# Overview of Ultra Wide Band (UWB) Impulse Radio

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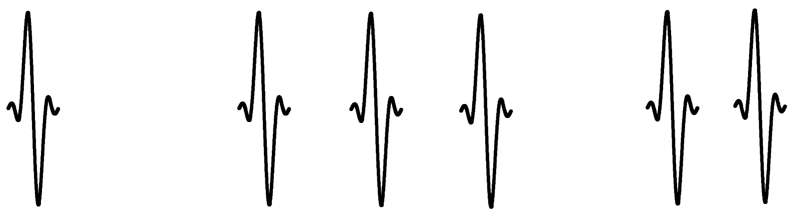
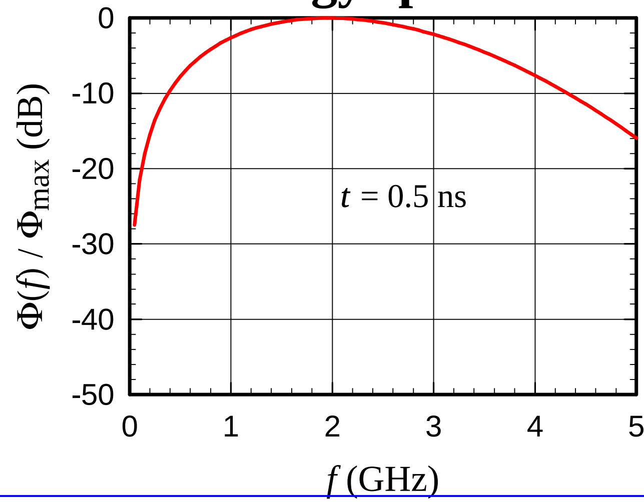
# What is Ultra Wide Band?

- **FCC definition of UWB signal: bandwidth is at least 20% of center frequency, or a bandwidth of at least 500 MHz**
- **Bandwidths can exceed 1 GHz**
- **Example: Pulsed UWB signal (pulse width: 0.5 ns).**

**Signal is a sequence of short pulses**



**Pulse energy spectrum**




- **The large UWB passband spans the operating frequencies of many existing licensed services**
- **Interference concerns: UWB to narrowband systems (main concern of FCC, NTIA), narrowband-to-UWB interference (UWB design issue)**

# Brief FCC / UWB History

- **FCC motivation: encourage development of potentially useful new technology without causing harmful interference to existing services and devices**
- **Sequence of FCC Notices and Orders**
  - **Notice of Inquiry in September 1998**
  - **Notice of Proposed Rule Making, June 2000**
  - **First Report and Order, April 2002: made legal unlicensed operation of UWB devices subject to certain restrictions**
  - **Reconsideration Order and Further NPRM, March 2003: responsive to Petitions for Reconsideration filed in response to the first R&O**
- **FCC categorizes its approach to legalizing UWB "conservative" with respect to preventing harmful interference to other devices and services. FCC has promised further evolution to UWB Rules**
- **Allowed UWB emission levels are less than or equal to the level allowed for unintentional radiators such as computers and other electronic devices (-41.3 dBm/MHz).**

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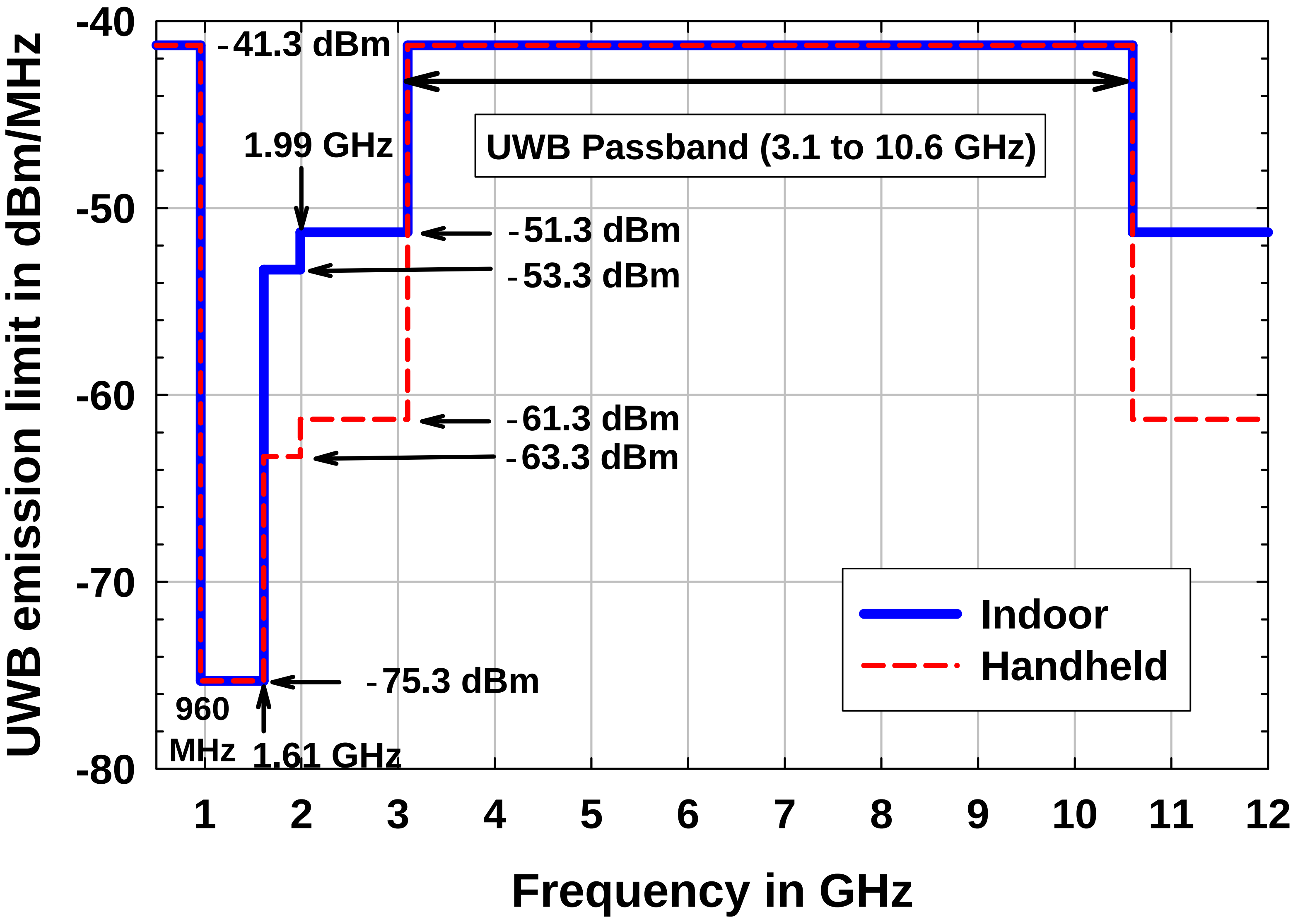
# FCC General UWB Emission Limits

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# Applications: DARPA's NETEX Program

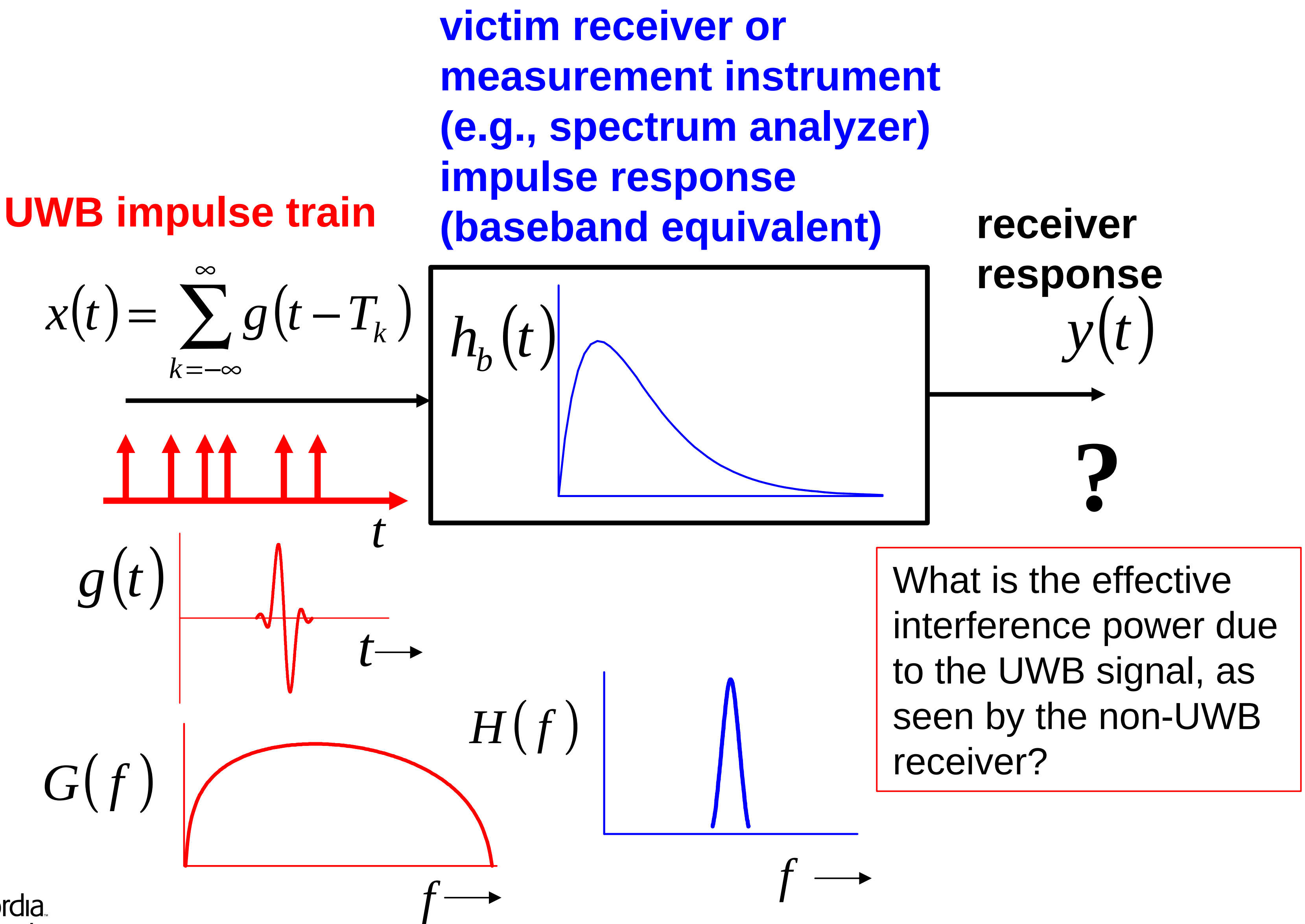
**Objective: Develop military UWB sensors and communications systems for operation in extreme environments**

- **Phase I:** Gain understanding of effects of UWB system operation on existing narrowband spectrum users
  - Testing (NAVAIR/Pax River): 16 legacy system, 39 modes, 1600 tests completed.
  - Modeling/Simulation (Telcordia) details below
  - UWB propagation and channel modeling (Virginia Tech)
- **Phase II:** (DARPA/ATO BAA 03-20, Industry Day April 7 '03)
  - Push UWB physical layer design to the point where it is capable of reliably supporting advanced LPD, ranging, location and networking protocols
  - Develop algorithms, protocols, and distributed control for robust, scalable ad hoc UWB networking
  - Demonstrate 20-node hand held radios, 50-node video network, and 50-node radar sensor integrated into high data rate short range network.

**http://www.darpa.mil/ato/solicit/NETEX/documents.htm**

# UWB: An Undesired Result

# UWB Interference Modeling

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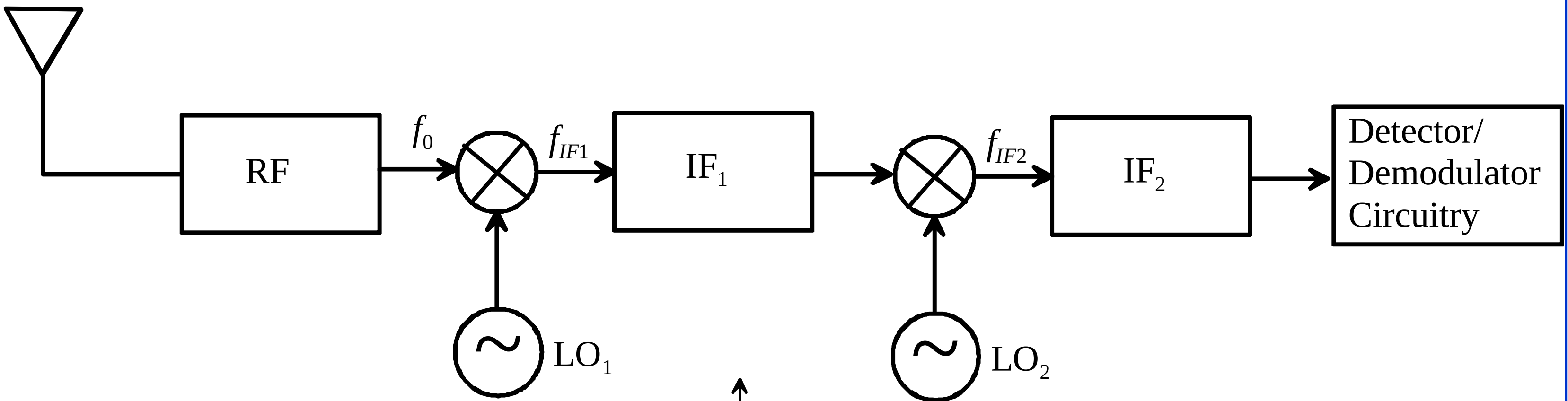
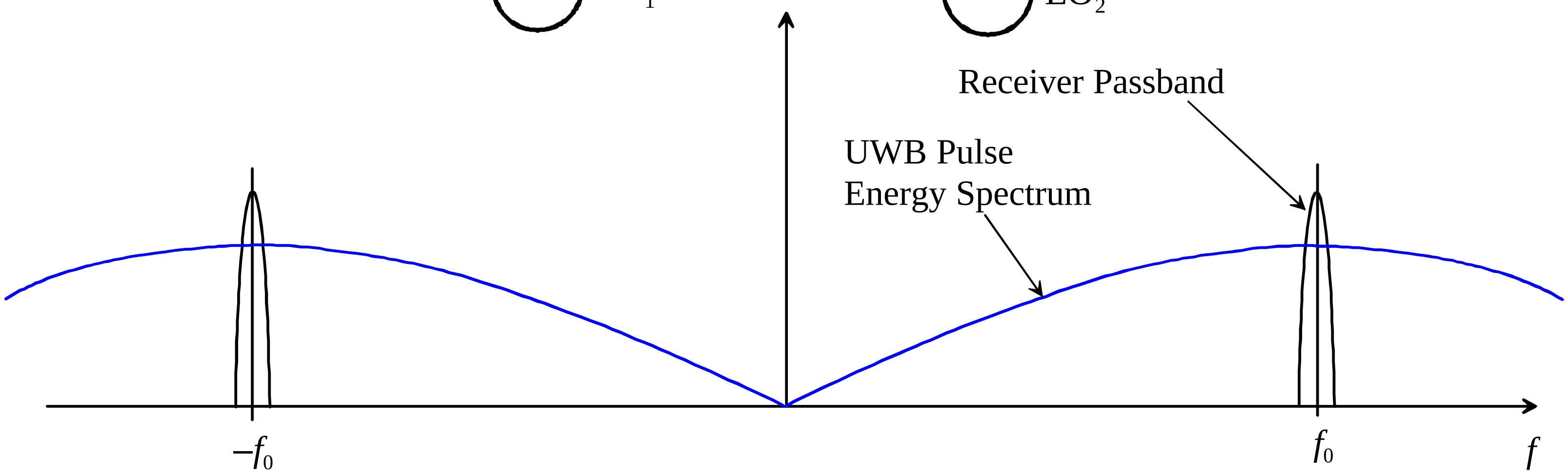
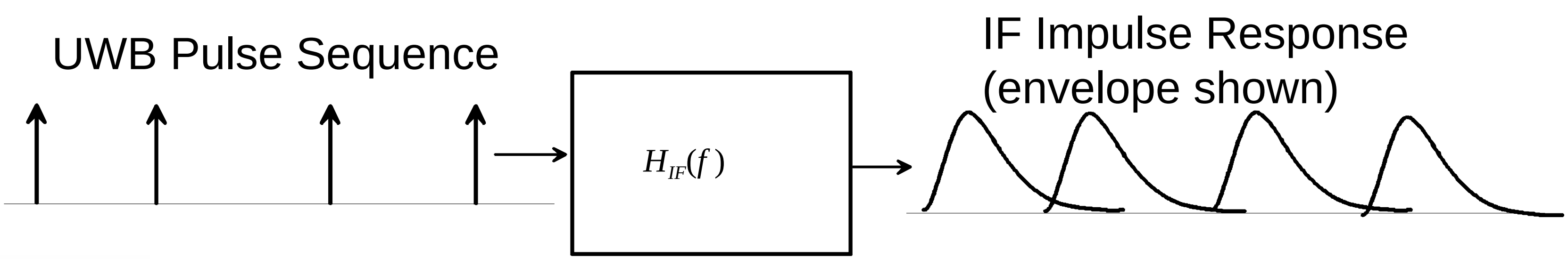
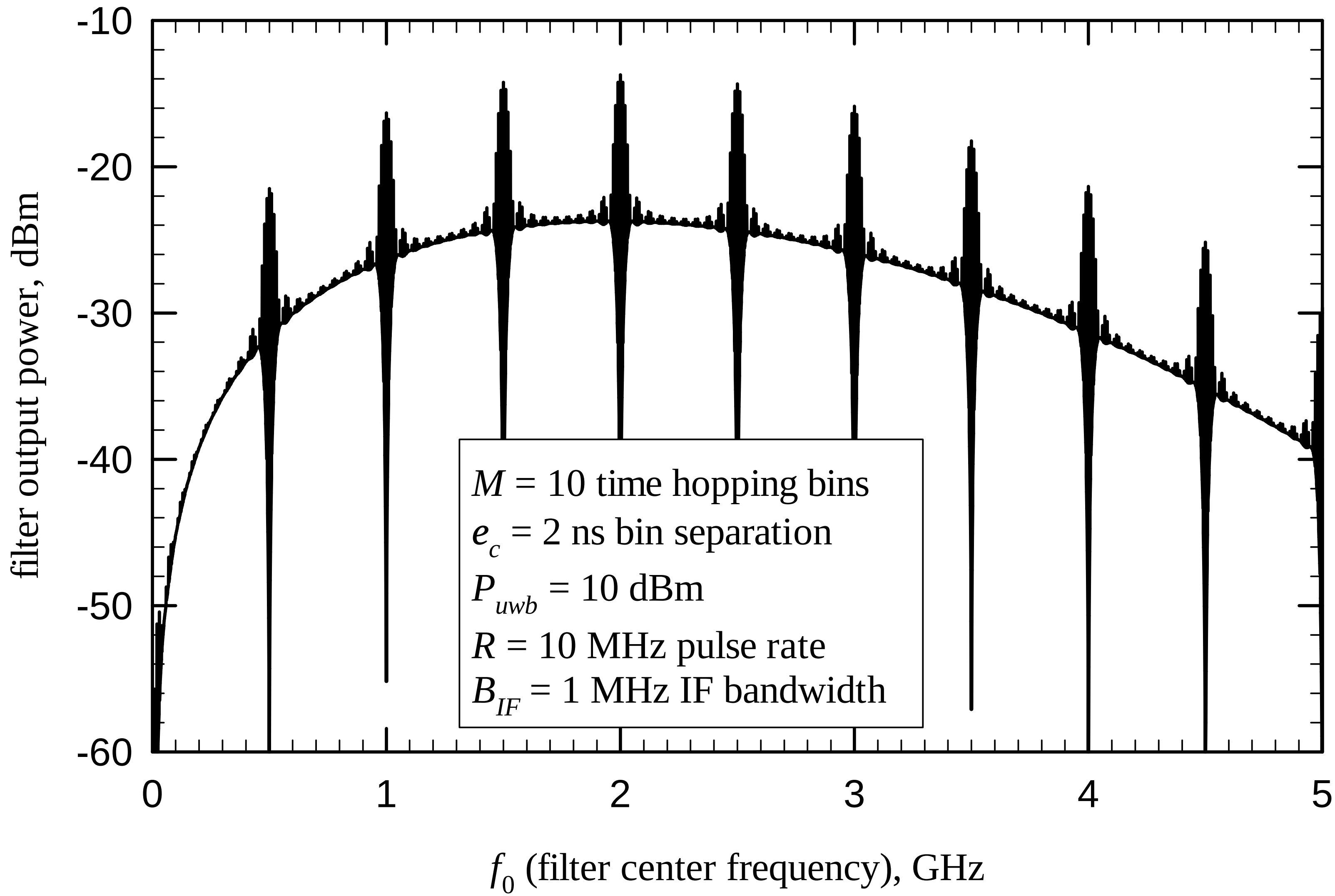
# Victim Receiver Model and Interference Filtering



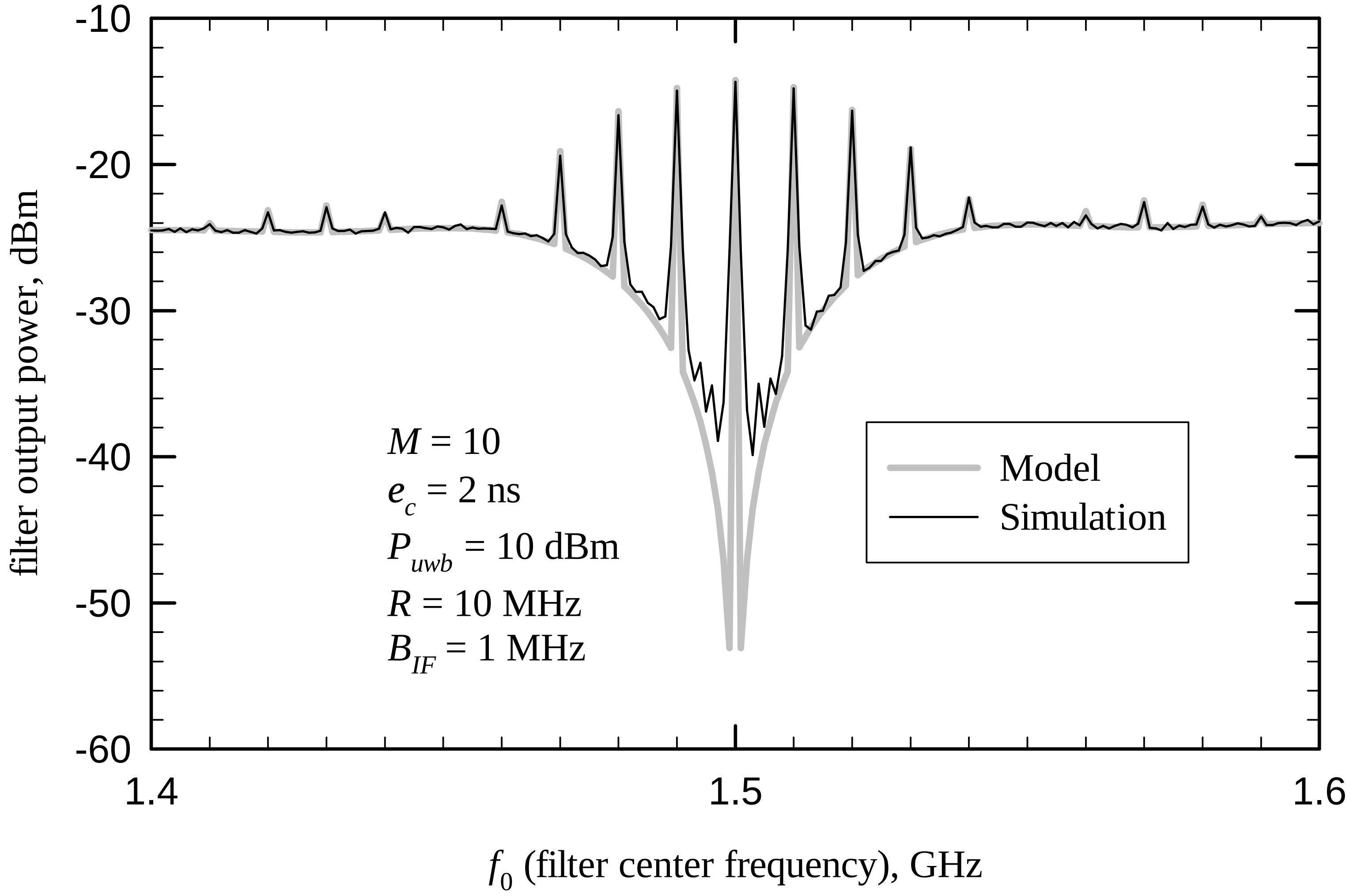



# Time Hopping PSD Example: Partial-Frame 2-ns Dithering



# Closeup – with Simulation Results

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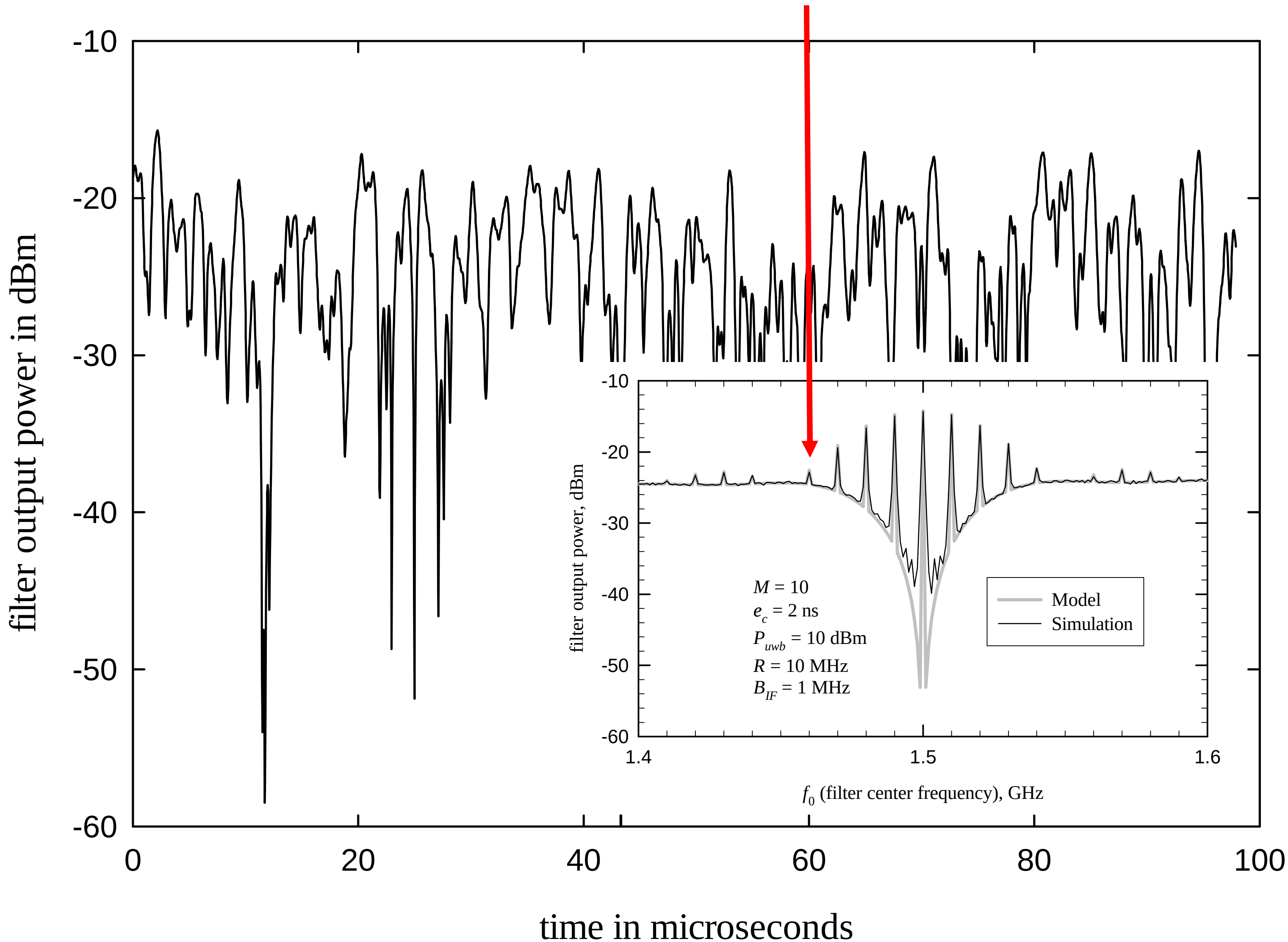
# Simulation – Zero Span – 1.46 GHz

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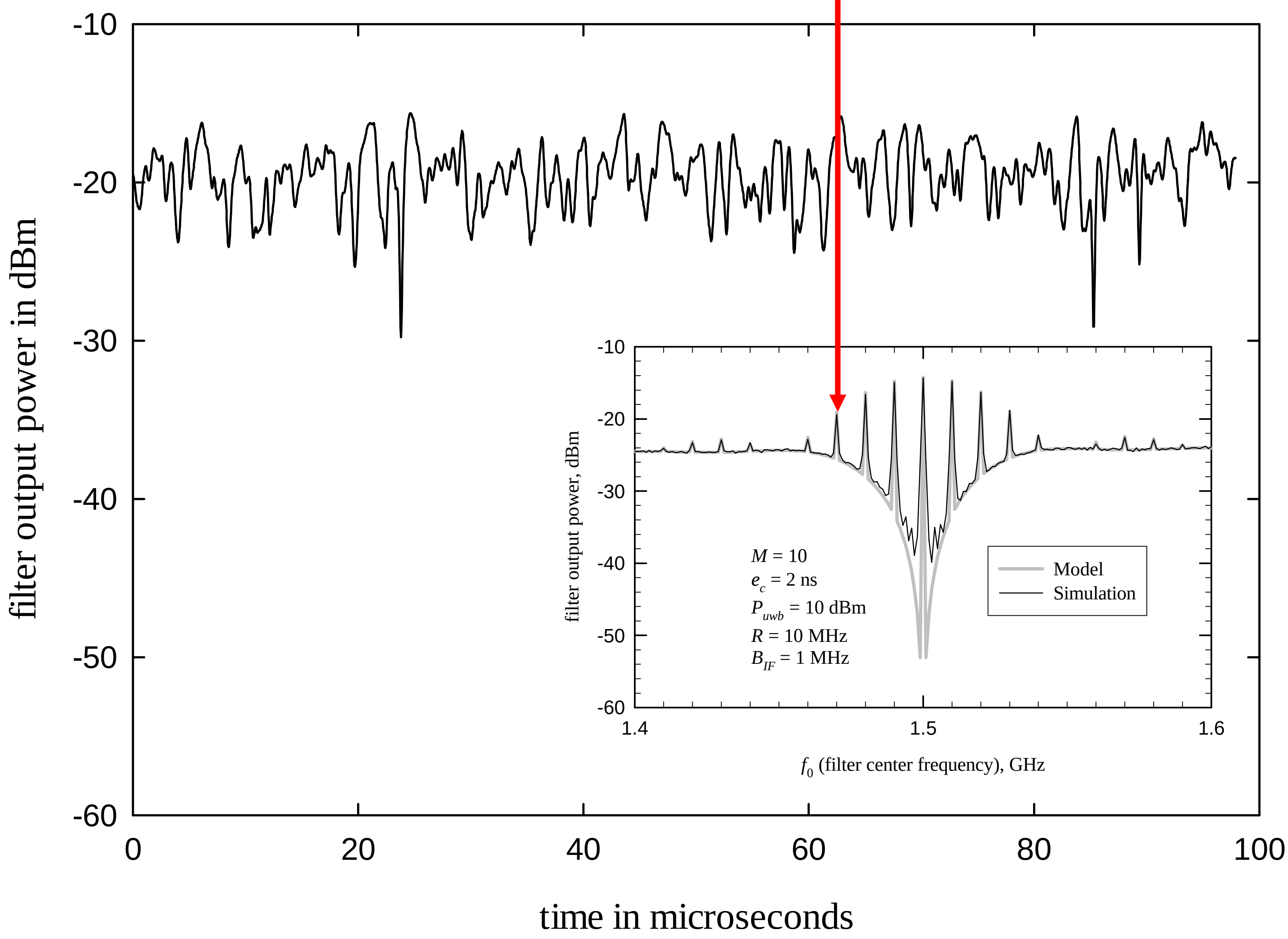
# Simulation – Zero Span – 1.47 GHz

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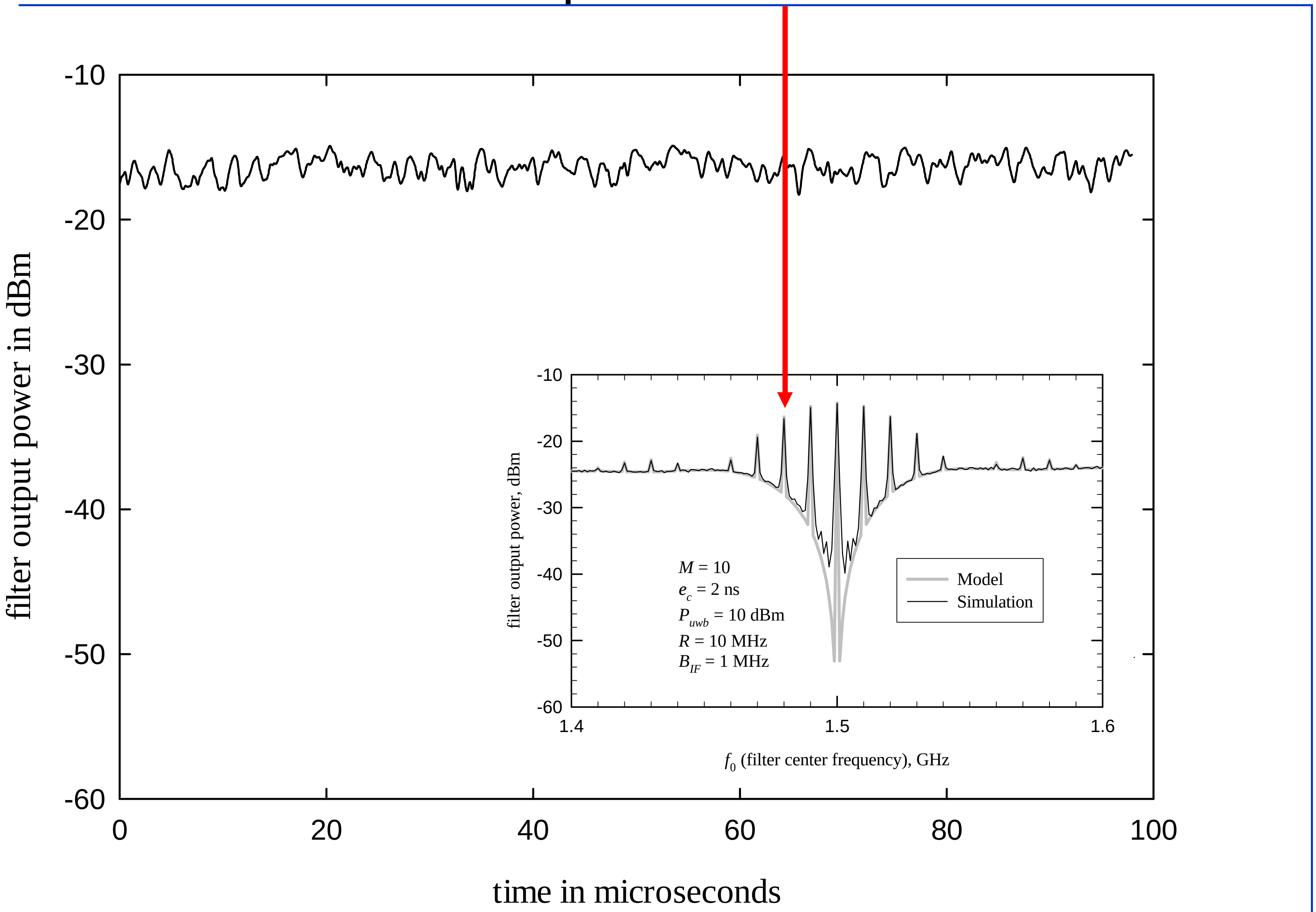
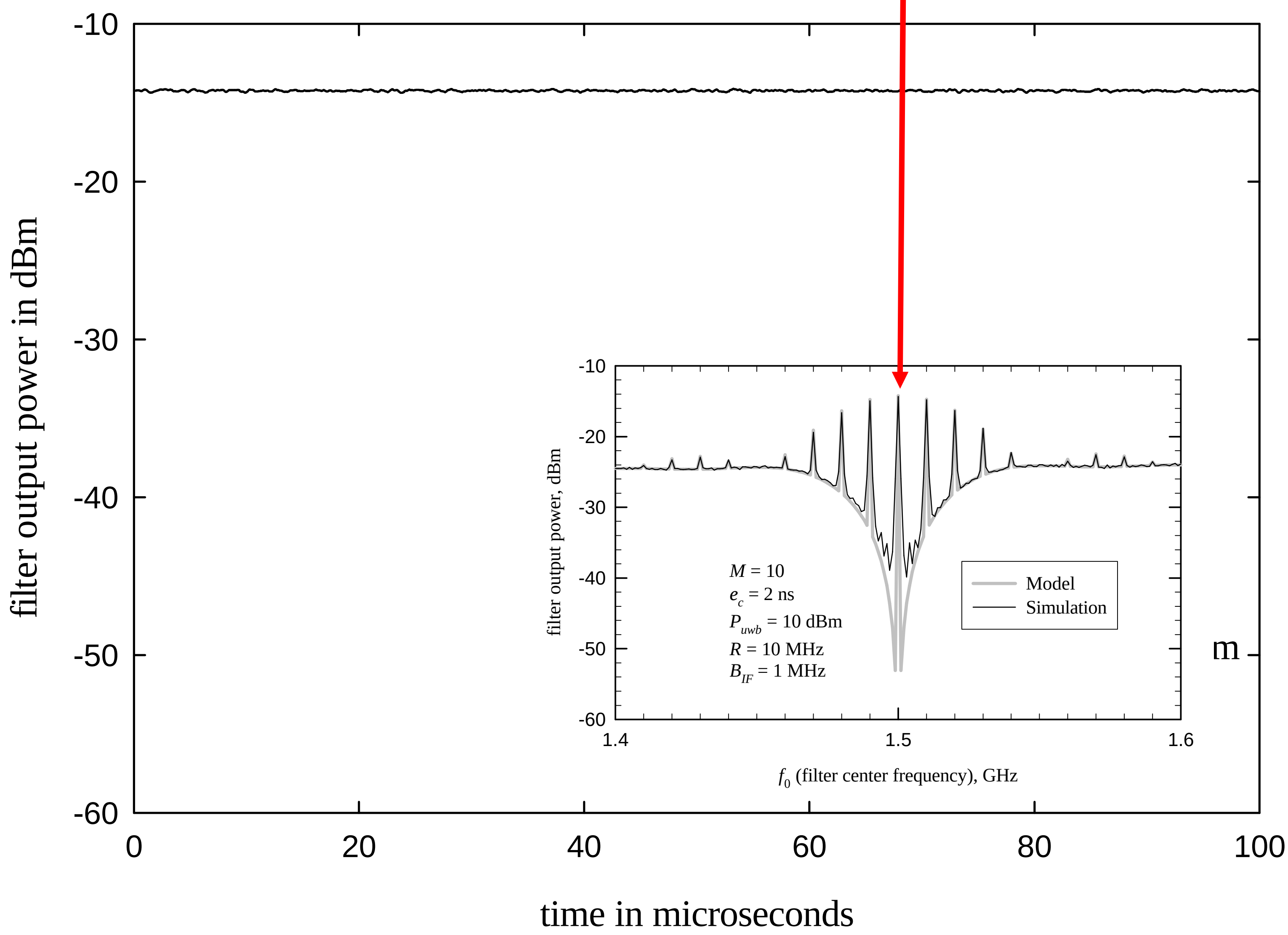
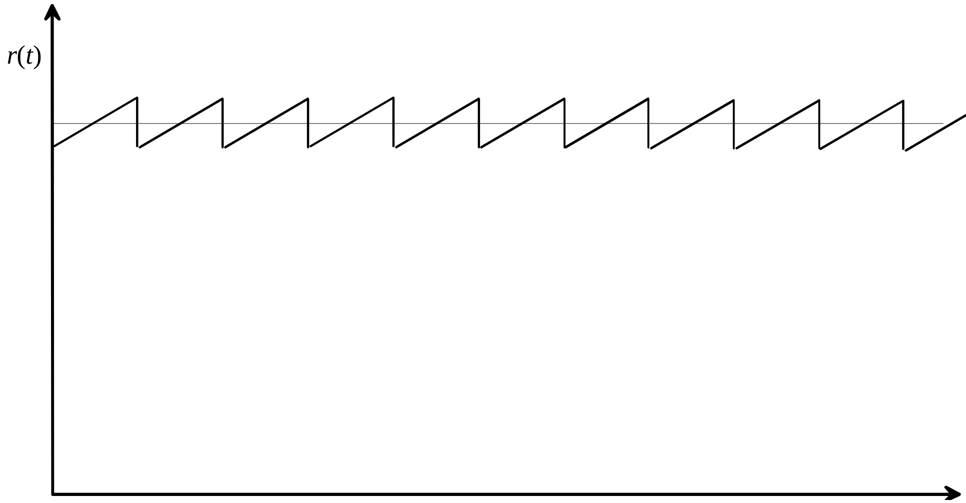
# Simulation – Zero Span – 1.48 GHz



# Simulation – Zero Span – 1.5 GHz



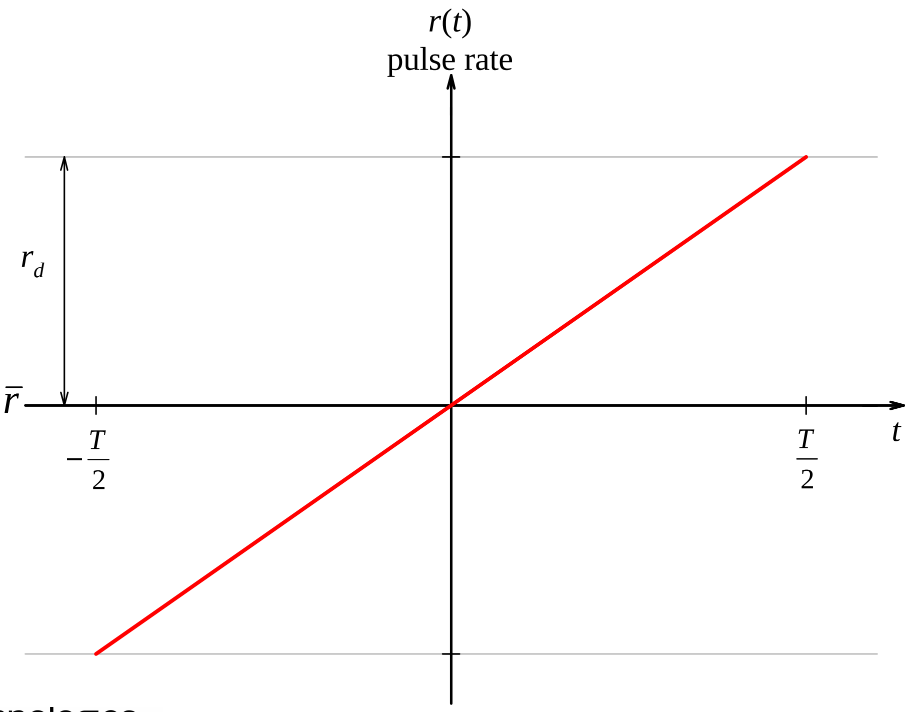
# Example: PSD of a Swept-PRF Signal




$$r(t) = \bar{r} + at \qquad -\frac{T}{2} < t \le \frac{T}{2}$$

$$a = 2r_d / T$$

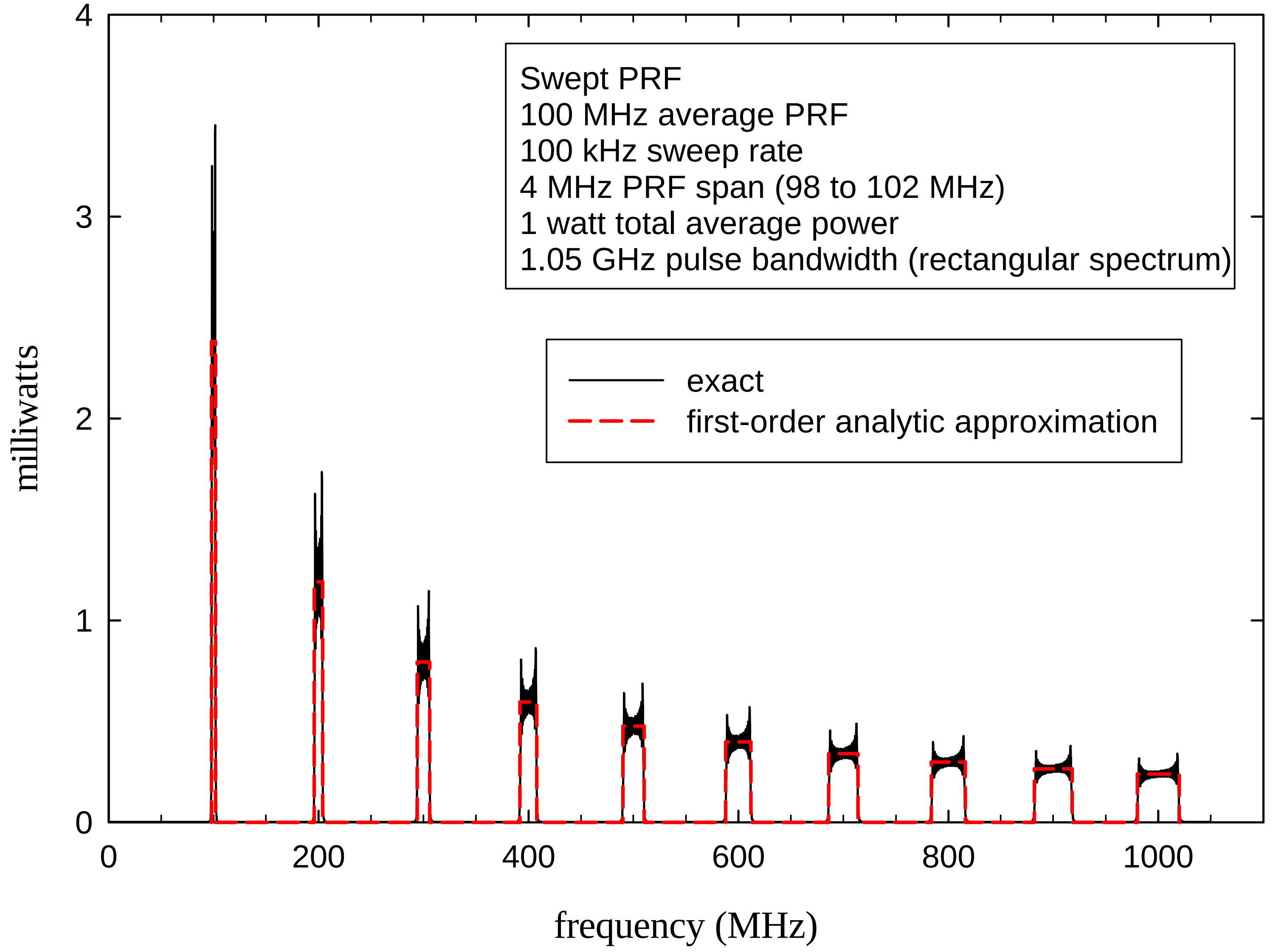
$$v(t) = \sum_{n=-M+1}^{M} d\left(t - T_n\right)$$




$$V(f) = \sum_{n=-M+1}^{M} e^{-j2pfT_n}$$

$$T_n = \frac{-\bar{r} + \sqrt{\bar{r}^2 + 2a\left(n + T^2/4\right)}}{a}$$

# Swept PRF PSD and Approximation

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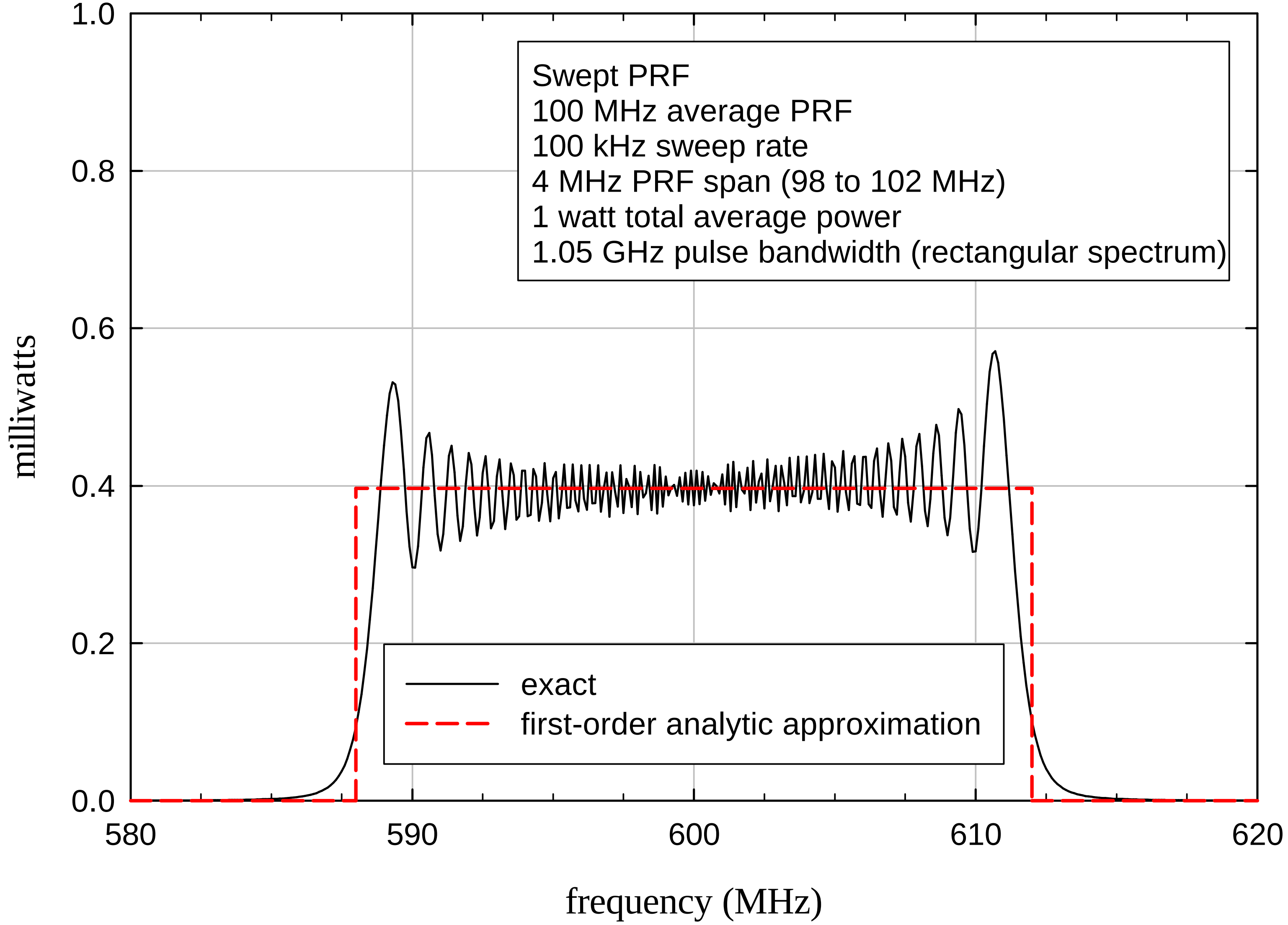
# Closeup of Swept PRF Spectrum

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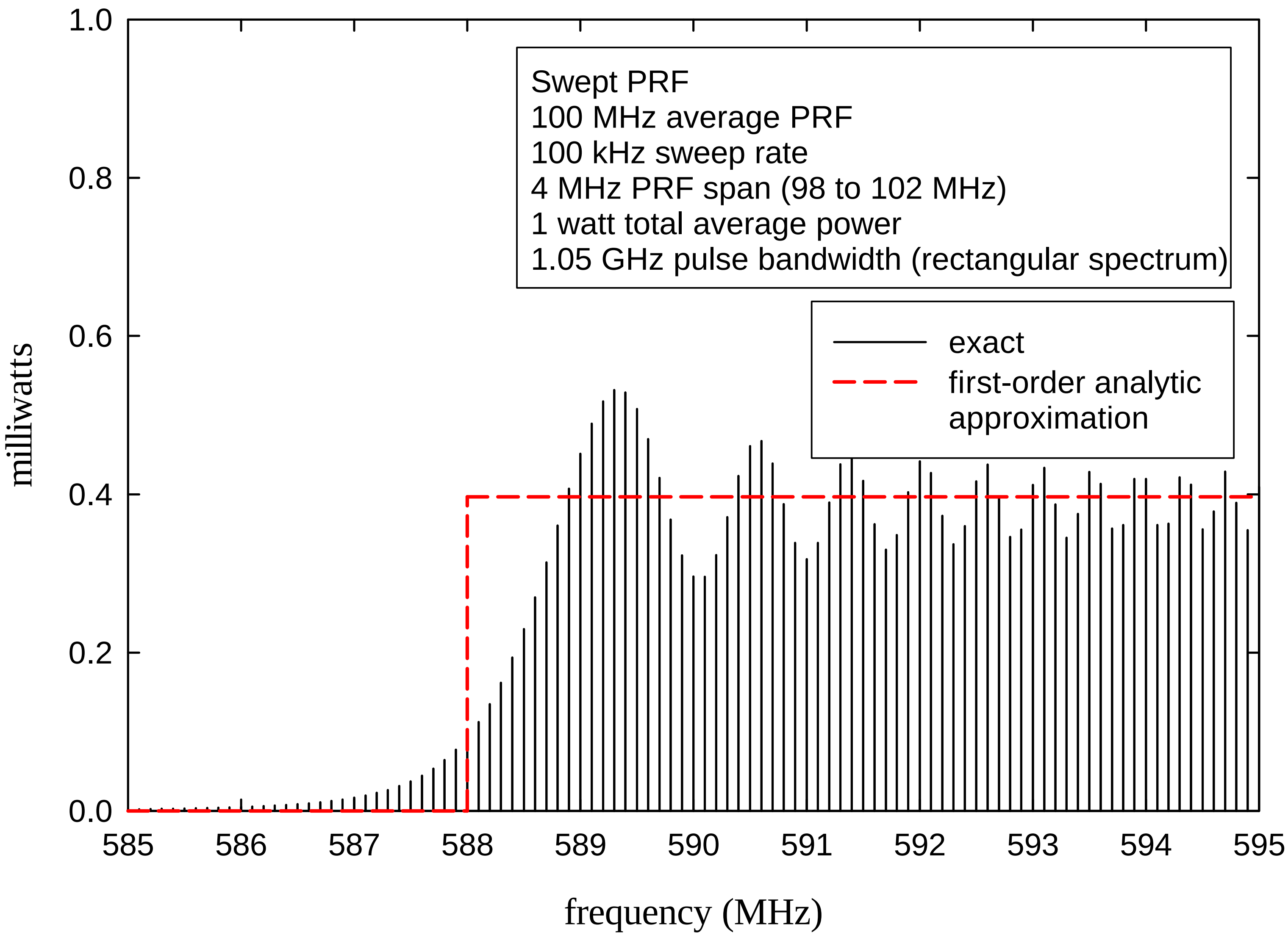
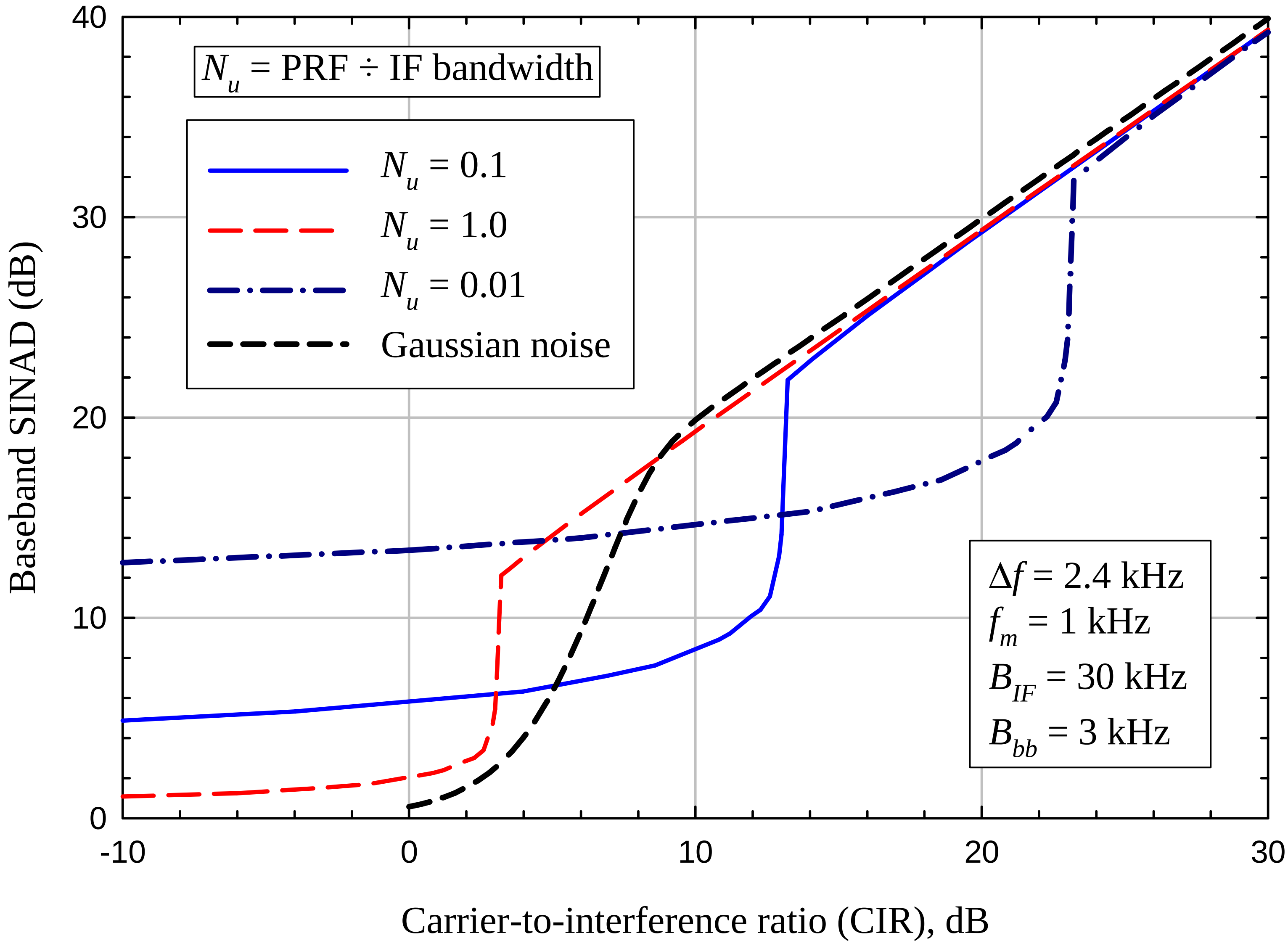
# Individual Tones of the Swept PRF PSD



# UWB Effects on Receiver Performance

- $N_u$ **is the ratio of the pulse rate to the IF bandwidth**
- **There are 3 primary interference cases:**
  - $N_u \leq 1$**, which gives pulsed interference to the detector**
  - $N_u > 1$ **with constant pulse rate, which can give a tone within the passband**
  - $N_u > 1$ **with dithering or modulation, which can give a noise-like signal**
- **The first two cases were explored for fixed-frequency digital communications receivers and for an analog FM receiver. The third case, in the limit, gives results similar to those of Gaussian noise, which are well-known.**
- **With** $N_u > 1$**, there can also be a combination of a tone and noise (as seen previously).**
- **Results are calculated based on the average UWB interference power within the receiver passband.**

# Modeling the Test Procedure for an FM Receiver

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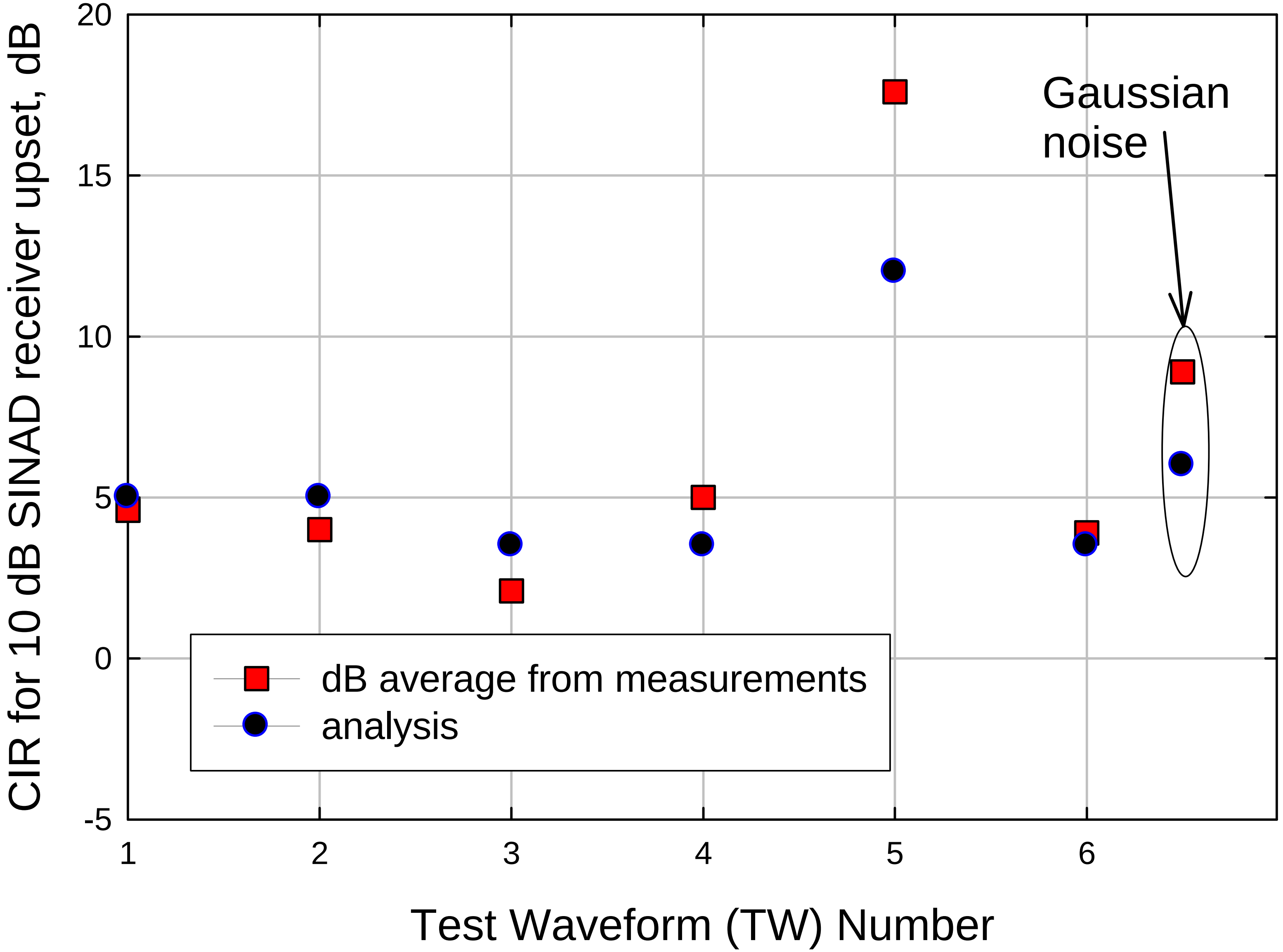
# Analysis vs. dB-Average Test Results (FM)

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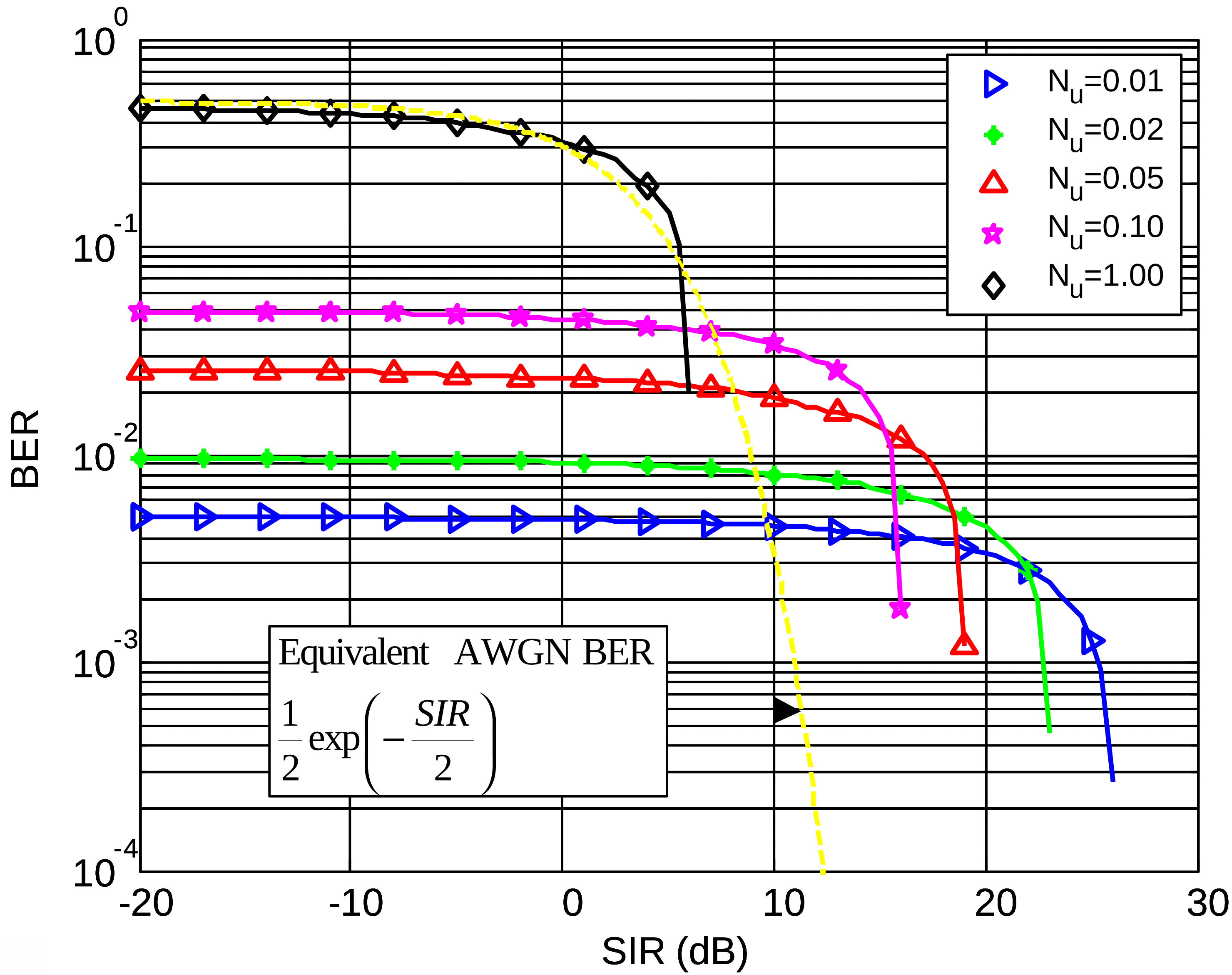
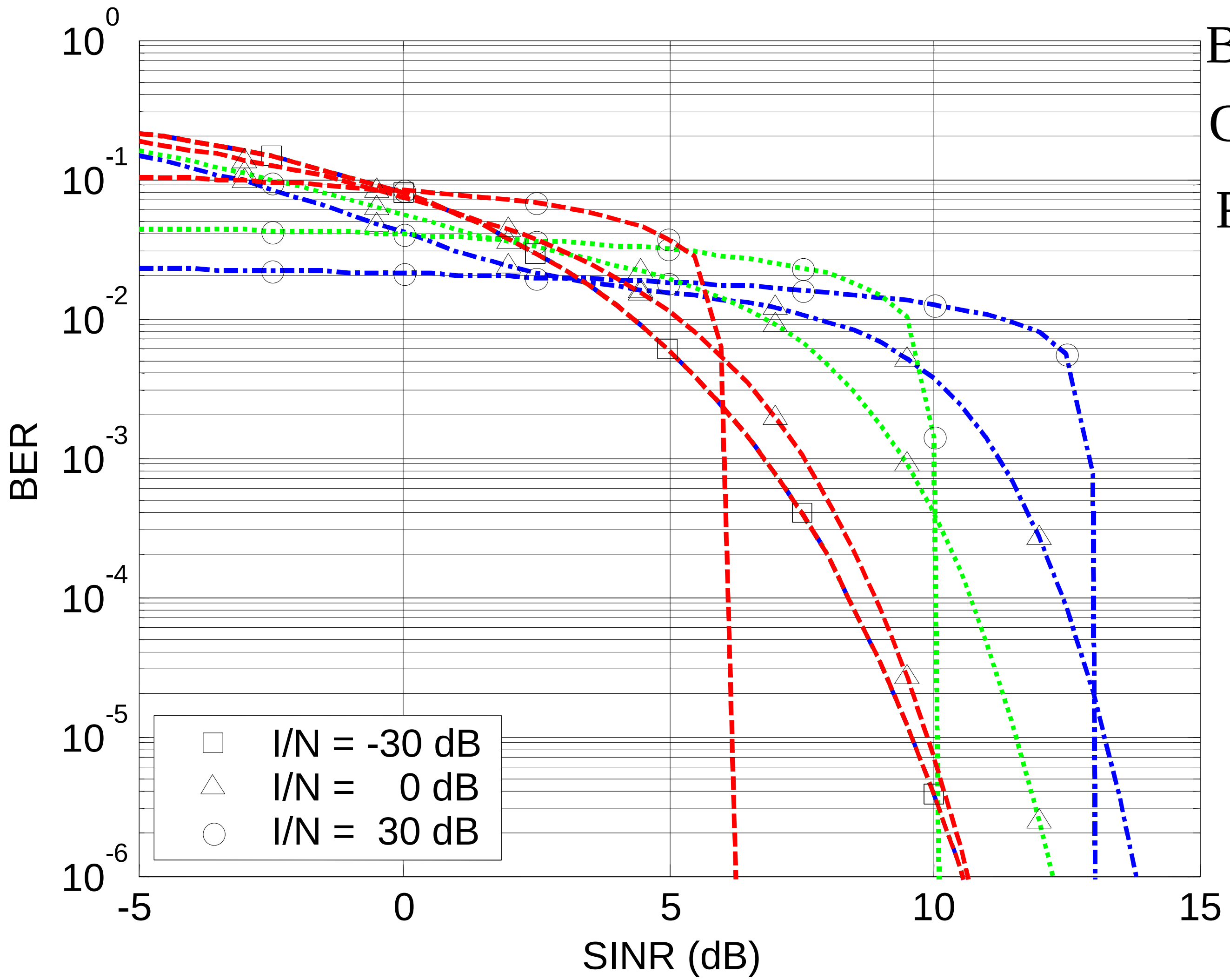
# UWB into a Noncoherent FSK Receiver



# Coherent PSK – Comparison of Rates




Blue: $N_u = 0.05$

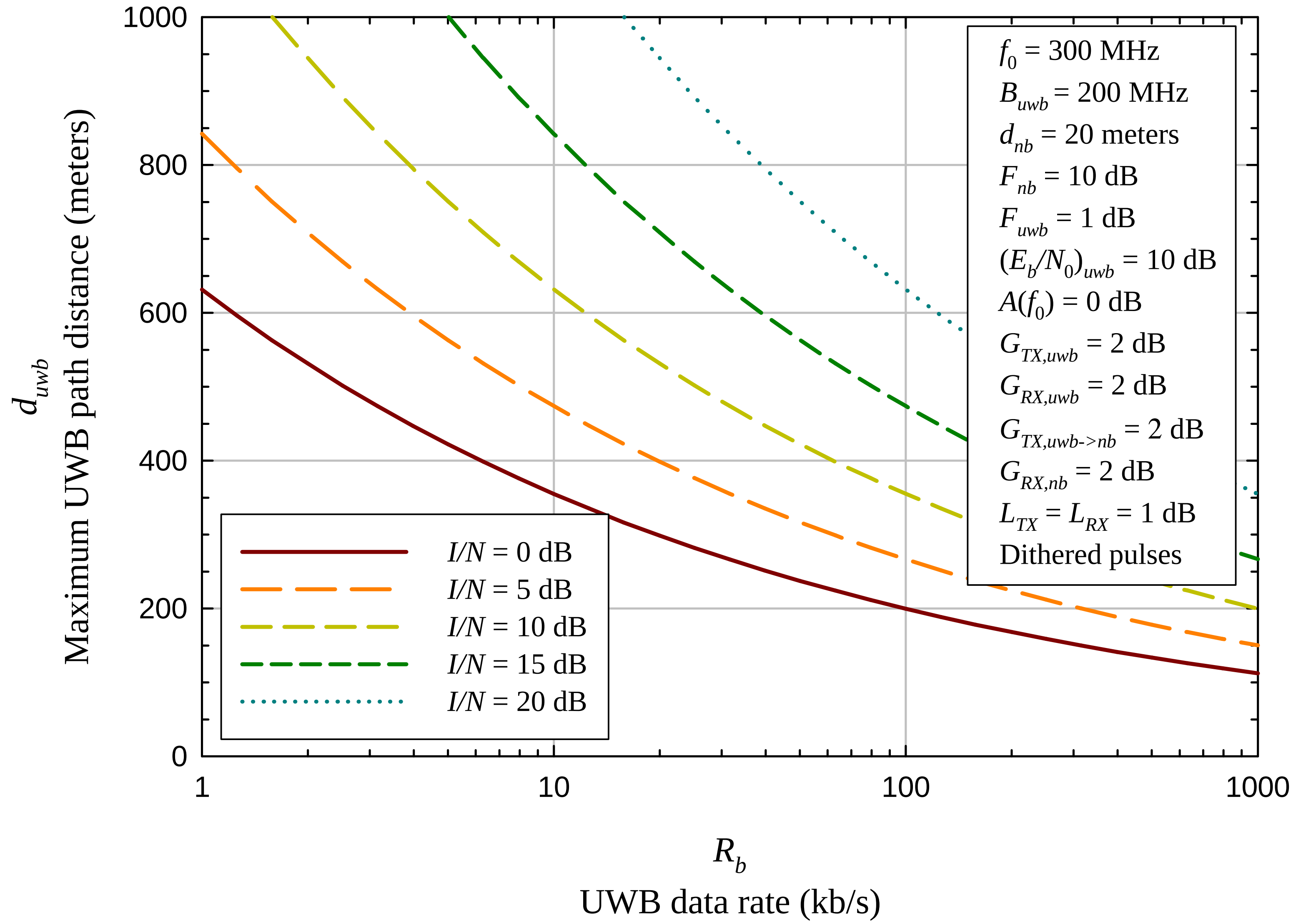
Green: $N_u = 0.1$

Red: $N_u = 0.25$

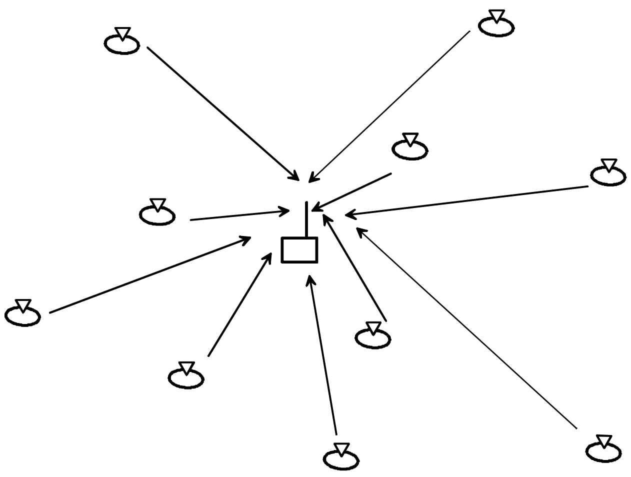
At low SINR, BER $\cong N_u/2$

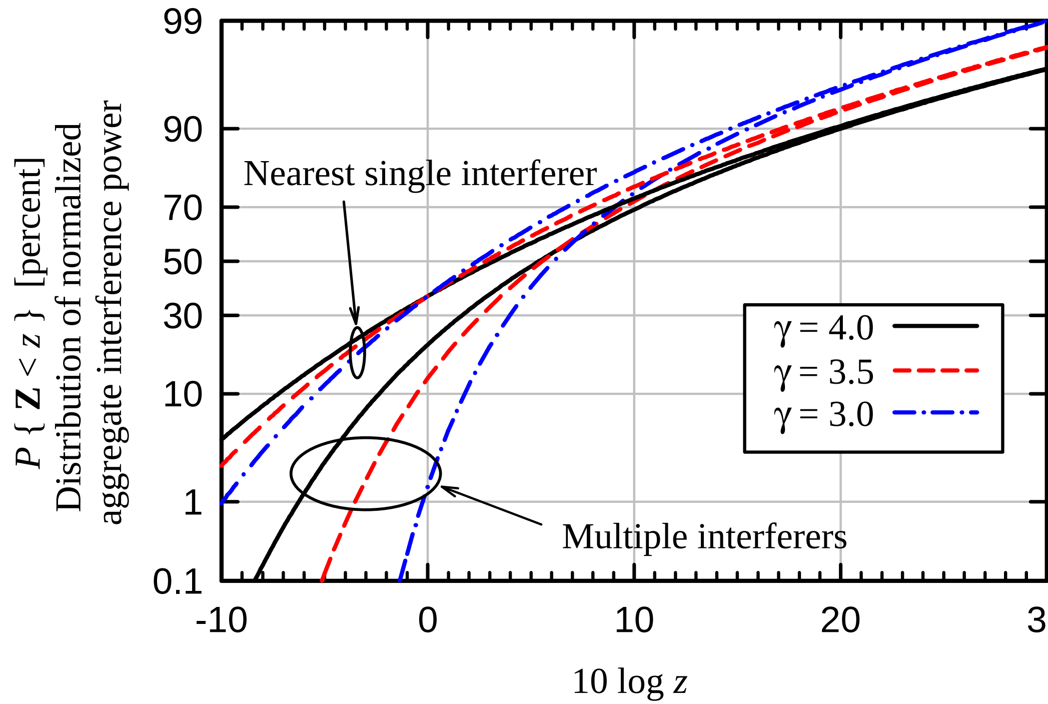
At low BER, SINR $\cong -10\log N_u$

# UWB/Legacy NB Coexistence Example



# Aggregate Interference – Closed form CDF





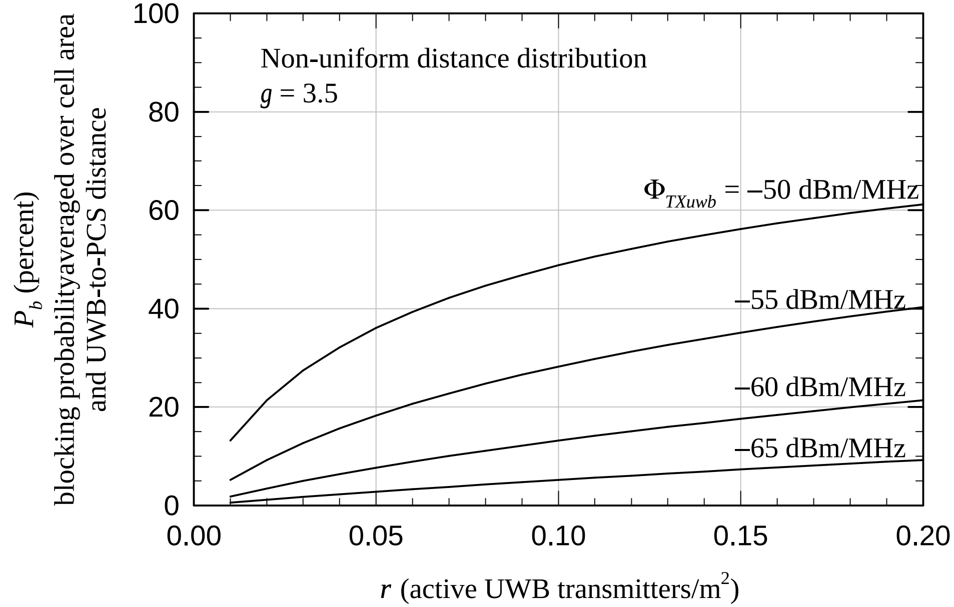

- **Uniformly random distribution of interfering transmitters**
- **Equal power**
- **No exclusion zone**

$$F_Z(z) = \Pr(Z < z) = 1 - \frac{1}{p} \sum_{k=1}^{\infty} \frac{\Gamma(kn)}{k!} \left[ \frac{\Gamma(1-n)}{z^n} \right]^k \sin kp(1-n), \quad z > 0$$

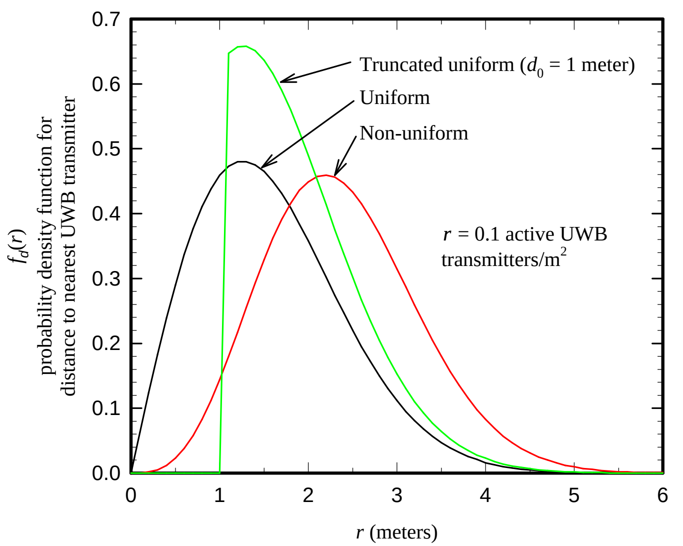
$$F_Z(z) = \exp\left(-z^{-n}\right) \quad z > 0 \quad \text{(nearest interferer)}$$

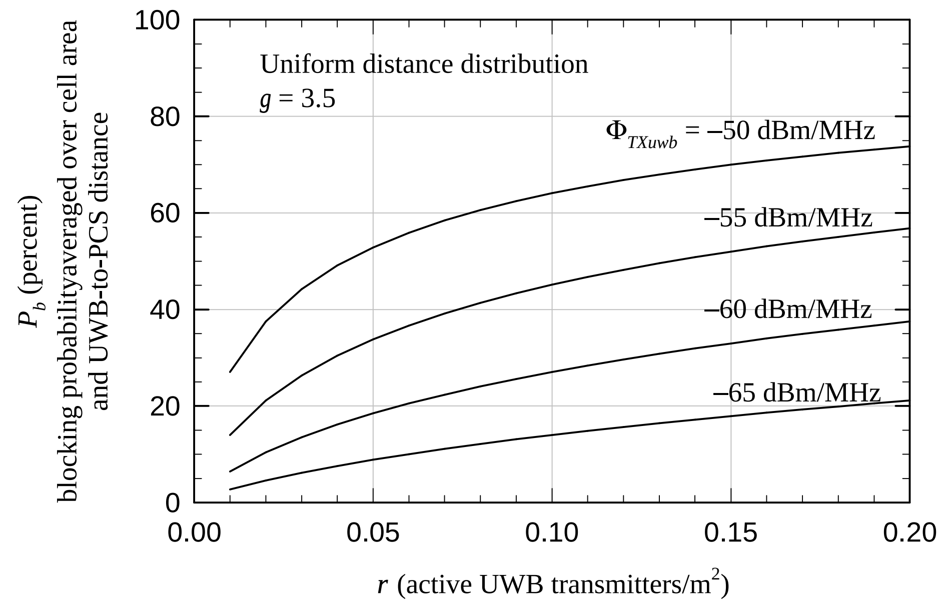
# IS-95 PCS Blocking vs. UWB Density

These curves show the average percentage of handsets blocked on the downlink as a function of UWB deployment density and transmit power spectral density



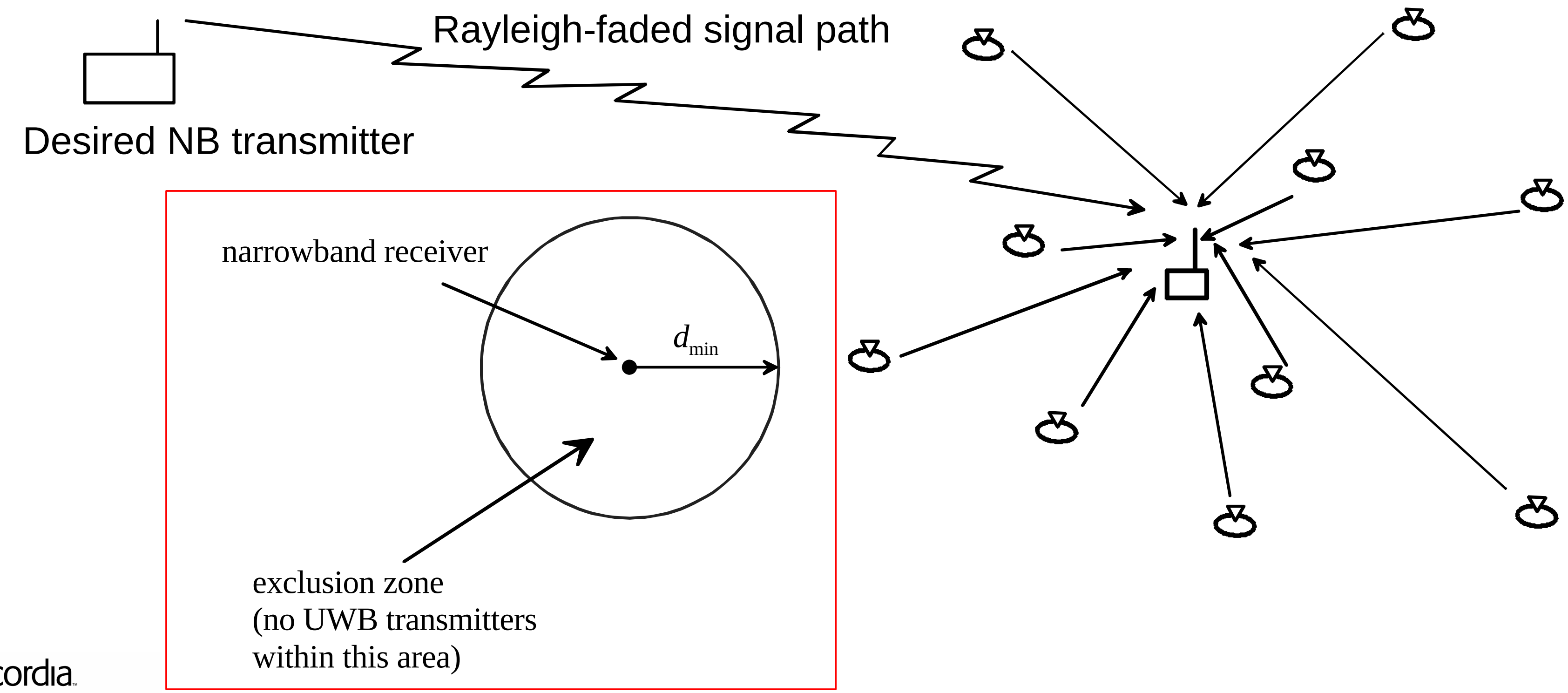

**Probability density functions for minimum UWB to PCS handset distance**



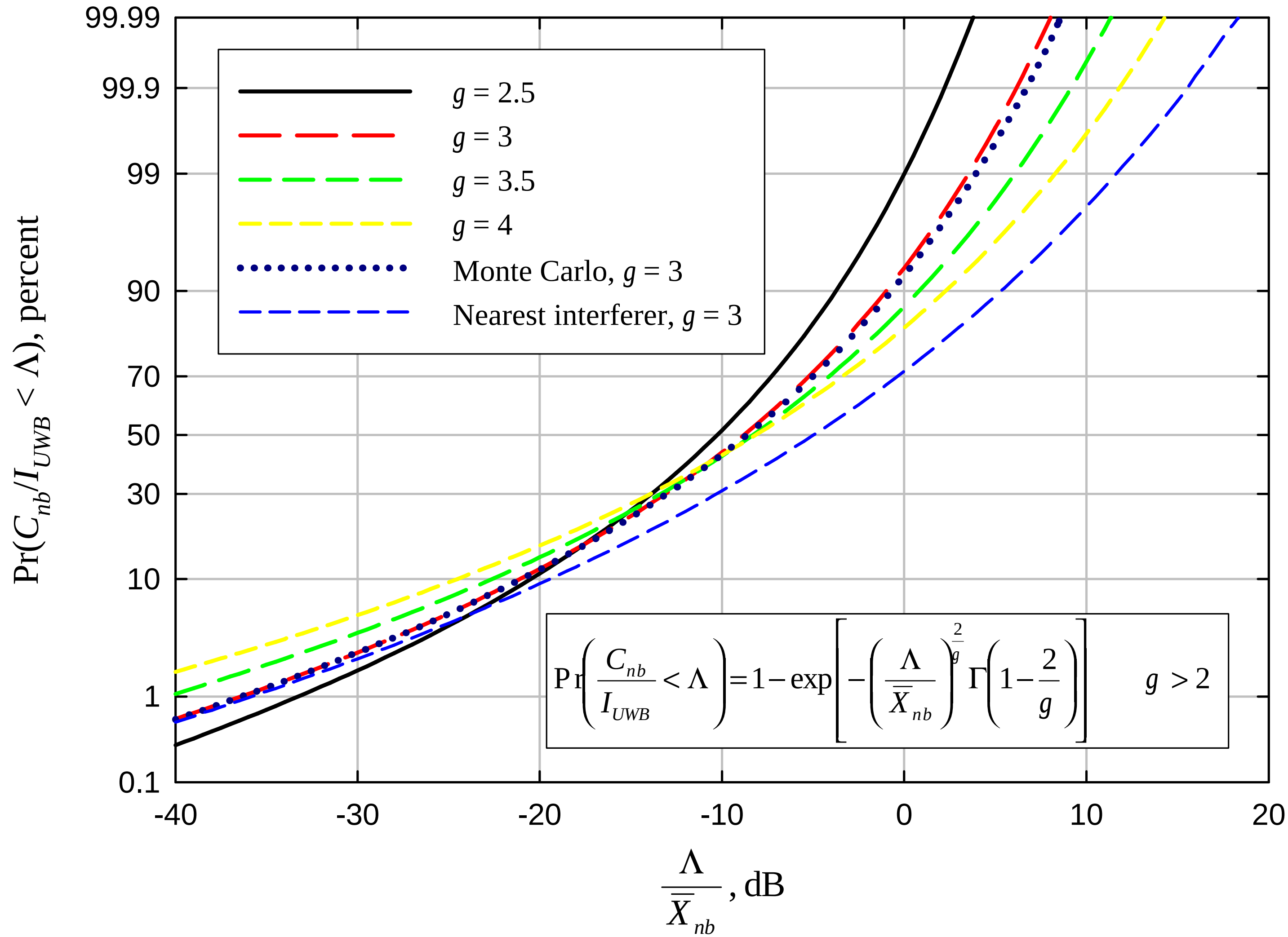



# *C/I* with Aggregate Interference

- **Desired signal to NB receiver Rayleigh-faded (terrestrial multipath).**
- **UWB transmitters uniformly randomly distributed spatially, no fading of interfering signals (short distances).**
- **May be an “exclusion zone” surrounding victim receiver within which there will be no UWB transmitters.**



# *C/I* CDF with Aggregate UWB Interference and no Exclusion Zone




$$\text{normalization}: \ \overline{X}_{nb} = \frac{\overline{C}_{nb}}{aP_{tx}(pr_a)^{g/2}}$$

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# The Larger Picture: UWB – Challenges, Questions, and Opportunities Going Forward

- **Design of UWB radios that can operate adaptively in the presence of strong in-band narrowband signals.**
- **UWB networking: MAC layer design, ad hoc routing protocols, QoS management, especially with narrowband interference.**
- **Applications – what is UWB best suited for (military and commercial)?**
  - **Radar/localization**
  - **Data networking?**
  - **Sensors?**
  - **Integrated applications (e.g., localization + communications).**
- **Can UWB be used to provide high data rate hotspots with connectivity to CMRS networks?**
- **Can UWB be used to increase the accuracy of E-911 indoors?**