model approximation

Fig. 3 Vehicle used for measuring in the environment of shopping mall

This narrow bandwidth reduces the effect of noise on the measurement, but causes relatively long sweep times. In order to avoid signal destruction and interference of the measured phase accuracy between transmitting (TX) and receiving (RX) antenna, the phase stable coaxial cables were used.

3.2. Matlab Testing & Simulation

Fig. 4 and Fig.5 show waveform depending on the parameters. After converting the signal from the frequency to the time domain, we have identified that the signal is not running perfectly according to the theoretical Saleh & Valenzuela model. The first peak of the first cluster and the first few rays are clearly identifiable, while the second and the third cluster are sometimes very difficult to identify, because the signal-to-noise ratio decreases rapidly. Therefore, we have failed to design a general algorithm which can automatically identify clusters and then automatically calculate specific parameters. The calculation of the SV model parameters, based on measured values, was carried out in simulation program Matlab and some calculations in Microsoft Excel. Cluster´s and ray´s exponential decay factors were interpreted by exponential functions. The structure and time course of the received signal is shown in the picture below.

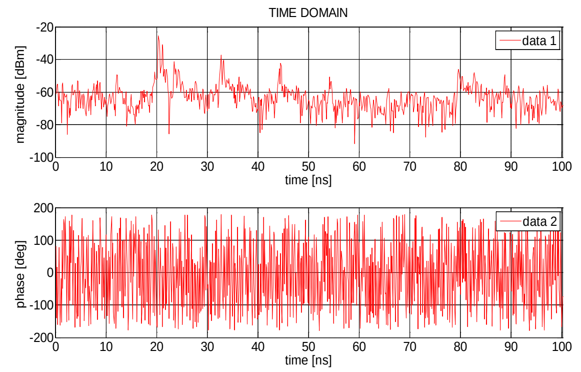

Fig. 4 Time course of the received signal

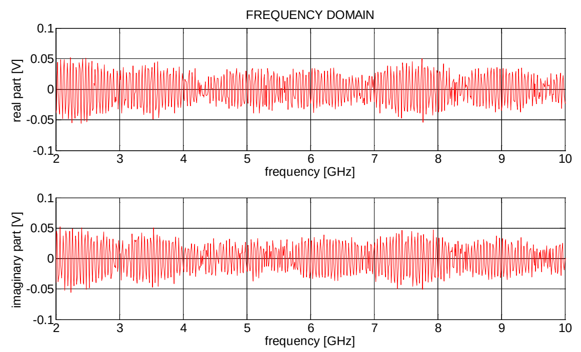

Fig. 5 Frequency response of the received signal

3.3. The Calculation of the SV parameters

The first Ray exponential decay factor [γ_1]

$$\alpha_1 = e^{-\gamma_1 t_1} \quad (14)$$

α_1 is magnitude of the 1.cluster (direct wave)
γ_1 is cluster exponential decay factor n.1 (median)
t_1 is time delay 1

The second Ray exponential decay factor [γ_2]

$$\alpha_2 - \alpha_1 = e^{-\gamma_2 (t_2 - t_1)} \quad (15)$$

where

$\alpha_2 - \alpha_1$ is sequence decrease magnitude of the 2. received cluster
α_2 is the first reflected wave (caused by multipath propagation)
γ_2 is cluster exponential decay factor n.2 (median)
$(t_2 - t_1)$ is time delay, start time of the 2.cluster

The third Ray exponential decay factor [γ_3]

$$\alpha_3 - \alpha_2 - \alpha_1 = e^{-\gamma_2 (t_3 - t_2)} \quad (16)$$

where

$\alpha_3 - \alpha_2 - \alpha_1$ is sequence decrease magnitude of the 3. cluster
α_3 is the second reflected wave (caused by multipath propagation)
γ_3 is cluster exponential decay factor n.2 (median)
$(t_3 - t_2)$is time delay, start time of the 3.cluster

Cluster exponential decay factor [Γ]

Exponential approximation of the three rays:

$$\alpha_{1,2,3} = e^{-\Gamma_1 \tau_1} \quad (17)$$

where

$\alpha_1, \alpha_2, \alpha_3$ is sequence decrease amplitude in certain time
$\tau_{1,2,3}$ are adequate / certain times

Cluster arrival rate [Λ]

$$\Lambda = \frac{s}{\tau_{c1}} \quad (18)$$

s is the distance between transmitting and receiving antenna
τ_{c1} is the median time of the 1.cluster

$$\tau_{c1} = \frac{1}{N} * \sum_1^N \tau_{RN} \quad (19)$$

where

N is the number of the rays in the cluster
τ_{RN} is time of the each ray

Ray arrival rate [λ]

$$\lambda_{1,2,3\ldots} = \frac{s_{1,2,3\ldots.}}{\tau_{1,2,3\ldots.}} \quad (20)$$

where

λ_1 is the rate of the first ray (in the 1.cluster)
$s_{1,2,3}$ is the distance between transmitting and receiving antenna

3.4. SV - parameter estimation

Estimated values of the SV model parameters are based on parameter values published in the article [10] Part III and also UWB model parameterization for 2-10

GHz and the parameters published in the article [3] and [13].

The mentioned publications do not indicate the exact conditions and methods of measurement, although in some cases there is defined at least the type of the environment (internal and external environment) and visibility (NLOS-Line of Sight and LOS-Non LOS). For the most relevant comparison of measured and calculated parameters are used results in the publication [10]. Estimated parameter values for the SV model, the external environment, are within the range of $31{,}7 < \Gamma$ [ns] $< 104{,}7$; $3{,}7 < \gamma_{1,2,3}$ [ns] $< 9{,}3$; $0{,}0048 < \Lambda$ [1/ns] $< 0{,}0243$; $0{,}92 < \lambda$ [1/ns] $< 2{,}41$.

4. RESULTS

4.1. Position of the antenna in relation to the starting point (90^0 degrees)

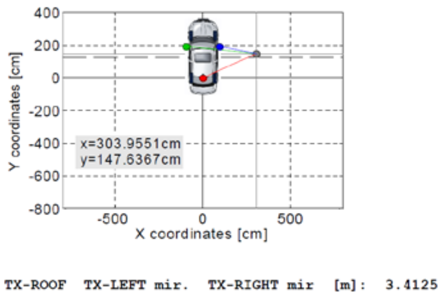

Fig. 6 Situation deployment receiving and transmitting antennas (90^0)

Table 1 Measured and calculated parameters of the SV model

Calculated parameters	Red (LOS)	Green (NLOS)	Blue (LOS)
Frequency range	2-10 GHz	2-10 GHz	2-10 GHz
Antenna gain	0 dB	0 dB	0 dB
Distance [m]	3,4125	4,05	2,175
Antenna type : mono-cone antenna with an omnidirectional pattern	dipole	dipole	dipole
Environment	outdoor parking	outdoor parking	outdoor parking
External temperature	22 ^0C	22 ^0C	22 ^0C
Bandwidth	10 Hz	10 Hz	10 Hz
S-V parameters			
γ_1	0,894	0,567	0,982
γ_2	0,752	0,648	0,757
γ_3	0,857	0,744	0,922
Γ	0,627	0,568	0,657
Λ_1 [1/ns]	0,284	0,297	0,287
λ_1 [1/ns]	0,300	0,300	0,300

4.2. Position of the antenna in relation to the starting point (180^0 degrees)

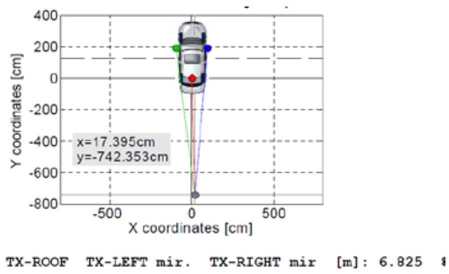

Fig. 7 Situation deployment receiving and transmitting antennas (180^0)

Table 2 Measured and calculated parameters of the SV model

Calculated parameters	Red (LOS)	Green (LOS)	Blue (LOS)
Frequency range	2-10 GHz	2-10 GHz	2-10 GHz
Antenna gain	0 dB	0 dB	0 dB
Distance [m]	6,825	8,925	8,8875
Antenna type : mono-cone antenna with an omnidirectional pattern	dipole	dipole	dipole
Environment	outdoor parking	outdoor parking	outdoor parking
External temperature	22 ^0C	22 ^0C	22 ^0C
Bandwidth	10 Hz	10 Hz	10 Hz
S-V parameters			
γ_1	0,374	0,222	0,221
γ_2	0,407	0,153	0,226
γ_3	0,484	0,185	0,192
Γ	0,347	0,144	0,15
Λ_1 [1/ns]	0,296	0,282	0,284
λ_1 [1/ns]	0,300	0,300	0,300

4.3. Position of the antenna in relation to the starting point (270^0 degrees)

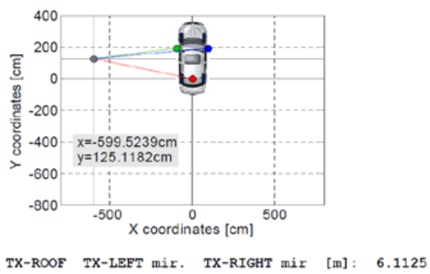

Fig. 8 Situation deployment receiving and transmitting antennas (270^0)

Table 3 Measured and calculated parameters of the SV model

Calculated parameters	**Red (LOS)**	**Green (LOS)**	**Blue (NLOS)**
Frequency range	2-10 GHz	2-10 GHz	2-10 GHz
Antenna gain	0 dB	0 dB	0 dB
Distance [m]	6,1125	5,0625	6,975
Antenna type : mono-cone antenna with an omnidirectional pattern	dipole	dipole	dipole
Environment	outdoor parking	outdoor parking	outdoor parking
External temperature	22 ^0C	22 ^0C	22 ^0C
Bandwidth	10 Hz	10 Hz	10 Hz
S-V parameters			
γ_1	0,421	0,562	0,405
γ_2	0,497	0,593	0,472
γ_3	0,369	0,463	0,383
Γ	0,286	0,38	0,312
Λ_1 [1/ns]	0,295	0,288	0,294
λ_1 [1/ns]	0,300	0,300	0,300

5. CONCLUSIONS

The main goal of the presented work was to calculate the UWB Saleh Vanelzuela model parameters from the measured data for specific outdoor environment. As it is the external environment, which is in our case specifically defined and the measuring method is precisely defined too, I believe that the given study will help to define the static SV parameters for this kind of environment. Calculated and simulated parameters were continuously compared with previously published measurements, see publication [10].

The referenced publications do not exactly describe measuring method and precisely specified environment, so it is not possible to compare the values completely. However, in most of the mentioned articles, there are values of the calculated and measured parameters of the SV model quite similar to our results. For this reason, I think that the given study will help to better understand SV model in UWB band.

The calculations do not consider the parameters of the angular distribution and the small differences in heights of the receiving antennas.

The method for read-out of individual clusters consisted of mechanical finding clusters in the spectrum of the signal and then fitting the exponential curve. Automated algorithm for finding clusters of subsequent automatic counting SV parameters in Matlab will be published in the next post.

There were performed several dozens of measurements and calculations and the results ranged within the interval up to 8 percent of the median value.

For the specified environment, we calculated the static SV model parameters as the ray exponential decay factor, cluster exponential decay factor and corresponding rates. Errors of the cluster exponential factors could have been caused by measurement inaccuracy and interference in the environment. Results are shown in the tab.1, 2, 3.

The publication focuses on the Saleh Valenzuela model and its use in the UWB frequency band. The study provides the methodology for measuring the transmission channel band UWB and method of calculating the parameters of the model defined above.

The appropriate means to verify the accuracy of the received data would be to use the control chain in the broadcasted signal in the channel altogether with the broadcast signal. By using the control chain, we could watch interfering effects on the transmitted signal.

The subsequent publication will include verification of the calculated parameters of the channel. The way, how SV parameters will be verified, will be based on the opposite procedure to the previous one. Using the Matlab simulation program, there will be generated signal, which will be buffered with the standard disturbances in the channel. On the receiving side, the timing of the signal will be transformed by the FFT to the frequency spectrum and it will be compared with measured values in real environment.

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