FM Range Calculation

This sheet is to estimate of the range that can be expected from an FM modulated system.

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The sheet calculates the range that can be expected from an FM modulated system It uses a modified-version of the Friss transmission equation. It starts by calculating the minimum signal strength in dBm that is required for successful operation. It uses two error-function-curves, the normal one (erfc) for average while gaussian noise (AWGN), and a second one used for Raleigh fading. The range is between the two.

Many of the other equations are adapted from *Pozar, Microwave & RF Design of Wireless Systems.* The propagation equations were found on *http://www.sss-mag/indoor.html* and *http://people.deas.harvard.edu/~jones/es151/prop_models/propagation.html.* The error function calculations are from "Wireless Communications", by Andrea Goldsmith.

$kHz := 1000 \cdot Hz$ $mW := 10^{-3} \cdot W$ $\mu s := 10^{-6} \cdot s$ $x := -5, -4.9 .. 25$ $ber(x) := 0.5 \, erfc\left(\sqrt{\frac{10^{\frac{x}{10}}}{2}}\right)$

This is the BER error function curve for coherent FSK and can be used to calculate BER for different Eb/No. This equation I found in "An Intro to Analogue & Digital Communications" by Simon Haykin.

The required Eb/No for BER = 0.1, is 2.2dB

$x := 1$ Given $BER = 0.5 \, erfc\left(\sqrt{\frac{10^{\frac{x}{10}}}{2}}\right)$ $EbNo\_dB(BER) := Find(x)$ $EbNo\_dB(0.001) = 9.800$

Raleigh fading

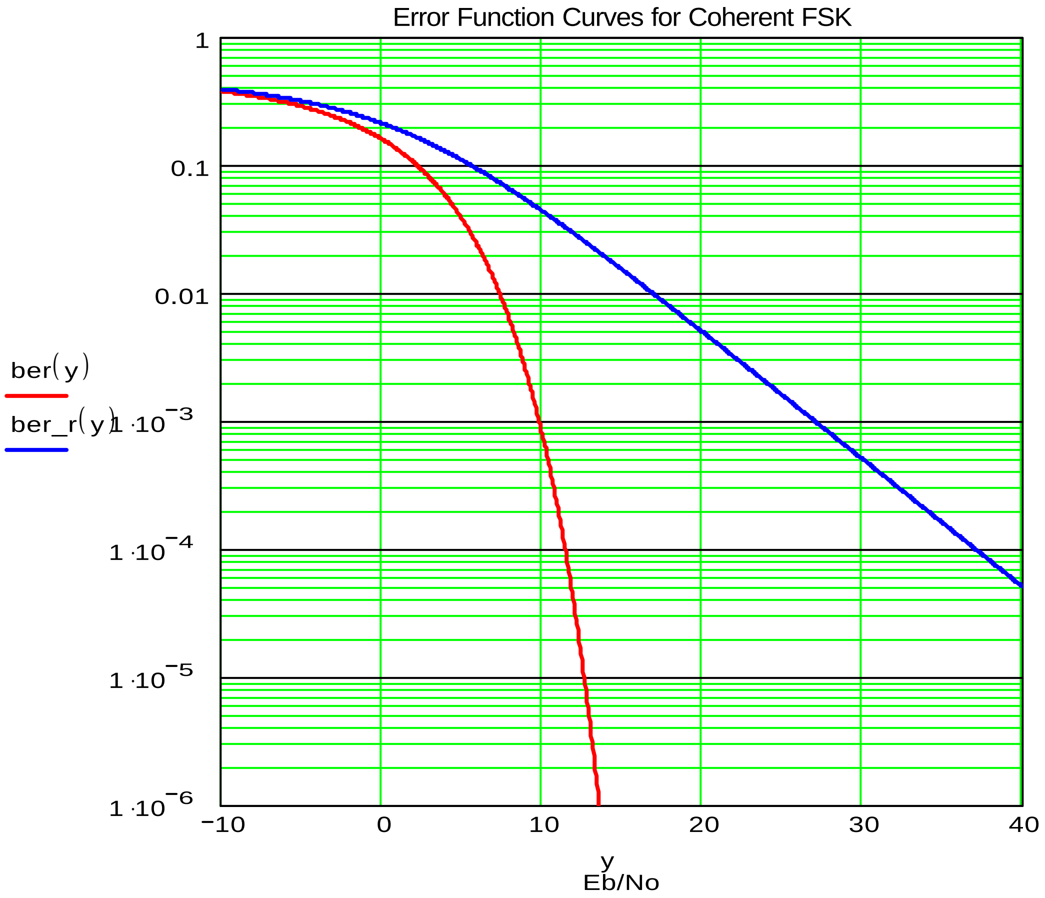
The real signal is likely to be subjected to fading of which the most severe version is **Raleigh fading**. This is best represented as an alternate Error Function Curve, and is calculated according to "Wireless Communications", by Andrea Goldsmith, equation 6.59.

$$ber\_r(x) := 0.5\left(1 - \sqrt{\frac{10^{\frac{x}{10}}}{2 + 10^{\frac{x}{10}}}}\right)$$

$$y := 1 \quad \text{Given} \quad BER = 0.5\left(1 - \sqrt{\frac{10^{\frac{y}{10}}}{2 + 10^{\frac{y}{10}}}}\right) \quad EbNo\_dB\_R(BER) := Find(y)$$

EbNo_dB_R(0.005) = 19.935 EbNo_dB_R(0.01) = 16.858

EbNo_dB_R(0.1) = 5.509 EbNo_dB_R(0.05) = 9.308



BER curves.
RED curve is with average white gaussian noise.
BLUE curve is with Raleigh fading.

Calculate the limit of sensitivity and the required receiver bandwidth

These depend on the deviation and bit period and are use the standard error function curve.

$$BT(fm\_dev, bit\_period) := fm\_dev \cdot bit\_period$$

$$Carsons\_BW(fm\_dev, bit\_period) := 2 \cdot \left(\frac{1}{2 \cdot bit\_period} + fm\_dev\right)$$

$$min\_detect\_signal\_dBm(BER, fm\_dev, bit\_period, rx\_NF\_dB) := -174 + 10 \cdot \log\left(\frac{Carsons\_BW(fm\_dev, bit\_period)}{Hz}\right) + EbNo\_dB(BER) + rx\_NF\_dB - 10 \log(2 BT(fm\_dev, bit\_period))$$

$$min\_detect\_signal\_W(BER, fm\_dev, bit\_period, rx\_NF\_dB) := 10^{\frac{min\_detect\_signal\_dBm(BER, fm\_dev, bit\_period, rx\_NF\_dB)}{10}} \cdot mW$$

$$min\_detect\_signal\_dBm\left(0.001, 20kHz, \frac{s}{2 \cdot 20000}, 7\right) = -108 \qquad Carsons\_BW\left(20kHz, \frac{s}{2 \cdot 20000}\right) = 80\, kHz$$

$$min\_detect\_signal\_dBm\left(0.001, 30kHz, \frac{s}{2 \cdot 10000}, 7\right) = -113 \qquad Carsons\_BW\left(30kHz, \frac{s}{2 \cdot 10000}\right) = 80\, kHz$$

$$min\_detect\_signal\_dBm\left(0.001, 35kHz, \frac{s}{2 \cdot 5000}, 7\right) = -117 \qquad Carsons\_BW\left(35kHz, \frac{s}{2 \cdot 5000}\right) = 80\, kHz$$

$$min\_detect\_signal\_dBm\left(0.001, 37.5kHz, \frac{s}{2 \cdot 2500}, 7\right) = -120 \qquad Carsons\_BW\left(37.5kHz, \frac{s}{2 \cdot 2500}\right) = 80\, kHz$$

These figures show that the sensitivity and BW for different deviations and bit period. The 2 for the bit period because the system is manchester encoded.

The sensitivity limit is for AWGN

$$min\_detect\_signal\_R\_dBm(BER, fm\_dev, bit\_period, rx\_NF\_dB) := -174 + 10 \cdot \log\left(\frac{Carsons\_BW(fm\_dev, bit\_period)}{Hz}\right) + EbNo\_dB\_R(BER) + rx\_NF\_dB - 10 \log(2 BT(fm\_dev, bit\_peri$$

$$min\_detect\_signal\_R\_W(BER, fm\_dev, bit\_period, rx\_NF\_dB) := 10^{\frac{min\_detect\_signal\_R\_dBm(BER, fm\_dev, bit\_period, rx\_NF\_dB)}{10}} \cdot mW$$

This plot shows the receive sensitivity limit for different BERs

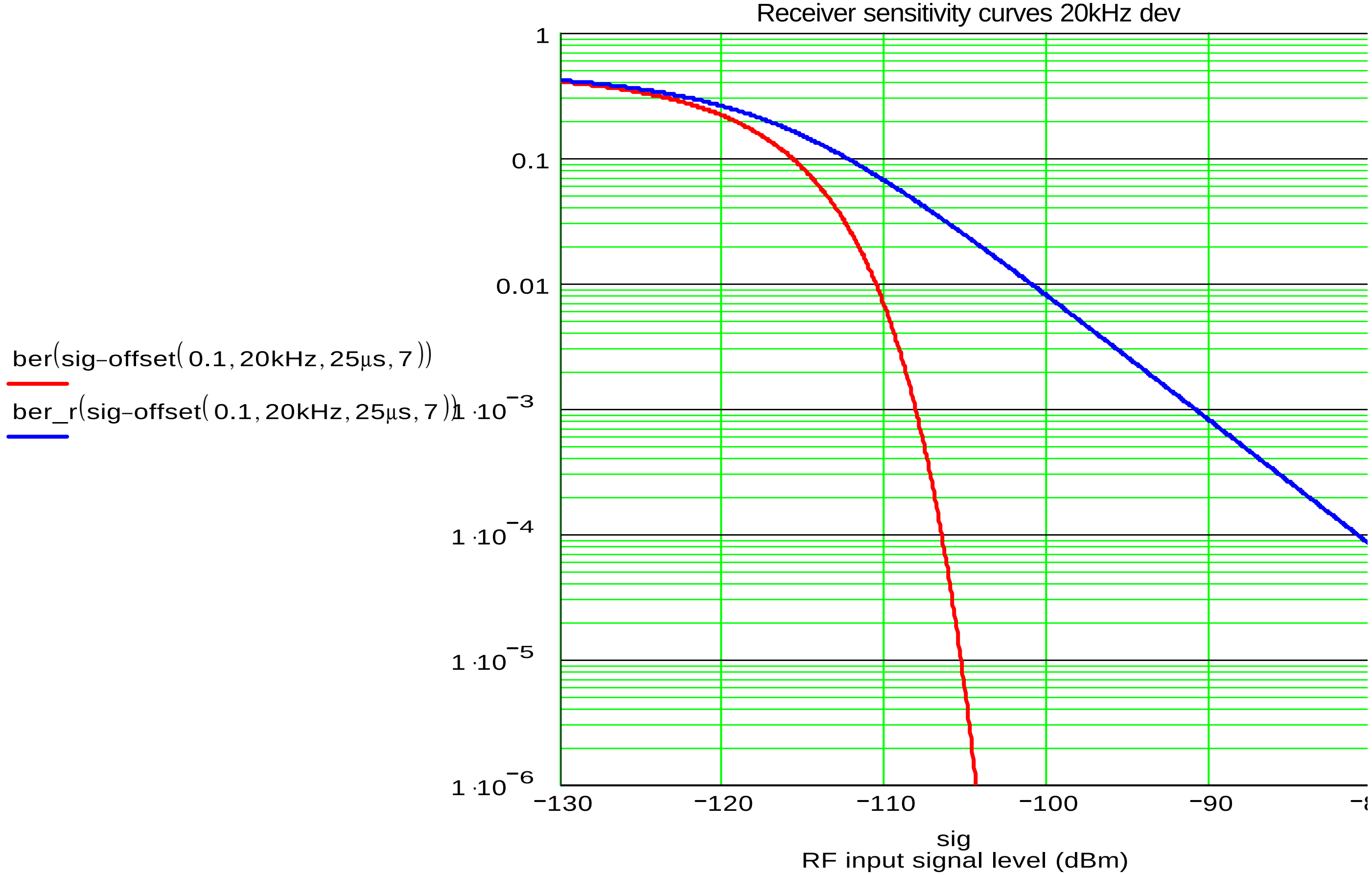
offset(BER, fm_dev, bit_period, rx_NF_dB) := min_detect_signal_dBm(BER, fm_dev, bit_period, rx_NF_dB) − EbNo_dB(BER)

offset(0.1, 20kHz, 25µs, 7) = −118.0

This graph is referred to as the error function curve and shows the input signal required for different BERs

in this case, a starting BER is required to make the convergence work, I have put 0.1.

This is a very useful plot to test receiver operation (use RED curve).



Receiver sensitivity curves for 20KHz dev, 25us bit period, 7dB NF.
RED curve is with average white gaussian noise.
BLUE curve is with Raleigh fading.

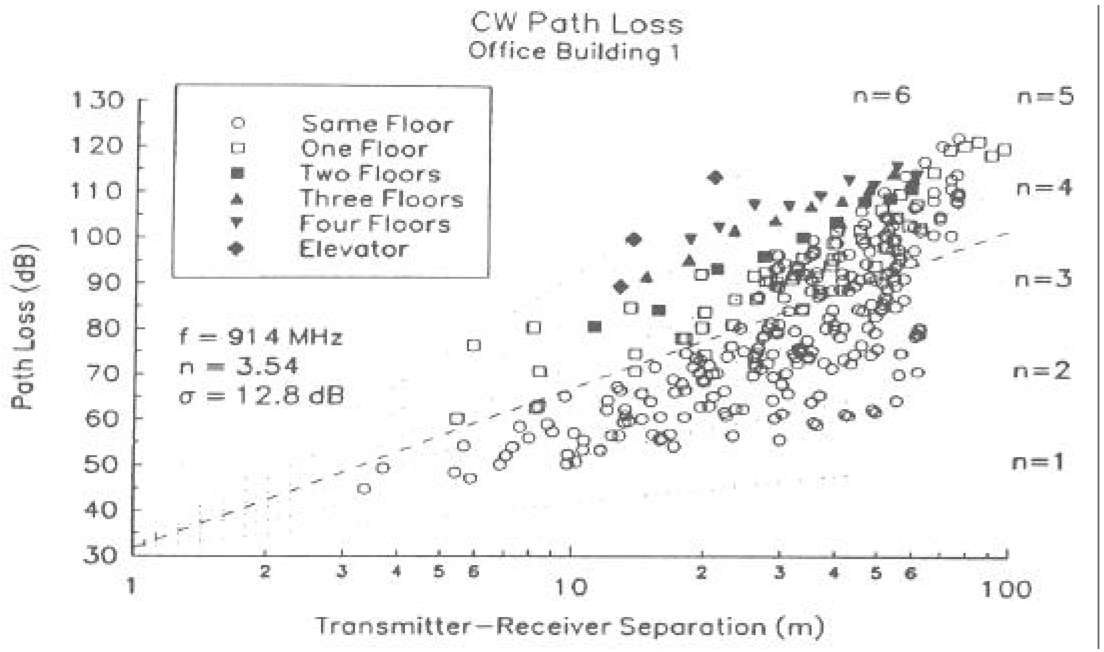
Calculate the expected range

Using a modified form of the Friss equation from **Rappaport & Theodore**. N is the propagation coefficient, refer to the picture below. These range calculations use both the **Raleigh** fading model and **non Raleigh** fading.

$freq := 860 \cdot MHz$ $N := 2.5$

The Friis equation is modified according plots from **Rappaport, Theodore** S., Wireless Communications - Principles & Practice, IEEE Press, 1996.

In this sheet I have set **N=2.5** as communication is same floor



$$antenna\_gain(antenna\_gain\_dB) := 10^{\frac{antenna\_gain\_(}{10}} \qquad tx\_power\_W(tx\_power\_dBm) := 10^{\frac{tx\_power\_dBm}{10}} \cdot mW$$

$$RangeRT\_R(tx\_power\_dBm, BER, fm\_dev, bit\_period, rx\_NF\_dB, antenna\_gain\_dB) := \frac{3 \cdot 10^{8} \frac{m}{s}}{4 \cdot \pi \cdot freq} \left(\frac{antenna\_gain(antenna\_gain\_dB)^{2} \cdot tx\_power\_W(tx\_power\_dBm)}{min\_detect\_signal\_R\_W(BER, fm\_dev, bit\_period, rx\_NF\_dB)} \right)^{\frac{1}{N}}$$

$$RangeRT(tx\_power\_dBm, BER, fm\_dev, bit\_period, rx\_NF\_dB, antenna\_gain\_dB) := \frac{3 \cdot 10^{8} \frac{m}{s}}{4 \cdot \pi \cdot freq} \left(\frac{antenna\_gain(antenna\_gain\_dB)^{2} \cdot tx\_power\_W(tx\_power\_dBm)}{min\_detect\_signal\_W(BER, fm\_dev, bit\_period, rx\_NF\_dB)} \right)^{\frac{1}{N}}$$

The range is calculated with the TX power in dBm and required BER for **Rappaport & Theodore,** with Raleigh fading on the left, non Raleigh on the right. I would expect communication to work reliably to the Raleigh limit, with decreasing performance to the higher limit

RangeRT(txpower(dBm), BER, dev, bitperiod, NF, Antennagain(dB))

Summary

This range is calculated with the TX power in dBm for **Rappaport & Theodore.** Note, the bit period is divided by 2 as the data is Manchester encoded over the air. Raleigh fading values on the right. The range is between the two values.

Range 1
6dBm TX, 7dB NF, 20kHz dev, 20kHz air data rate, average antenna gain -15dB, 200bits, no FEC.

$$\mathrm{RangeRT\_R}\left(6, 0.005, 20\mathrm{kHz}, \frac{\mathrm{s}}{2\cdot 20000}, 7, -15\right) = 25\,\mathrm{m}$$

$$\mathrm{RangeRT}\left(6, 0.005, 20\mathrm{kHz}, \frac{\mathrm{s}}{2\cdot 20000}, 7, -15\right) = 75\,\mathrm{m}$$

Range 2
TX 6dBm, 1:5 FEC, Use LNA, better antennas, quarter data rate, no Manchester.

$$\mathrm{RangeRT\_R}\left(6, 0.2, 30\mathrm{kHz}, \frac{\mathrm{s}}{5000}, 3, -5\right) = 4069\,\mathrm{m}$$

$$\mathrm{RangeRT}\left(6, 0.2, 30\mathrm{kHz}, \frac{\mathrm{s}}{5000}, 3, -5\right) = 4896\,\mathrm{m}$$

Range 3
TX 20dBm, 1:20 FEC, better antennas, quarter data rate, no Manchester.

$$\mathrm{RangeRT\_R}\left(20, 0.05, 30\mathrm{kHz}, \frac{\mathrm{s}}{5000}, 6, -5\right) = 4984\,\mathrm{m}$$

$$\mathrm{RangeRT}\left(20, 0.05, 30\mathrm{kHz}, \frac{\mathrm{s}}{5000}, 6, -5\right) = 7889\,\mathrm{m}$$