Equations, Variables, and Functional Role of the RFI Model

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1 Propagation and Link Budget

1.1 Free-Space Path Loss (ITU-R P.525)

$$L_{\text{fs}}(f,d) = 32.45 + 20\log_{10}(f_{\text{MHz}}) + 20\log_{10}(d_{\text{km}}) \tag{1}$$

- **Used for:** Modeling geometric spreading loss between a transmitter and a receiver for both desired and interfering signals.
- **Provides:** Frequency- and distance-dependent attenuation used to convert transmitter EIRP into received power.
- **Variables:**
  - L_{fs}: free-space path loss [dB]
  - f_{MHz}: carrier frequency [MHz]
  - d_{km}: propagation distance [km]

1.2 Received Carrier Power

$$C = EIRP_{\text{tx}}(f) + G_{\text{rx}}(f,\theta_0) - L_{\text{path}}(f,d_0) - L_{\text{other}} \tag{2}$$

- **Used for:** Establishing the interference-free reference level of the victim communication link.
- **Provides:** Received carrier power used as the baseline for all interference and SNR degradation metrics.
- **Variables:**
  - C: received carrier power [dBW]
  - $EIRP_{\text{tx}}$: transmit equivalent isotropically radiated power [dBW]
  - G_{rx}: receive antenna gain toward the desired signal [dB]
  - L_{path}: propagation losses (free-space and fixed atmospheric) [dB]
  - L_{other}: fixed additional losses (polarization, implementation) [dB]

2 Antenna Pattern Model

2.1 Receive Antenna Off-Axis Gain (ITU-R S.1528-type)

Main-lobe region:

$$G_{\text{rx}}(\theta) = G_{\max} - 12\left(\frac{\theta}{\theta_{3\text{dB}}}\right)^2 \tag{3}$$

Side-lobe region:

$$G_{\text{rx}}(\theta) = G_{\max} - 30\ \text{dB} \tag{4}$$

- **Used for:** Modeling angular discrimination of the receive antenna for off-axis interfering signals.
- **Provides:** Receive antenna gain as a function of arrival angle.
- **Variables:**
  - $G_{\text{rx}}(\theta)$: receive antenna gain at off-axis angle θ [dB]
  - $G_{\max}$: maximum (boresight) antenna gain [dB]
  - θ: off-axis angle relative to antenna boresight [deg]
  - $\theta_{3\text{dB}}$: 3-dB beamwidth of the antenna [deg]

3 Interference Modeling

3.1 Single-Entry Interference Power

$$I_i = EIRP_i(f) - L_{\text{fs}}(f, d_i) - L_{\text{atm}}(f, d_i, W_i) + G_{\text{rx}}(f, \theta_i) - L_{\text{misc}} \tag{5}$$

- **Used for:** Computing the received interference contribution from a single interfering transmitter.
- **Provides:** Interference power at the victim receiver from interferer i.
- **Variables:**
  - I_i: interference power from source i [dBW]
  - $EIRP_i$: equivalent isotropically radiated power of interferer i toward the victim [dBW]
  - d_i: distance between interferer i and victim receiver [km]
  - θ_i: off-axis angle of interferer i at the victim antenna [deg]
  - L_{atm}: atmospheric or weather-dependent attenuation [dB]
  - L_{misc}: fixed miscellaneous losses [dB]

3.2 Aggregate Interference Power

$$I_{\text{agg}} = 10 \log_{10} \left(\sum_i 10^{I_i/10} \right) \tag{6}$$

- **Used for:** Combining multiple simultaneous interference sources into a single equivalent interference level.
- **Provides:** Total aggregate interference power consistent with ITU-R aggregate-interference methodology.
- **Variables:**
  - I_{agg}: aggregate interference power [dBW]
  - I_i: individual interference powers [dBW]

3.3 Carrier-to-Interference Ratio

$$\frac{C}{I} = C - I_{\text{agg}} \tag{7}$$

- **Used for:** Assessing the dominance of the desired signal over aggregate interference.
- **Provides:** Carrier-to-interference ratio used for robustness comparison.
- **Variables:**
  - C/I: carrier-to-interference ratio [dB]

4 Noise and Signal-to-Noise Ratio

4.1 Thermal Noise Power

$$N = 10 \log_{10} \left(k_{\text{B}} T_{\text{sys}} B \right) \tag{8}$$

- **Used for:** Modeling the intrinsic noise floor of the receiver.
- **Provides:** Thermal noise power at the receiver input.
- **Variables:**
  - N: thermal noise power [dBW]
  - k_{B}: Boltzmann constant [J/K]
  - T_{sys}: system noise temperature [K]
  - B: receiver bandwidth [Hz]

4.2 Interference-Free Signal-to-Noise Ratio

$$\text{SNR}_0 = C - N \tag{9}$$

- **Used for:** Defining the baseline link margin without interference.
- **Provides:** Reference SNR for evaluating interference-induced degradation.
- **Variables:**
  - SNR_0: interference-free signal-to-noise ratio [dB]

4.3 Signal-to-Noise Ratio with Interference

$$\mathrm{SNR_I} = 10\log_{10}\left(\frac{10^{C/10}}{10^{N/10} + 10^{I_{\mathrm{agg}}/10}}\right) \tag{10}$$

- **Used for:** Evaluating link performance in the presence of interference.
- **Provides:** Operational signal-to-noise ratio under interference conditions.
- **Variables:**
  - $\mathrm{SNR_I}$: signal-to-noise ratio with interference [dB]

5 RFI-Induced Attenuation

5.1 SNR Loss Due to Interference

$$\Delta\mathrm{SNR} = \mathrm{SNR_0} - \mathrm{SNR_I} \tag{11}$$

- **Used for:** Isolating degradation caused solely by RFI.
- **Provides:** SNR loss used for probabilistic ITU-R compliance evaluation.
- **Variables:**
  - $\Delta\mathrm{SNR}$: RFI-induced attenuation [dB]

6 Equivalent Power Flux Density

6.1 Equivalent Power Flux Density (EPFD)

$$\mathrm{EPFD} = EIRP_i - L_{\mathrm{fs}}(f, d_{\mathrm{km}}) + G_{\mathrm{rx}} - 10\log_{10}(B_{\mathrm{MHz}}) \tag{12}$$

- **Used for:** Expressing interference in a receiver-independent metric for regulatory and satellite compatibility analysis.
- **Provides:** Equivalent power flux density per unit bandwidth, directly comparable to ITU-R EPFD protection limits.
- **Variables:**
  - EPFD: equivalent power flux density [dBW/m^2/MHz]
  - $EIRP_i$: equivalent isotropically radiated power of interferer i [dBW]
  - $L_{\mathrm{fs}}(f, d_{\mathrm{km}})$: free-space path loss per ITU-R P.525 [dB]
  - d_{km}: interferer-to-victim distance [km]
  - G_{rx}: receive antenna gain in the direction of the interferer [dB]
  - B_{MHz}: reference bandwidth [MHz]

This formulation expresses EPFD using a link-budget approach consistent with the rest of the model; geometric spreading is fully captured by the free-space path loss term L_{fs} defined in ITU-R P.525.