

RF System Formulas

Iulian Rosu, YO3DAC / VA3IUL, <http://www.qsl.net/va3iul/>

$$\text{Noise_Floor}_{[\text{dBm}]} = -174 + 10 \cdot \text{LOG}(\text{BW}_{[\text{Hz}]}) + \text{Noise_Figure}_{[\text{dB}]} + \text{Gain}_{[\text{dB}]}$$

$$\text{Minimum_Detectable_Signal}_{[\text{dBm}]} = [-174 + 3_{\text{dB}}] + 10 \cdot \text{LOG}(\text{BW}_{[\text{Hz}]}) + \text{Noise_Figure}_{[\text{dB}]}$$

$$\text{Spurious_Free_Dynamic_Range}_{[\text{dB}] \text{ ord } 2} = (1/2) * [174 + \text{IIP2}_{[\text{dBm}]} - \text{Noise_Figure}_{[\text{dB}]} - 10 \cdot \text{LOG}(\text{BW}_{[\text{Hz}]})]$$

$$\text{Spurious_Free_Dynamic_Range}_{[\text{dB}] \text{ ord } 3} = (2/3) * [174 + \text{IIP3}_{[\text{dBm}]} - \text{Noise_Figure}_{[\text{dB}]} - 10 \cdot \text{LOG}(\text{BW}_{[\text{Hz}]})]$$

$$\text{Noise_Figure}_{[\text{dB}]} = 174 + \text{RX_Sensitivity}_{[\text{dBm}]} - 10 \cdot \text{LOG}(\text{BW}_{[\text{Hz}]}) - \text{Signal/Noise}_{[\text{dB}]}$$

$$\text{RX_Sensitivity}_{[\text{dBm}]} = -174 + 10 \cdot \text{LOG}(\text{BW}_{[\text{Hz}]}) + \text{Noise_Figure}_{[\text{dB}]} + \text{Signal/Noise}_{[\text{dB}]}$$

$$\text{Signal/Noise}_{[\text{dB}]} = 174 + \text{RX_Sensitivity}_{[\text{dBm}]} - 10 \cdot \text{LOG}(\text{BW}_{[\text{Hz}]}) - \text{Noise_Figure}_{[\text{dB}]}$$

$$\text{RX_Dynamic_Range}_{[\text{dB}]} = \text{RX_Sensitivity}_{[\text{dBm}]} - \text{P1dB}_{[\text{dBm}]}$$

$$\text{Blocking_Dynamic_Range}_{[\text{dB}]} = \text{P1dB}_{[\text{dBm}]} - \text{Noise_Floor}_{[\text{dBm}]} - \text{Signal/Noise}_{[\text{dB}]}$$

$$\text{Co-channel_rejection}_{[\text{dB}]} = \text{Co-channel_interferer}_{[\text{dBm}]} - \text{RX_Sensitivity}_{[\text{dBm}]}$$

$$\text{RX_selectivity}_{[\text{dB}]} = -\text{Co-ch_rejection}_{[\text{dB}]} - 10 \cdot \text{LOG}[10^{(-\text{IF_filter_rej}_{[\text{dB}]/10})} + 10^{(-\text{LO_spur}_{[\text{dBc}]/10})} + \text{IF_BW}_{[\text{Hz}]} * 10^{(\text{SB_Noise}_{[\text{dBc/Hz}]/10})}]$$

$$\text{Image_frequency}_{[\text{MHz}]} = \text{RF_frequency}_{[\text{MHz}]} \pm 2 * \text{IF_frequency}_{[\text{MHz}]}$$

$$\text{Half_IF}_{[\text{MHz}]} = \text{RF_frequency}_{[\text{MHz}]} \pm \text{IF_frequency}_{[\text{MHz}]} / 2$$

$$\text{Half_IF}_{[\text{dBm}]} = [\text{OIP2}_{[\text{dBm}]} - \text{RX_Sensitivity}_{[\text{dBm}]} - \text{Co-channel_rejection}_{[\text{dB}]}] / 2$$

$$\text{IM_rejection}_{[\text{dB}]} = [2 * \text{IIP3}_{[\text{dBm}]} - 2 * \text{RX_Sensitivity}_{[\text{dBm}]} - \text{Co-Channel_rejection}_{[\text{dB}]}] / 3$$

$$\text{IIP3}_{[\text{dBm}]} = \text{Interferer_level}_{[\text{dBm}]} + [\text{Interferer_level}_{[\text{dBm}]} - \text{RX_level}_{[\text{dBm}]} + \text{Signal/Noise}_{[\text{dB}]}] / 2$$

$$\text{OIP3}_{[\text{dBm}]} = \text{Pout}_{[\text{dBm}]} + [\text{IM3}_{[\text{dBc}]} / 2] = \text{Pout}_{[\text{dBm}]} + [\text{Pout}_{[\text{dBm}]} - \text{IM3}_{[\text{dBm}]}] / 2$$

$$\text{IM3}_{[\text{dBm}]} = 3 * \text{Pout}_{[\text{dBm}]} - 2 * \text{OIP3}_{[\text{dBm}]}$$

$$\text{IM3}_{\text{out unequal_input_levels(left_side)}}_{[\text{dBm}]} = \text{Pout_Left}_{[\text{dBm}]} - 2 * [\text{OIP3}_{[\text{dBm}]} - \text{Pout_Right}_{[\text{dBm}]}]$$

$$\text{OIP2}_{[\text{dBm}]} = \text{Pout}_{[\text{dBm}]} + \text{IM2}_{[\text{dBc}]} = 2 * \text{Pout}_{[\text{dBm}]} - \text{IM2}_{[\text{dBm}]}$$

$$\text{IM2}_{[\text{dBm}]} = 2 * \text{Pout}_{[\text{dBm}]} - \text{OIP2}_{[\text{dBm}]}$$

$$\text{IIP2(cascaded_stages)}_{[\text{dBm}]} = \text{IIP2}_{\text{last stage}_{[\text{dBm}]}} - \text{Gain}_{\text{total}_{[\text{dB}]} + \text{Selectivity @ } 1/2 \text{ IF}_{[\text{dB}]}$$

$$\text{IIP2(Direct_Conversion_Receiver)}_{[\text{dBm}]} \geq 2 * \text{AM_Interferer}_{[\text{dBm}]} - \text{Noise_Floor}_{[\text{dBm}]}$$

$$\text{Full_Duplex_Noise@RX_inp}_{[\text{dBm}]} = -174 - \text{TX_Noise@RX_band}_{[\text{dBm/Hz}]} - \text{Duplexer_rejection}_{[\text{dB}]}$$

$$\text{Crest_Factor}_{[\text{dB}]} = 10 \cdot \text{LOG}[\text{Peak_Power}_{[\text{w}]} / \text{Average_Power}_{[\text{w}]}] = \text{Peak_Power}_{[\text{dBm}]} - \text{Average_Power}_{[\text{dBm}]}$$

$$\text{MultiCarrier_Peak_to_Average_Ratio}_{[\text{dB}]} = 10 \cdot \text{LOG}(\text{Number_of_Carriers})$$

$$\text{MultiCarrier_Total_Power}_{[\text{dBm}]} = 10 \cdot \text{LOG}(\text{Number_of_Carriers}) + \text{Carrier_Power}_{[\text{dBm}]}$$

$$\text{Processing_Gain}_{[\text{dB}]} = 10 \cdot \text{LOG}[\text{BW}_{[\text{Hz}]} / \text{Data_Rate}_{[\text{Hz}]}]$$

$$\text{Eb/No}_{[\text{dB}]} = \text{S/N}_{[\text{dB}]} + 10 \cdot \text{LOG}[\text{BW}_{[\text{Hz}]} / \text{Data_Rate}_{[\text{Hz}]}]$$

$$\text{RX_Input_Noise_Power_max}_{[\text{dBm}]} = \text{Sensitivity}_{[\text{dBm}]} + \text{Processing_Gain}_{[\text{dB}]} - \text{Eb/No}_{[\text{dB}]}$$

$$\text{Carrier_Noise_Ratio}_{[\text{dB}]} = 10 \cdot \text{LOG}[\text{Eb/No}] + 10 \cdot \text{LOG}[\text{Bit_Rate}_{[\text{bps}]} / \text{BW}_{[\text{Hz}]}]$$

$$\text{Bandwidth_Efficiency}_{[\text{bps/Hz}]} = \text{Bit_Rate}_{[\text{bps}]} / \text{BW}_{[\text{Hz}]}$$

$$\text{Integer_PLL_freq_out}_{[\text{MHz}]} = [N_{(\text{VCO_divider})} / R_{(\text{Ref_divider})}] \cdot \text{Reference_frequency}_{[\text{MHz}]}$$

$$\text{Required_LO_PhaseNoise}_{[\text{dBc/Hz}]} = \text{RX_level}_{[\text{dBm}]} - \text{Blocking_level}_{[\text{dBm}]} - \text{Signal/Noise}_{[\text{dB}]} - 10 \cdot \text{LOG}(\text{BW}_{[\text{Hz}]})$$

$$\text{PLL_PhaseNoise}_{[\text{dBc/Hz}]} = 1\text{Hz_Normalized_PhaseNoise}_{[\text{dBc/Hz}]} + 10 \cdot \text{LOG}(\text{Comparison Frequency}_{[\text{Hz}]} + 20 \cdot \text{LOG}(N))$$

$$\text{PLL_Lock_Time}_{[\text{usec}]} = [400 / \text{Loop_BW}_{[\text{kHz}]}] \cdot [1 - 10 \cdot \text{LOG}(\text{Frequency_tolerance}_{[\text{Hz}]} / \text{Frequency_jump}_{[\text{Hz}]})]$$

$$\text{PLL_Switching_Time}_{[\text{usec}]} = 50 / F_{\text{comparison}}_{[\text{MHz}]} = 2.5 / \text{Loop_Bandwidth}_{[\text{MHz}]}$$

$$\text{PhaseNoise_on_SpectrumAnalyzer}_{[\text{dBc/Hz}]} = \text{Carrier_Power}_{[\text{dBm}]} - \text{Noise_Power@Freq_offset}_{[\text{dBm}]} - 10 \cdot \text{LOG}(\text{RBW}_{[\text{Hz}]})$$

$$\text{PLL_Phase_Error}_{\text{RMS}} [^\circ] = 107 \cdot 10^{(\text{PhaseNoise}_{[\text{dBc/Hz}]} / 20)} \cdot \sqrt{\text{Loop_BW}_{[\text{Hz}]}}$$

$$\text{PLL_Jitter}_{[\text{seconds}]} = \text{PLL_Phase_Error}_{\text{RMS}} [^\circ] / (360 \cdot \text{Frequency}_{[\text{Hz}]})$$

$$\text{EVM}_{\text{RMS}} [\%] = 1.74 \cdot \text{PLL_Phase_Error}_{\text{RMS}} [^\circ]$$

$$\text{TX_PhaseNoise_limit}_{[\text{dBc/Hz}]} = \text{Power_limit@Offset_from_carrier}_{[\text{dBc}]} + 10 \cdot \text{LOG}(\text{BW}_{[\text{Hz}]})$$

$$\text{ACLR}_{[\text{dBc}]} = 20.75 + 1.6 \cdot \text{Crest_Factor}_{[\text{dB}]} + 2 \cdot [\text{Input_Power}_{[\text{dBm}]} - \text{PA_IIP3}_{[\text{dBm sine}]}]$$

$$\text{EVM}_{[\%]} = [10^{(-\text{Signal/Noise}_{[\text{dB}]} / 20)}] \cdot 100 \quad \text{EVM}_{[\text{dB}]} = 20 \cdot \text{LOG}(\text{EVM}_{[\%]} / 100)$$

$$\text{Signal/Noise}_{[\text{dB}]} = 20 \cdot \text{LOG}(\text{EVM}_{[\%]} / 100)$$

$$\text{Corrected_EVM}_{[\%]} = \sqrt{\text{Residual_EVM}_{[\%]} \cdot \text{Measured_EVM}_{[\%]}}$$

$$\text{ADC_SNR}_{[\text{dB}]} = (\text{Nr_of_Bits} \cdot 6.02) + 1.76 + 10 \cdot \text{LOG}(\text{Sampling_Frequency}_{[\text{Hz}]} / 2 \cdot \text{BW}_{[\text{Hz}]})$$

$$\text{ADC_Nyquist_frequency}_{[\text{Hz}]} = \text{Sampling_Frequency}_{[\text{Hz}]} / 2$$

$$\text{ADC_NoiseFigure}_{[\text{dB}]} = \text{Full_Scale_Pin}_{[\text{dBm}]} - \text{SNR}_{[\text{dB}]} - 10 \cdot \text{LOG}(\text{FS_sampling_rate} / 2) - \text{Thermal_Noise}_{[\text{dBm/Hz}]}$$

$$\text{ADC_NoiseFloor}_{[\text{dBFS}]} = \text{SNR}_{[\text{dB}]} + 10 \cdot \text{LOG}(\text{FS_sampling_rate} / 2)$$

$$\text{ADC_Spurious_Free_Dynamic_Range}_{[\text{dB}]} = \text{Desired_Input_Signal}_{[\text{dB}]} - \text{Highest_Amplitude_Spurious}_{[\text{dB}]}$$

$$\text{ADC_Input_Dynamic_Range}_{[\text{dB}]} = 20 \cdot \text{LOG}(2^{\text{Nr_of_Bits}} - 1)$$

$$\text{VSWR} = (1 + \Gamma) / (1 - \Gamma) = (\text{Vinc} + \text{Vref}) / (\text{Vinc} - \text{Vref}) = (Z_L - Z_0) / (Z_L + Z_0)$$

$$\text{Reflection_Coefficient } \Gamma = (\text{VSWR} - 1) / (\text{VSWR} + 1) = \text{Vref} / \text{Vinc}$$

$$\text{Return_Loss}_{[\text{dB}]} = -20 \cdot \text{LOG}(\Gamma)$$

$$\text{Mismatch_Loss}_{[\text{dB}]} = -10 \cdot \text{LOG}[1 - \Gamma^2]$$

$$\text{Reflected_Power}_{[W]} = \text{Incident_Power}_{[W]} * \Gamma^2$$

$$\text{Power_Absorbed_by_the_Load}_{[W]} = 4 * \text{Incident_Power}_{[W]} * [\text{VSWR}/(1+\text{VSWR}^2)]$$

$$\text{Characteristic_Impedance } Z_0 = \sqrt{L/C}$$

$$\text{Resonant_Frequency}_{[Hz]} = 1 / [2 * \Pi * \sqrt{L * C}]$$

$$L = X_s / \omega ; \quad C = 1 / (\omega * X_p) ; \quad \omega = 1 / \sqrt{L * C} ; \quad Q_{(\text{series LC})} = X_s / R_s ; \quad Q_{(\text{parallel LC})} = R_p / X_p$$

$$\text{Free_Space_Path_Loss}_{[dB]} = 27.6 - 20 * \text{LOG}[\text{Frequency}_{[MHz]}] - 20 * \text{LOG}[\text{Distance}_{[m]}]$$

$$\text{RX_inp_level}_{[dBm]} = \text{TX_Power}_{[dBm]} + \text{TX_Ant_Gain}_{[dB]} - \text{Free_Space_Path_Loss}_{[dB]} - \text{Cable_loss}_{[dB]} + \text{Rx_Ant_Gain}_{[dB]}$$

$$\text{Antenna_Polarization_Mismatch_Loss}_{[dB]} = 20 * \text{LOG}(\cos \phi) \quad [\text{for linear polarized antennas}]$$

$$\text{Antenna_Factor}_{[dB]} = 20 * \text{LOG}[(12.56 / \lambda_{[m]}) * \sqrt{\frac{30}{R_{\text{load}}[\text{ohms}] * 10^{(\text{Antenna_Gain}[\text{dBi}]/10)}}}]$$

$$\text{EIRP}_{[W]} = \text{Power}_{[W]} * 10^{\text{Antenna_Factor}[\text{dB}] / 10}$$

$$\text{Antenna_Near_Field}_{[m]} = 2 * \text{Antenna_Dimension}_{[m]}^2 / \lambda_{[m]}$$

$$T_e = (\text{Noise_Factor}_{[\text{lin}]} - 1) * T_o_{[290K]}$$

$$\text{ENR}(\text{Excess_Noise_Ratio}) = 10 * \text{LOG} [(T_{\text{ENR}} - T_o_{[290K]}) / T_o_{[290K]}]$$

$$\text{Noise_Figure_Test}(\text{Y_Factor_Method})_{[dB]} = 10 * \text{LOG}[(10^{(\text{ENR}/10)}) / (10^{(Y/10)})]; \quad Y = \text{NF}_{\text{out}} - \text{NF}_{\text{inp}}$$

$$\text{RMS Noise Voltage across a Resistor } (V) = \sqrt{[4 * R[\text{ohms}] * k[\text{Boltzman}] * \text{Temp}[\text{K}] * \text{BW}[\text{Hz}]}$$

IP3 (all linear) – Cascaded Stages

$$IP3_{\text{INPUT}} = 10 \log \left(\frac{1}{\frac{1}{IP_1} + \frac{1}{IP_2} + \dots + \frac{1}{IP_N}} \right)$$

$IP3_{\text{INPUT}}$: equivalent system input intercept point (dBm)

IP_1 : IP3 of first stage transferred to input (mW)

IP_N : IP3 of last stage transferred to input (mW)

$$IP3_{\text{TOTAL}} = \frac{1}{\frac{1}{IP3_1} + \frac{G_1}{IP3_2} + \frac{G_1 G_2}{IP3_3} + \frac{G_1 G_2 G_3}{IP3_4} + \dots}$$

Noise Factor (all linear) - Cascaded Stages

$$F_{\text{IN}} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots$$

$$\text{Noise_Figure}_{[dB]} = 10 * \text{LOG}(F)$$

Noise Factor (all linear) – Identical Cascaded Stages

$$F = I + M$$

$$M = \frac{F - 1}{1 - \frac{1}{G}}$$

$$\text{AM_Modulation_Index} = \frac{V_{\text{max}}[V_{pp}] - V_{\text{min}}[V_{pp}]}{V_{\text{max}}[V_{pp}] + V_{\text{min}}[V_{pp}]} = 2 * \sqrt{\frac{\text{Power_sideband}(\text{usb_lsb})[W]}{\text{Power_carrier}[W]}}$$

$$\text{AM_Total_Power}_{[W]} = \text{Power_carrier}_{[W]} * [(1 + \text{AM_Modulation_Index}^2) / 2]$$

$$\text{AM_Bandwidth}_{[Hz]} = 2 * \text{Highest_Modulation_Frequency}_{[Hz]}$$

$$\text{FM_Modulation_Index} = \text{Max_Frequency_Deviation}_{[Hz]} / \text{Max_Modulation_Frequency}_{[Hz]}$$

$$\text{FM_Bandwidth}_{[Hz]} = 2 * \text{Max_Modulation_Frequency}_{[Hz]} * [1 + \text{FM_Modulation_Index}]$$