

Objective

Simulate and understand how a coaxial cable introduces dispersive distortion to a Wi-Fi-band signal. Use and compare two independent numerical approaches:

- **Method A:** Fourier-series / per-harmonic phase method. Decompose the input waveform into discrete frequency bins, apply the dispersive phase delay $e^{j\phi(\omega)}$ to each bin, then reconstruct by inverse DFT.
- **Method B:** Frequency-domain filtering. Define a dispersive transfer function $H(\omega) = A(\omega)e^{j\phi(\omega)}$ for the cable, multiply the input spectrum by $H(\omega)$, and inverse DFT.

Problem Statement

1. Medium: Coaxial cable.

- Length: $L = 100$ m.
- Nominal characteristic impedance: $Z_0 = 50 \Omega$.
- Phase velocity model:

$$v_p(\omega) = \frac{c}{\sqrt{\epsilon_r}} \left(1 + \frac{\kappa}{\omega^2} \right),$$

where c is the speed of light, $\epsilon_r \approx 2.1$ (typical dielectric), and κ is a small dispersion constant.

- Phase shift: $\phi(\omega) = -\frac{\omega L}{v_p(\omega)}$.
- Optionally include attenuation: $A(\omega) = e^{-\alpha(\omega)L/2}$ (5% extra Mark)

Input Waveforms

Two different input test signals must be used to study dispersive effects:

(a) Gaussian-modulated pulse:

- Center frequency $f_c = 2.4$ GHz.
- Gaussian envelope:

$$x_a(t) = \cos(2\pi f_c t) e^{-\frac{t^2}{2\sigma_t^2}},$$

where σ_t is chosen such that the -3 dB bandwidth $\Delta f \approx 20$ MHz.

- Purpose: Observe pulse broadening, group-delay dispersion, and peak reduction after propagation through the coaxial cable.

(b) NRZ modulated sequence:

- Bit sequence (random 0/1 stream) mapped to $\{-1, +1\}$ polarity.
- Bit rate: $R_b = 10$ Mbps (corresponding bandwidth ~ 10 MHz).
- Carrier upconversion:

$$x_b(t) = \left(\sum_k b_k \cdot \text{rect}\left(\frac{t - kT_b}{T_b}\right) \right) \cos(2\pi f_c t),$$

where $T_b = 1/R_b$ is the bit duration.

- Purpose: Observe inter-symbol interference (ISI), eye diagram distortion, and amplitude reduction after dispersive propagation.

2. Tasks:

- Implement Method A and Method B for the chosen cable model.
- Plot and compare:
 - Input vs. output in time domain (real and envelope).
 - Input vs. output spectra (magnitude and phase).
 - Group delay $\tau_g(\omega) = -\frac{d\phi}{d\omega}$.
- Quantify:
 - Pulse broadening (RMS and FWHM).
 - Peak amplitude reduction.
 - Difference between Method A and Method B outputs (error norms).

3. Parameter sweeps:

- Vary dispersion strength κ (e.g. 0, 10^{-19} , 10^{-18} s²).
- Vary cable length L (10 m, 50 m, 100 m).
- Vary signal bandwidth (5 MHz, 20 MHz, 40 MHz).

4. Analysis questions:

- Do the two methods produce identical results? Under what conditions might they differ?
- How does group-delay variation across the band affect Wi-Fi symbols?
- Which method is more efficient and numerically stable?
- What practical implications arise for Wi-Fi transmission through long coaxial cables (e.g. indoor distribution networks)?

5. An additional 10% marks will be awarded for any critical and important analysis results beyond the analysis questions provided