Ultra Wide Band Radio Fundamentals

Link Budget

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Outline

- Link budget in short
- PSD and BW of interest
- SNR and modulation
- Simulation time!

Outline

Link budget in short

1. What: **Determine the maximum distance** of propagation at a given bit rate under a maximum BER constraint for the UWB point-to-point link.

2. Why: **Coexistence** with other radio signals requires compliance with emission masks regulated by the FCC.

Link Budget Formula (1/2)

The BER constraint can be seen as an SNR constraint, thus:

$$\mathrm{SNR}_0 \leq \mathrm{SNR} = \frac{\mathscr{E}_r}{\mathscr{E}_N} = \frac{\mathscr{P}_r\, T_b}{\frac{1}{2} K T_0 F}.$$

System margin

$$\mathrm{SNR}\;/\;\mathrm{SNR}_0 =: M \geq 1$$

$\mathscr{P}_r$ is the available received power

PSD of Tx signal

$$\mathscr{P}_r = \int_{f_L}^{f_H} \frac{2\mathscr{S}_{pp}(f)}{A_{fs}(f)}\, df$$

$$A_{fs}(f) = \frac{4\pi D^2}{G_T\, G_R}\frac{4\pi}{\lambda^2}, \quad \lambda = c/f.$$

Remind from lecture:

1. Required energy at the receiver

$$E_r = M \cdot SNR_{spec} \cdot E_{noise}$$

receiving antenna temperature

$$E_r = M \cdot SNR_{spec} \cdot \frac{1}{2} k\left(Temp_A + \left(F(f) - 1\right) Temp_0\right)$$

standard temperature (290K)

$$P_r T_b = M \cdot SNR_{spec} \cdot \frac{1}{2} k\left(Temp_A + \left(F(f) - 1\right) Temp_0\right)$$

$$\Rightarrow P_r = \frac{E_r}{T_b} = \frac{M\, SNR_0 E_N}{T_b}$$

2. Received power

$$P_r = 2\int_{f_L}^{f_H} \frac{P_S(f)}{A_{FS}(f)} df = 2\int_{f_L}^{f_H} \frac{P_S(f)}{\frac{(4\pi)^2 D^2 f^2}{G_T G_R c^2}} df$$

$P_S(f)$ double-sided transmitted power spectral density

$A_{FS}(f)$ Free-space attenuation

Link Budget Formula (2/2)

Solving in D:

$$D = \left[\frac{G_T G_R \left(\frac{c}{4\pi}\right)^2 T_b}{M \, \mathrm{SNR}_0 \, \mathscr{E}_N} \int_{f_L}^{f_H} \frac{2 \mathscr{S}_{pp}(f)}{f^2} df \right]^{1/2}$$

Thus, the maximum link distance depends upon the:

1. **bit rate**: T_b with $D \propto 1/\sqrt{R_b}$
2. **PSD of Tx signal and BW of interest**: $\mathscr{S}_{pp}(f)$ and $[f_L, f_H]$
3. **min SNR to achieve the fixed BER**: SNR_0

Outline

Link budget in short

PSD and BW of interest

SNR and modulation

Simulation time!

Choose the signal to transmit (1/2)

CASE 1. We transmit the 5^{th} derivative of a gaussian pulse. You can accomplish this task in many ways:

1. writing the PSD directly*, with $N = 5$:

$$\mathscr{S}_{pp}(f) = A_{max} \frac{(2\pi f \sigma)^{2N}}{N^N e^{-N}} e^{-(2\pi f \sigma)^2}$$

where:

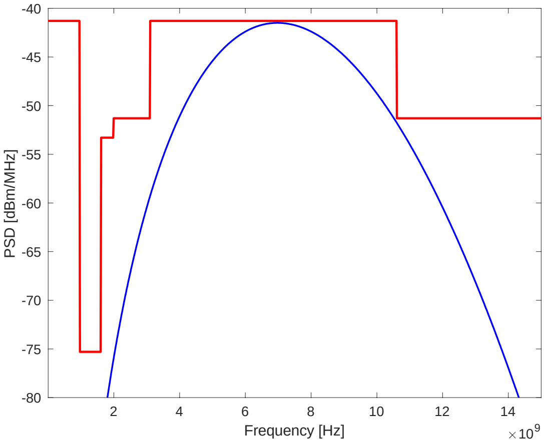
- $A_{max} = 10^{-13.15}$ W/Hz
- sigma=51 ps
- fMax = 30 GHz

2. using the function `gaussian_wf` then computing the PSD.

*[According to (Sheng et al., 2003)].

Choose the signal to transmit (1/2)

Why the 5^{th} derivative?



Choose the signal to transmit (2/2)

CASE 2. We transmit an ideal signal that fully exploit the 3.1–10.6 GHz bandwidth of the FCC mask.

The PSD of the signal is the mask itself, in that range.

NB: verify that the total power of the signal is 0.55 mW.

Choose the signal to transmit (2/2)

CASE 2. We transmit an ideal signal that takes full advantage of the 3.1–10.6 GHz bandwidth of the FCC mask.

Frequency in MHz	$EIRP_{mb}$ in dBm
0–960	-41.3
960–1610	-75.3
1610–1990	-53.3
1990–3100	-51.3
3100–10600	-41.3
Above 10600	-51.3

Outline

M–PAM and M–PPM probability of error in AWGN channel

M–PAM

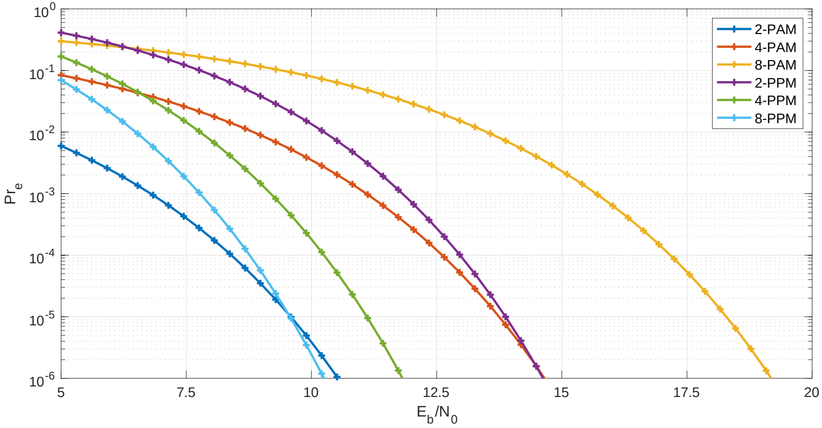
$$\Pr_e^{PAM} = \left(1 - \frac{1}{M}\right) \operatorname{erfc} y \quad \text{with} \quad y^2 = \frac{3 \log_2 M}{M^2 - 1} \frac{\mathcal{E}_b}{N_0}$$

M–PPM

$$\Pr_e^{PPM} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \left\{ 1 - \left[1 - \frac{1}{2} \operatorname{erfc}\left(\frac{\eta + m}{\sqrt{2}} \right) \right]^{M-1} \right\} e^{-\eta^2/2} d\eta$$

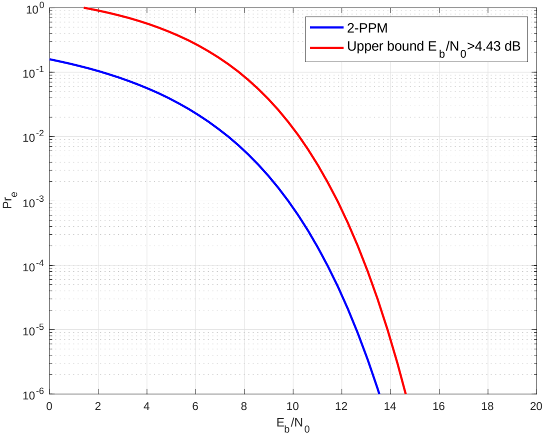
with $m = \sqrt{2 \log_2 M \; \mathcal{E}_b / N_0}$.

M–PAM and M–PPM



M–PPM approximation (tight for Eb/N0>4.43 dB)

$$\Pr_e < e^{-\log_2 M (E_b / N_0 - 2\log_e 2)/2}$$



Outline

Simulation time! (1/3)

We shall write a script that, given a specified symbol Pr_e, returns the minimum required $E_b/N0$.

The function declaration could be:

```
EbN0=getEbN0(MOD, M, Pre)
```

with:

- `MOD` (modulation type): 1 (PAM), 2 (PPM)
- `M` (bit per symbol)
- `Pre` (symbol probability of error): 1e-3
- Range of E_b/N_0: 0-20dB

Simulation time! (2/3)

The core link-budget routine, that computes the maximum link distance, is the follow.

The function declaration could be:

```
D=distcmpt(EbN0min, Gt, Gr, MdB, FdB, Rb, PSDss,BOI)
```

with:

- `EbN0min`: required Eb/N0
- `Gt`: tx antenna gain
- `Gr`: rx antenna gain
- `MdB`: system margin in dB
- `FdB`: rx noise figure
- `Rb`: bit rate
- `PSDss`: single sided PSD
- `BOI`: bandwidth of Interest

Simulation time! (3/3)

Parameters for function `distcmpt`:

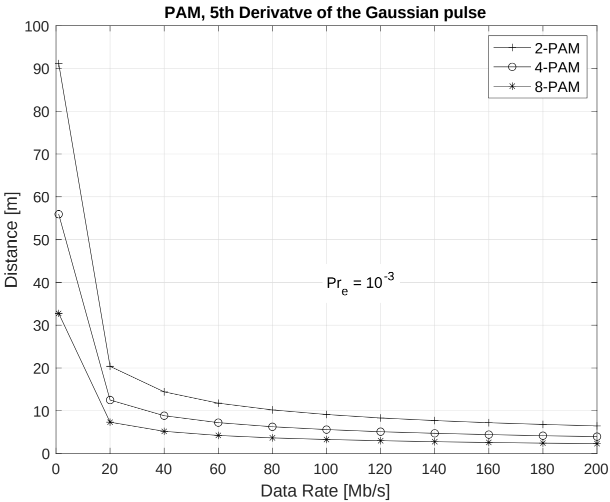
`EbN0min`: just computed
`Gt` = 1
`Gr` = 1
`FdB` = 7 dB

`MdB` = 5 dB
`Rb` = [1, 20:20:200] Mb/s
`f_MAX`= 30 GHz

We will consider two cases for the bandwidth of interest and PSD :

- Case 1:
  - `PSDss`: SS-PSD of 5th deriv. of Gaussian Pulse
  - `BOI` obtained as the -3 dB bandwidth of the pulse
- Case 2:
  - `PSDss`: FCC mask
  - `BOI` = 3.1 – 10.6 GHz

Results: case 1 - gaussian pulse, Mod = 1 (PAM)



Results: case 2 - ideal signal, Mod = 1 (PAM)