The Third IEEE Workshop on
Wireless Local Area Networks

Ultra Wide Band Signal Simulations Using FDTD Method

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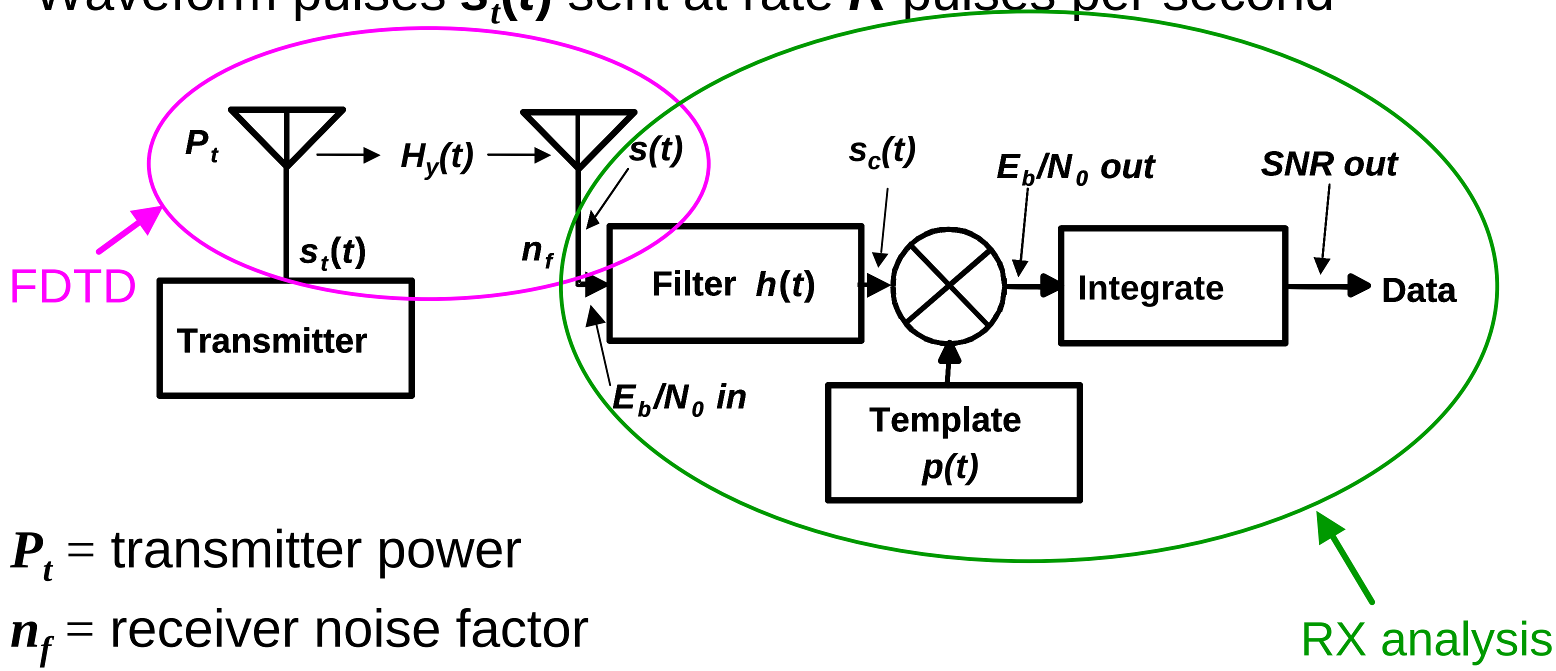
Introduction

- UWB signals generally more complex than sinusoids [1, 2]
  - Sinusoids remains sinusoidal throughout link
  - UWB waveforms and spectra change from transmitter, to radiation, to the receiver
- FDTD method used to study waveforms across link
  - Compared with measurements
  - Receiver efficiency predicted
- UWB Wireless link characterized

UWB Wireless Link

Waveform pulses $\boldsymbol{s_t(t)}$ sent at rate $\boldsymbol{R}$ pulses per second



P_t = transmitter power

n_f = receiver noise factor

$H_y(t)$ = copolarized transverse magnetic field

$s_t(t)$, $s(t)$ = transmitter and received voltage waveforms

$p(t)$ = template waveform

$h(t)$ = receiver filter impulse response

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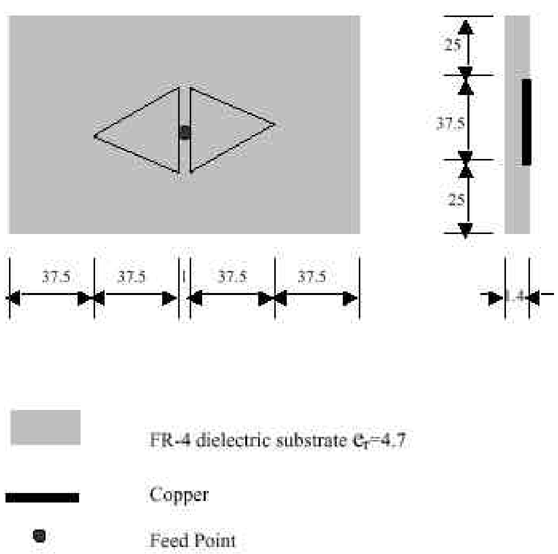
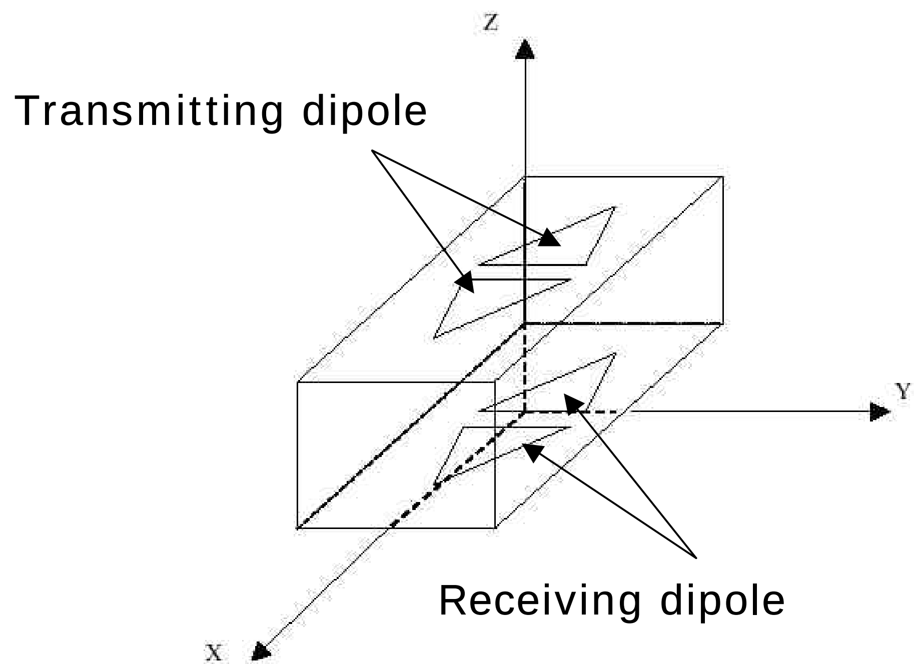
FDTD Simulations

- Radiation between UWB dipole pair [3] simulated [4] with Finite Difference Time Domain (FDTD) method [5]

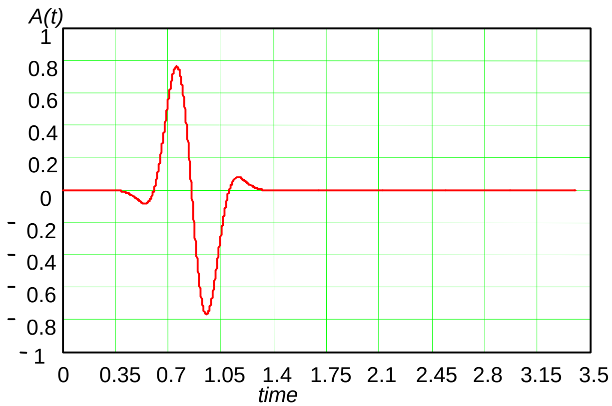




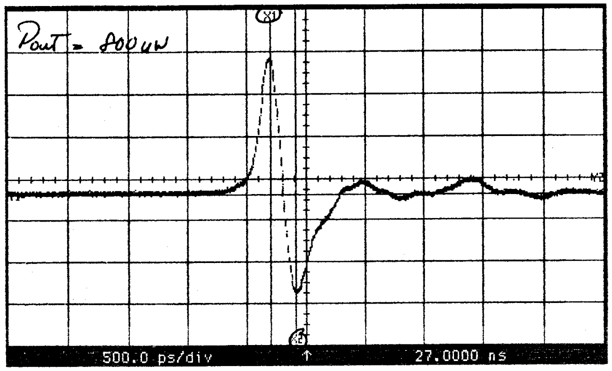
Waveform "A": Stimulus and Response

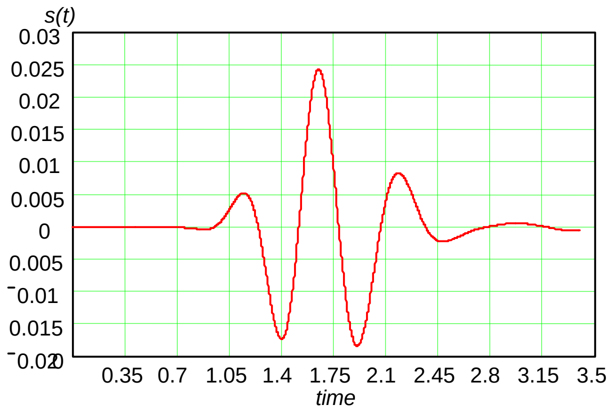
Calculated:

Measured:

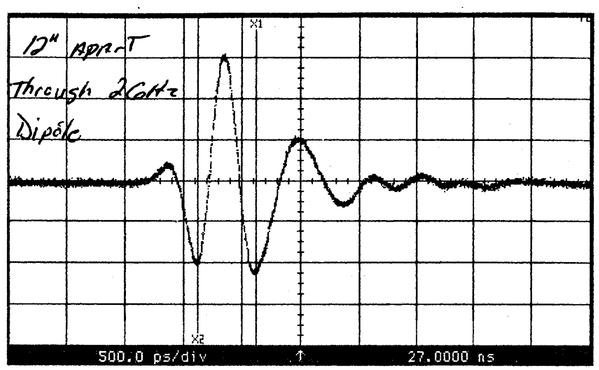


TX





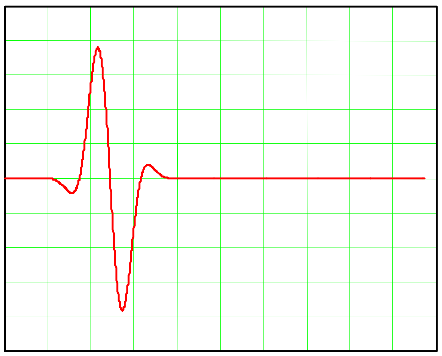
RX

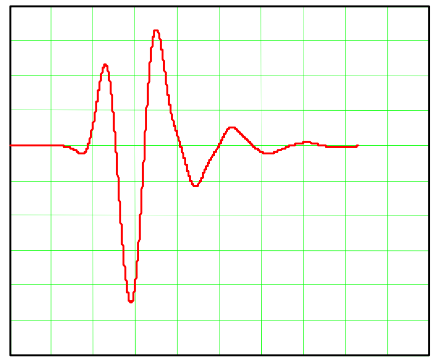


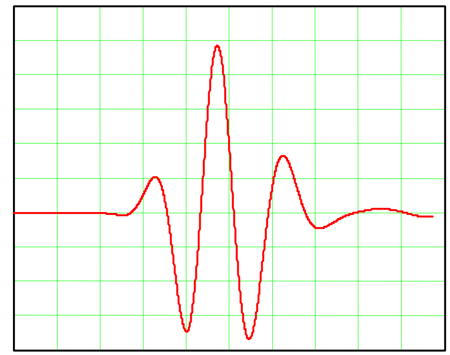
XFDTD Simulations of UWB Waveforms and their Spectra

"A" at TX antenna: | H-field: | RX antenna load:

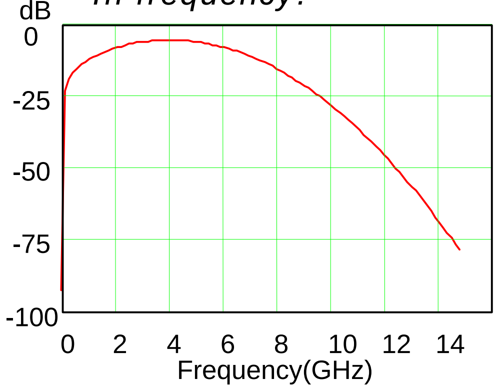
In time:

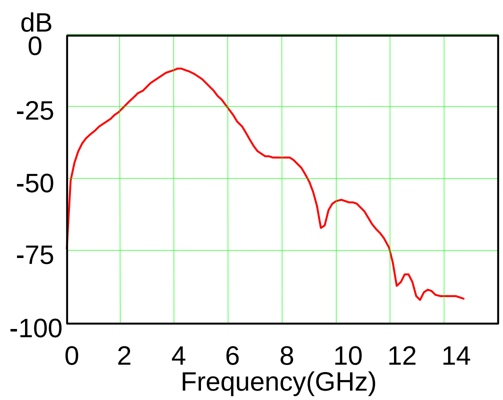


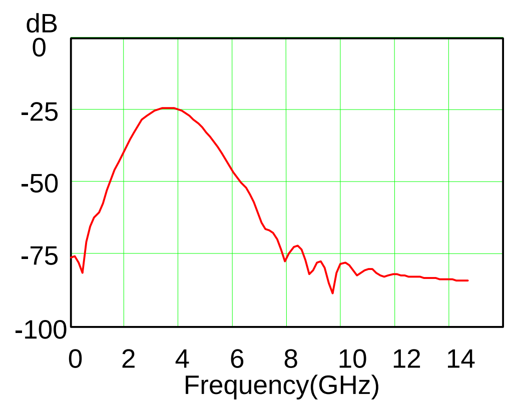




In frequency:







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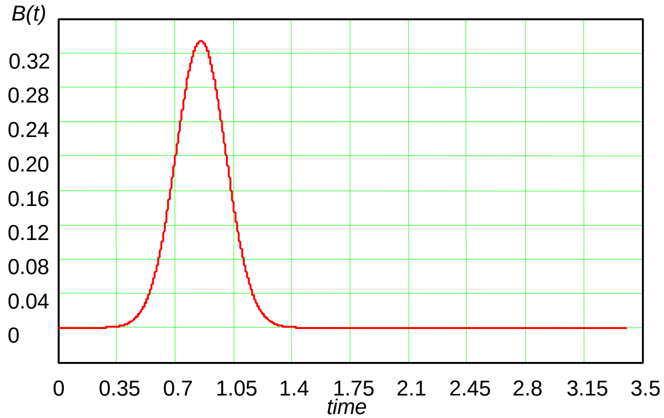
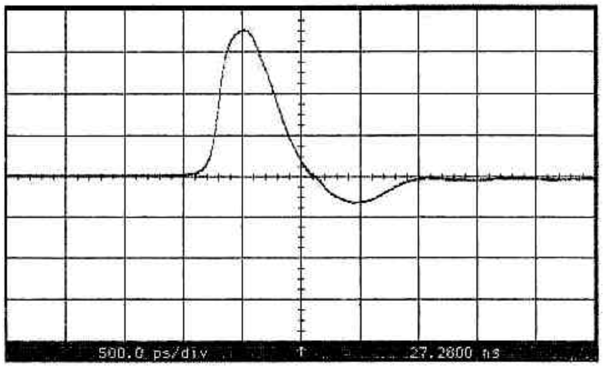
Waveform "B": Stimulus and Response

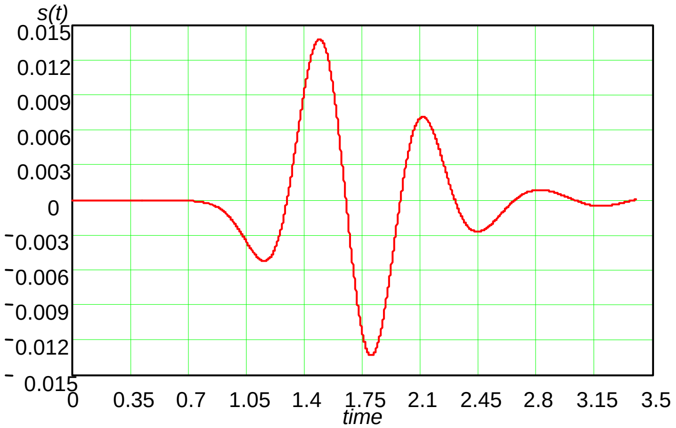
Calculated:

Measured:

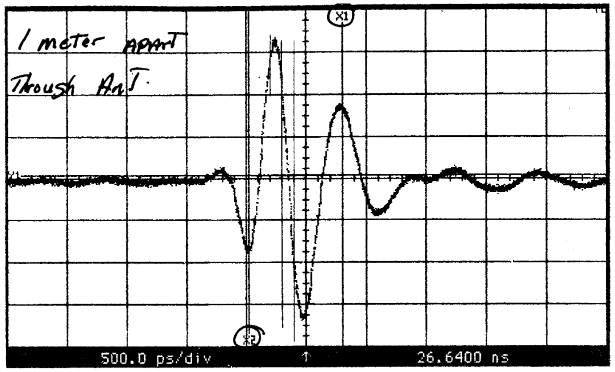


TX





RX



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Transmitted Power Spectral Density

- "Sine wave equivalent" power density at distance d is

$$P_{DENSITY,CW} = P_t\, G_t(\, f_c\,)/(4\pi d^{\,2})$$

- Power spectral density is

$$P_D(\, f\,) = |\mathcal{F}\,\{H_y\,(t)\}|^2\, \eta_0$$

- Which integrates to $P_{DENSITY}$ and includes transmit antenna gain $G_t\,(\, f\,)$

Receive Antenna Aperture

- Received co-polarized signal is:

$$P_{RX} = \int_{-\infty}^{\infty} |F\{H_y(t)\}|^2 \eta_0 A_e(f)\, df$$

- And $|F\{H_y(t)\}|^2\eta_0 = P_D(f)$ power spectral density of $H_y(t)$ integrates to $P_{DENSITY}$;

$$\eta_0 = \mu_0 c = 376.73 \text{ ohms}$$

- Aperture factor for a unity gain antenna is:

$$A_e(f) = (c/f)^2/4\pi$$

UWB Propagation

- UWB transmissions analyzed, for convenience, by free space propagation at a "center frequency" f_c
- Propagation assumed to be "sine wave equivalent" at the center frequency
- For a given EIRP=P_tG_t , the CW or sine-wave equivalent is:

$$P_{RX,\,CW} = P_{DENSITY,CW} A_e(f_c)$$

The "Sine Wave Equivalent" Propagation

- Actual received signal relative to the sine-wave equivalent signal is

$$A_F = \sqrt{\frac{\eta_0 \int_{-\infty}^{\infty} |\mathcal{F}\{H_y(t)\}|^2 A_e(f)\, df}{A_e(f_c)\, P_t\, G_t(f_c)/(4\pi d^2)}}$$

- Value of A_F is waveform dependent, but generally close to 1; hence "sine wave equivalent" propagation usually justified

Example:
Gaussian Derivative *H*-Field

- <u>If</u>: magnetic field at distance *d* in time domain can be represented by

$$H_y(t) = \left(\frac{t^2}{\tau^2} - 1\right)\exp\left(\frac{-1}{2}\,\frac{t^2}{\tau^2}\right)\sqrt{\frac{4}{\tau\,3\sqrt{\pi}}}$$

- <u>Then</u>: magnetic field at distance *d* in frequency domain is

$$H_y(f) = (f\,\tau)^2 \exp\left[\frac{-1}{2}\,(2\pi\,f\,\tau)^2\right]\sqrt{\tau}\left(\frac{8}{3}\sqrt{6}\,\pi\right)^{\frac{9}{4}}$$

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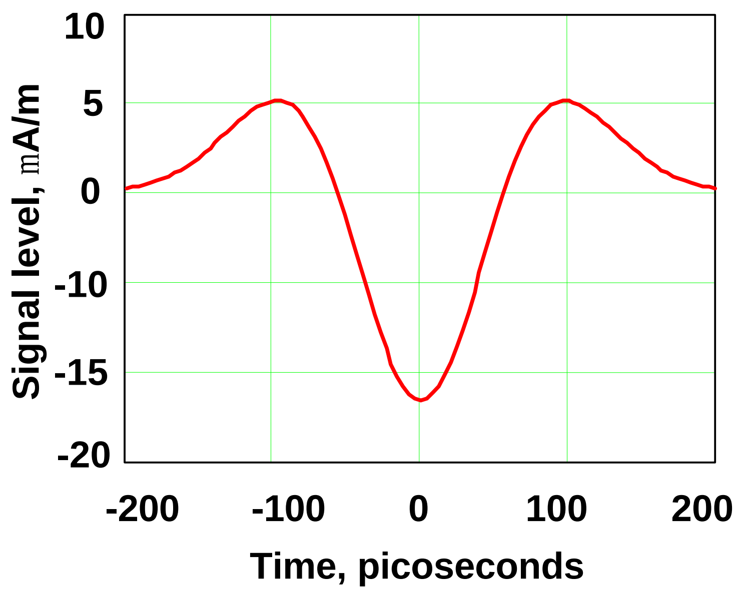
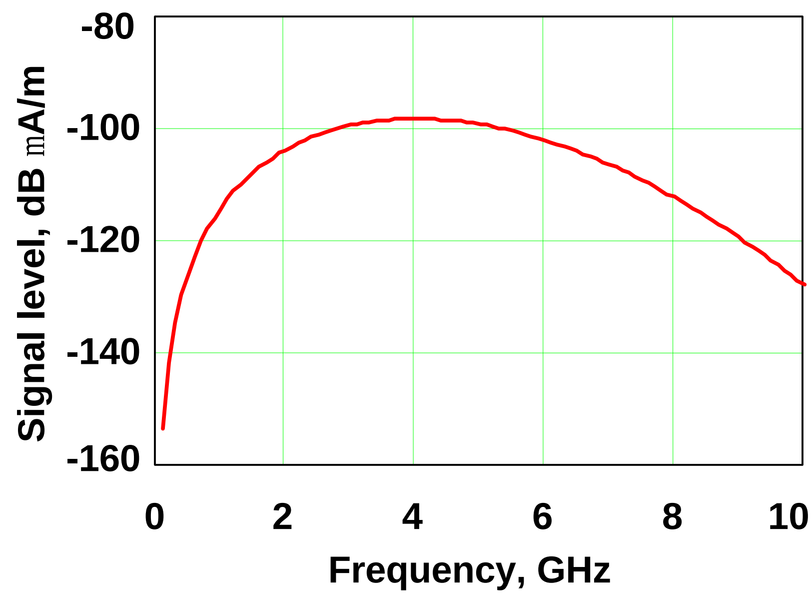
Example: A_F for Gaussian Derivative H-field





$$A_F = \sqrt{\frac{\eta_0 \int_{-\infty}^{\infty} |F\{H_y(t)\}|^2 A_e(f)\, df}{A_e(f_c)\, P_t G_t(f_c)/(4\pi d^2)}} = 1.15$$

UWB Path Link

- Receive antenna gain is constant over bandwidth of pulse
- Path attenuation between unity gain antennas:

$$P_L = 20\log\left(\frac{c\,A_F}{4p d f_c}\right) - L_w\left(d - d_w\right)\Phi(d > d_w)$$

- A_F = antenna “sine-wave equivalent” aperture factor
- L_w = in-building attenuation, dB/m
- d_w = distance to first wall

Bit Energy to Noise Density Ratio

- At receiver antenna load:
  [independent of wave shape!]

$$\left.\frac{E_b}{N_0}\right|_{in} = \frac{\int s(t)^2 dt}{N_0 n_f}$$

- At correlator output:

$$\left.\frac{E_b}{N_0}\right|_{c:out} = \frac{\left|\int\int s(\tau)h(t-\tau)\, d\tau \;\; p(t)\, dt\right|^2}{N_0\, n_f \int \left|\int p(\tau)h(t-\tau)\, d\tau\right|^2 dt}$$

- Efficiency:

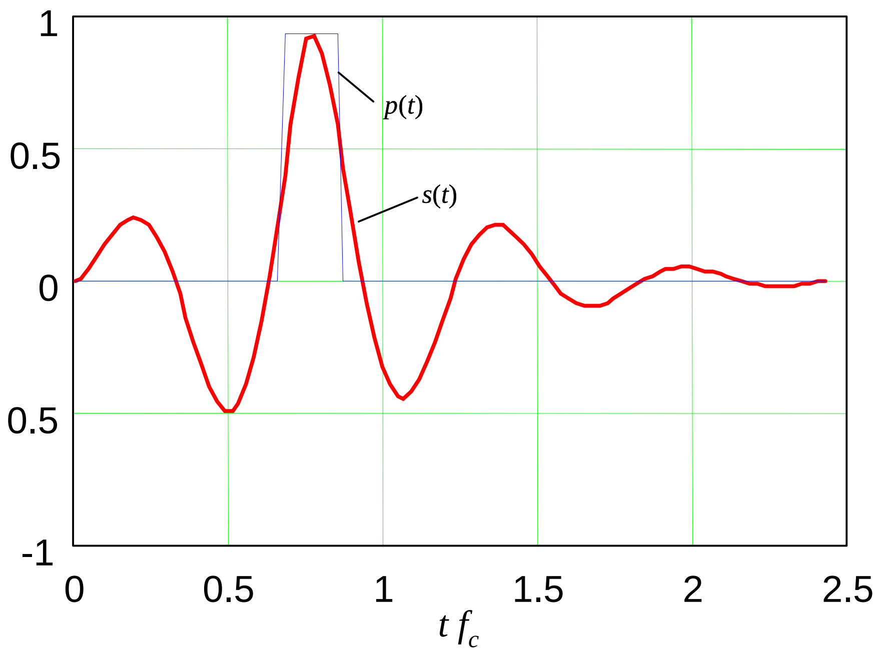
$$e_c = (E_b/N_0)_{c:out} \, / \, (E_b/N_0)_{in}$$

- Optimum for:

$$\int p(\tau)h(t-\tau)\, d\tau = Cs(t)$$

Signal "A" and Pulse Template

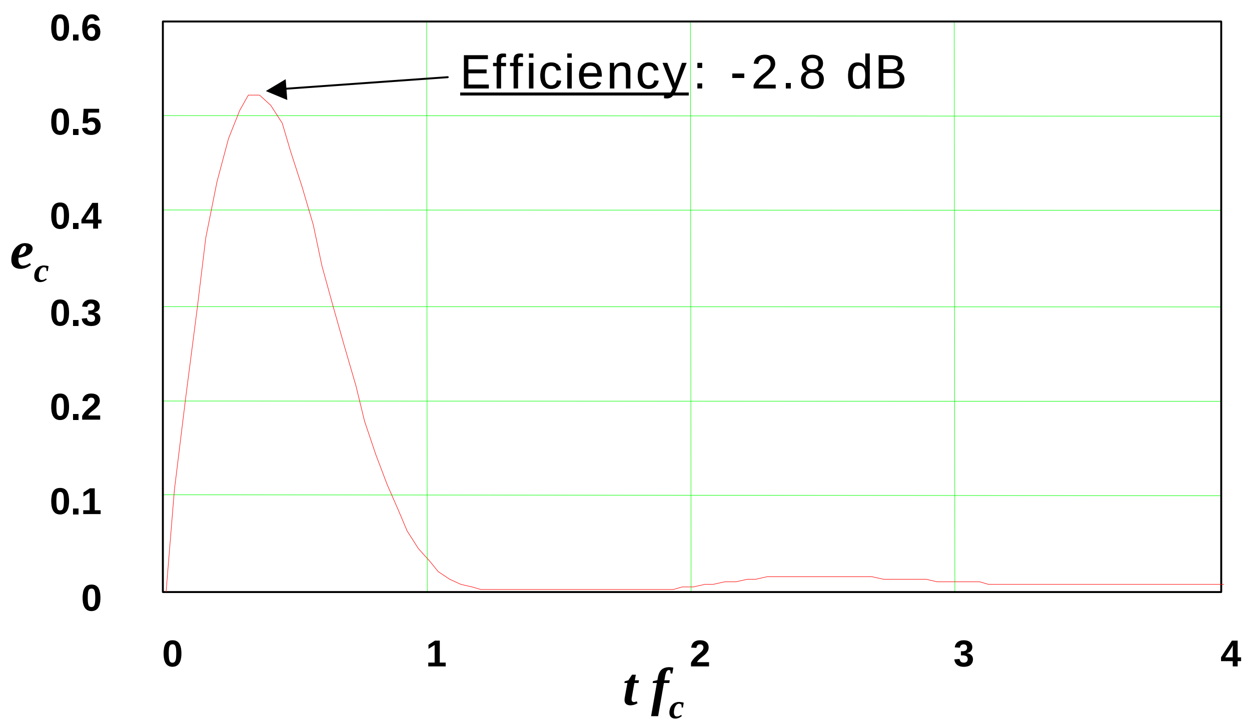
- Red: Signal at correlator input: $s_c(t)$
- Blue: Optimum width template: $p(t)$



Rectangular pulse is optimally centered at signal amplitude peak,
[*better templates possible*]

Sampler Cell Efficiency "A" Waveform

- Efficiency e_c *vs*. template width tf_c with rectangular template pulse $p(t)$



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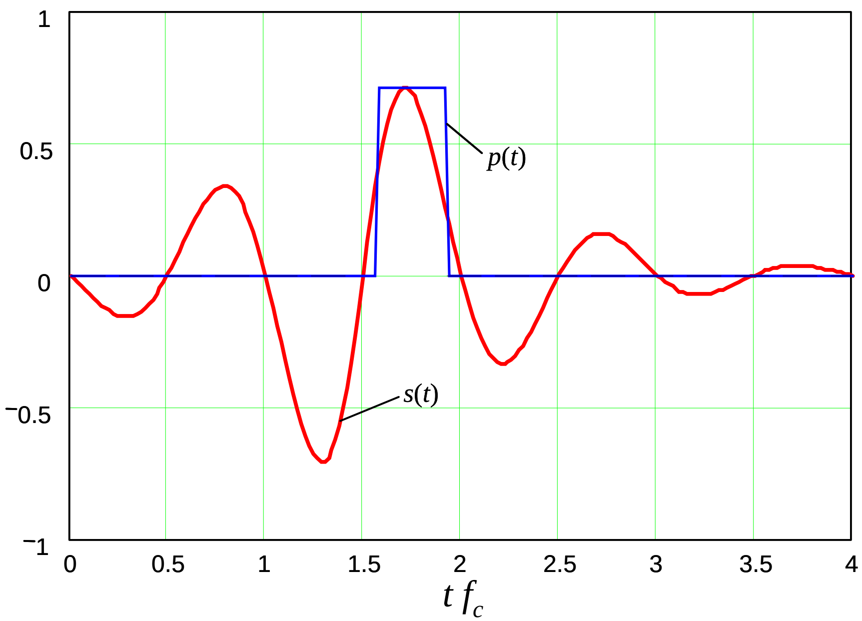
Signal “B” and Pulse Template

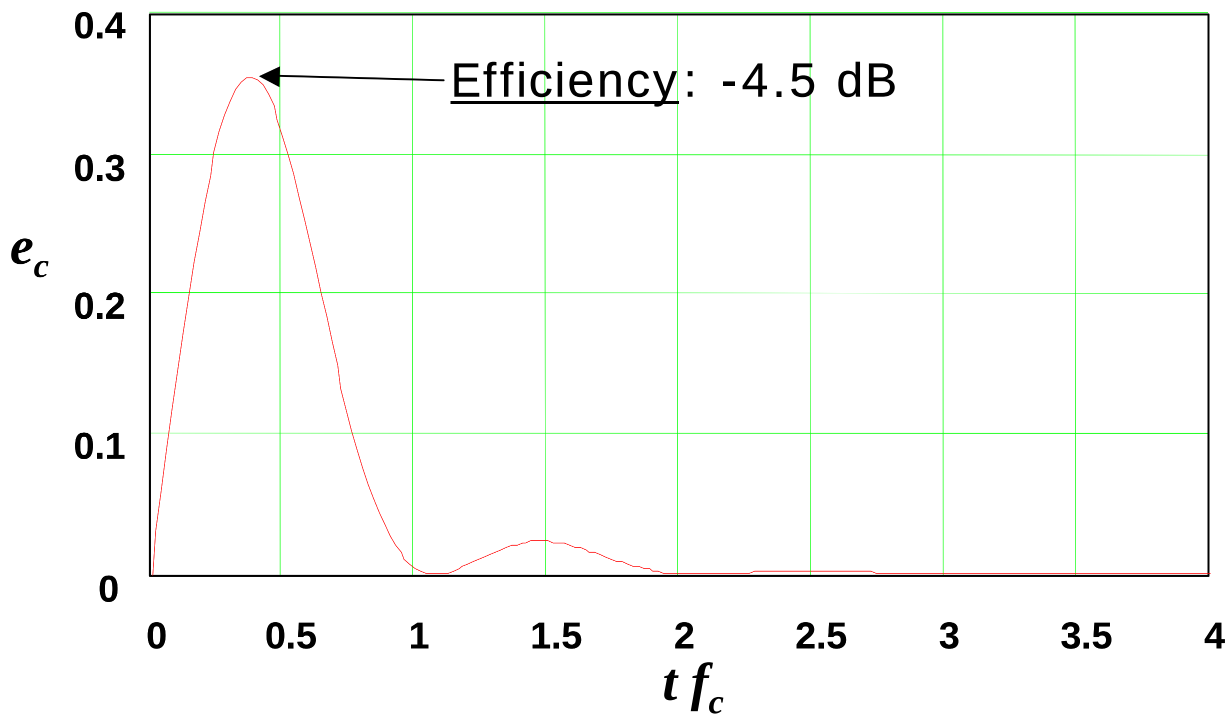
- Red: Signal at correlator input: $s_c(t)$
- Blue: Optimum width template: $p(t)$



Template pulse is optimally centered at signal amplitude peak

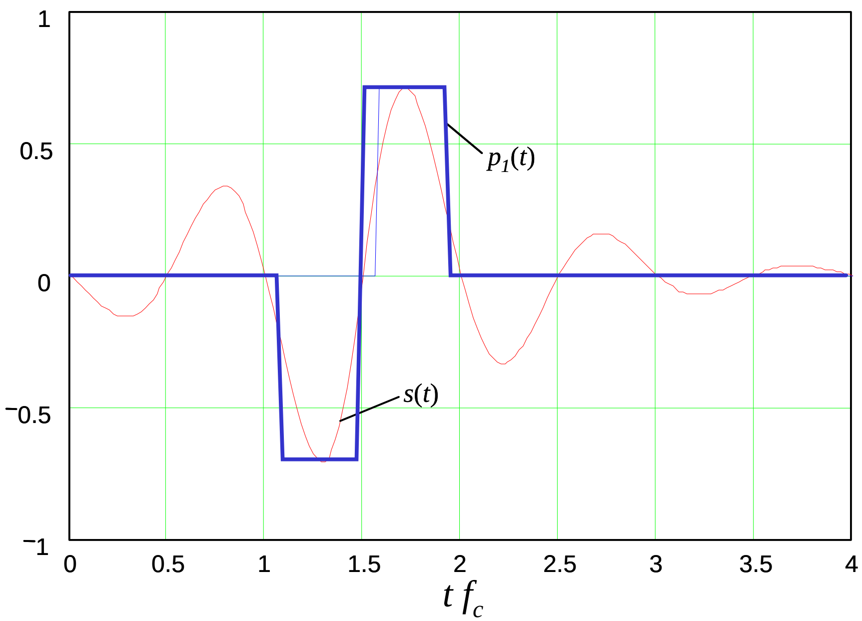
Sampler Cell Efficiency "B" Waveform

- Efficiency e_c *vs*. template width tf_c with rectangular template pulse $p(t)$



Signal Waveform “B” and Bipolar Sampler

- Red: Signal $s(t) = \sin\left[2\pi f_c (t - t_0)\right] \exp\left(-\left|t - t_0\right| \frac{\pi f_c}{Q_R}\right) \Phi(t)$
- Blue: Optimum width <u>bipolar</u> template



<u>Efficiency</u>: -1.6 dB

Receiver System *SNR*

- Received power [6] is:

$$P_{RX} = P_{EIRP}\,(A_f\,c/4\pi d f_c)^2\ 10^{-L_w(d-d_w)\Phi(d > d_w)}$$

- Input signal to noise at impulse rate *R*:

$$SNR_{in} = (E_b/N_0)_{in}\,R/B_{RF} = P_{RX}/\,n_f\,kTB_{RF}$$

- Receiver implementation losses:

$$L_{sys} = -10\,\log(e_c/n_f)$$

Receiver System *SNR*

- Integrating I impulses per bit a R bps:

$$R\,I = B_{data}$$

- System signal to noise at output:

$$SNR_{out} = (E_b / N_0)_{out}\, R / B_{data} = (e_c / n_f) P_{RX} / kTB_{data}$$

- Finally, processing gain is:

$$PG = SNR_{out} / SNR_{in} = e_c\, B_{RF} / B_{data}$$

Receiver Sensitivity

- Receiver sensitivity S is:

$$S = 10\log(kTB) + SNR + NF + e_c$$

- Assuming a needed $SNR=7$ dB, noise figure $NF=3$ dB and loss $e_c = 2$ dB

$$S = -104 \text{ dBm/MHz}$$

- System gain is $-S$ dB/mW$_{\text{EIRP}}$

Summary

- Impulse transmissions studied using FDTD method
- Link performance impacted by UWB wave forms
- UWB Receiver performance characterized
- Watch future IEEE VTS News for:

UWB Radio: an Emerging PAN and Positioning Technology

References

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