ECE 451

Automated Microwave Measurements

TL Characterization

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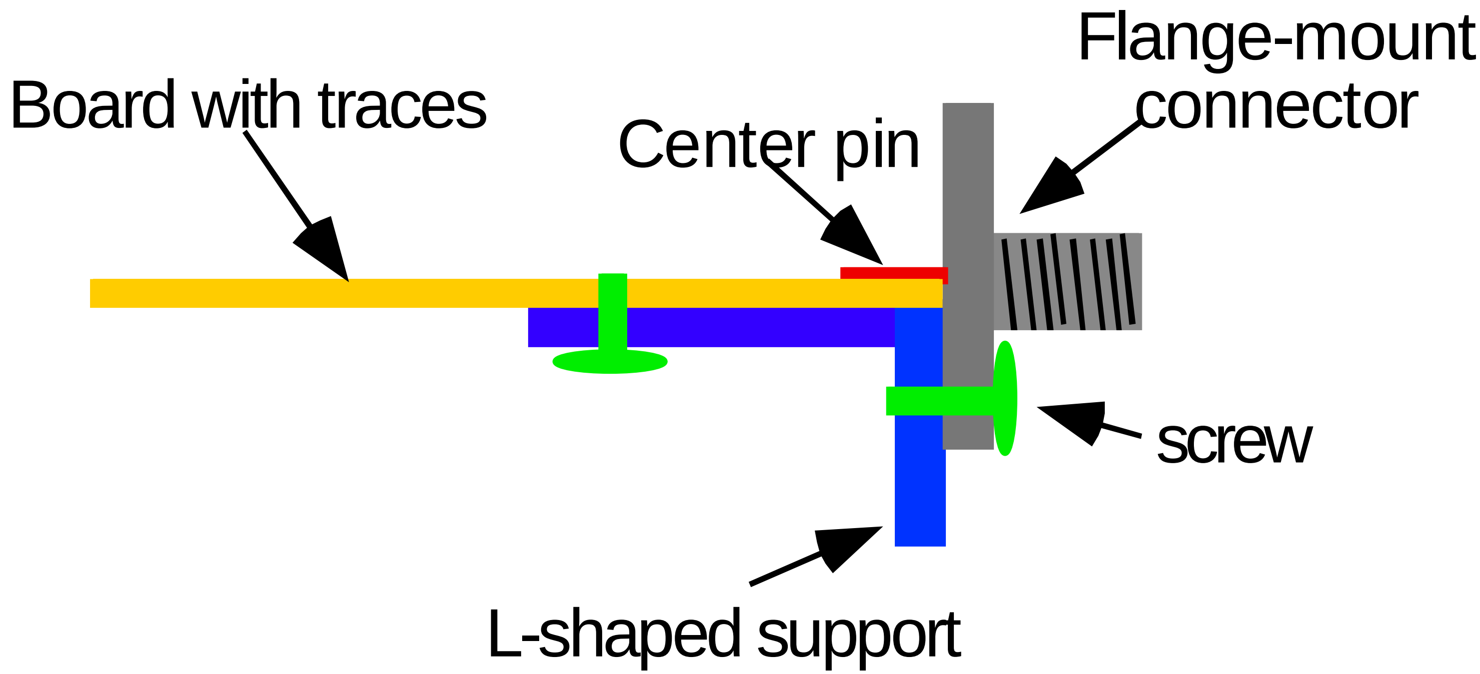
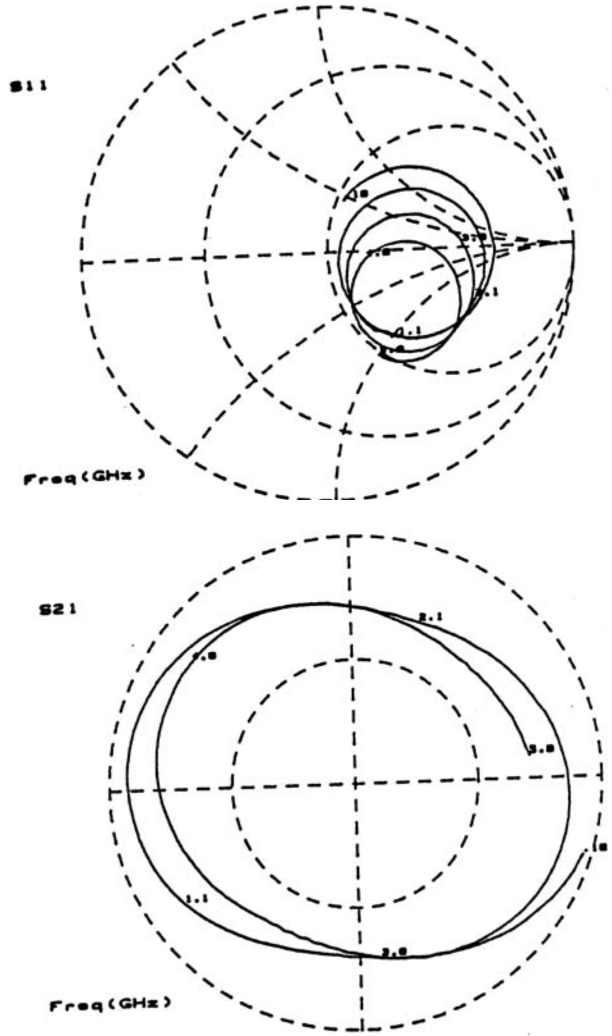
Coaxial-Microstrip Transition



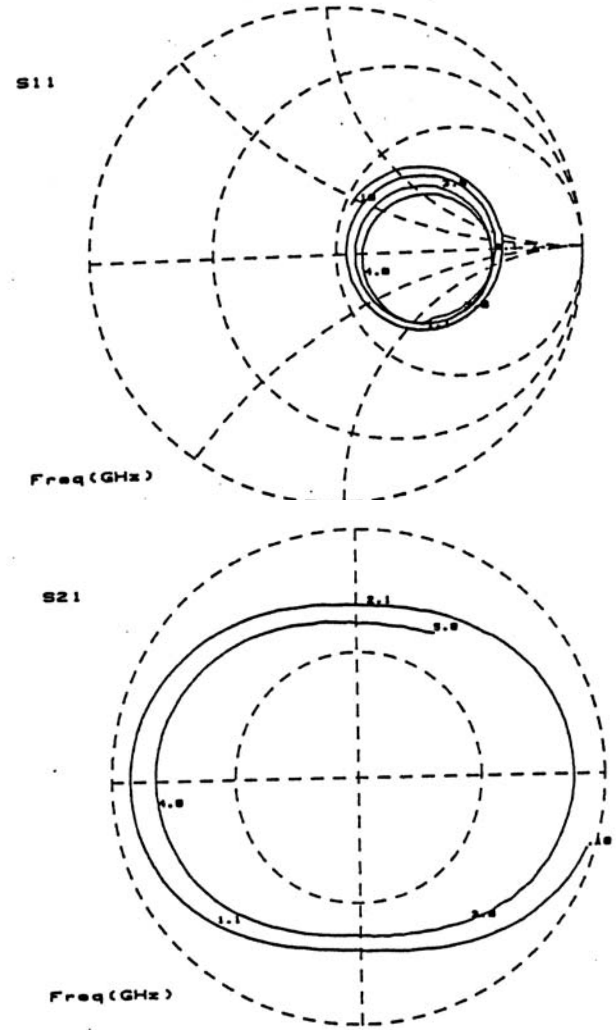
Remove effects of discontinuities before processing data!

Coaxial-Microstrip Transition

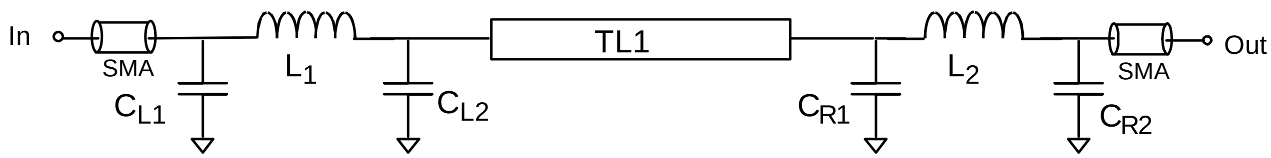
With parasitics



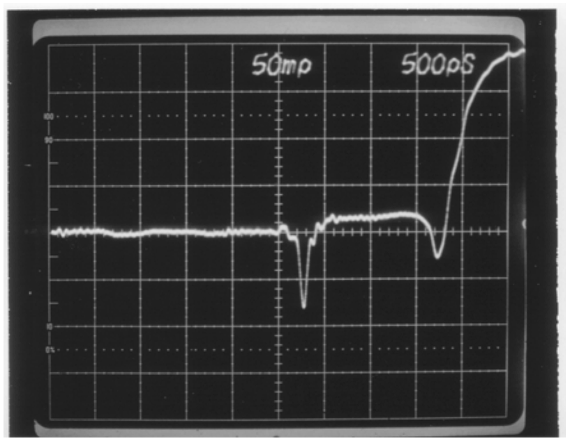
No parasitics



Coaxial-Microstrip Transition

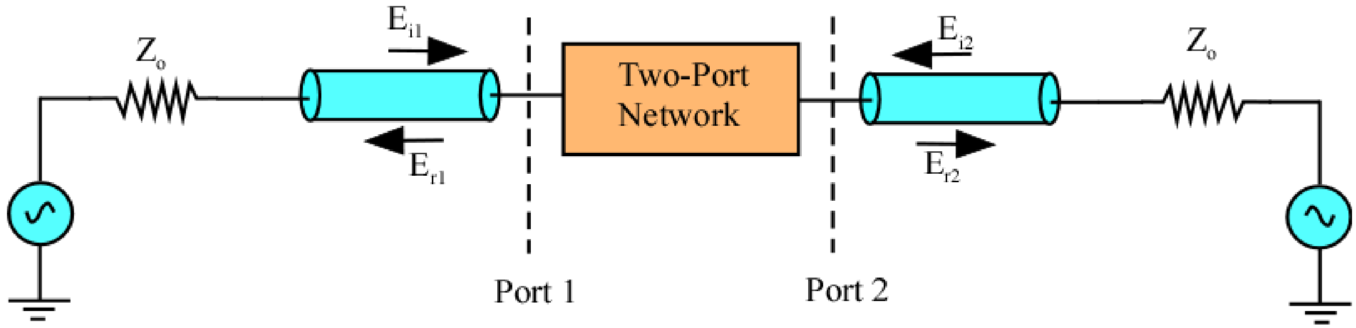


Equivalent Circuit



TDR Plot

High-Frequency Characterization



Transmission-Line Scattering Parameters

$$S_{21} = \frac{(1-\Gamma^2)X}{1-\Gamma^2 X^2} \qquad S_{11} = \frac{(1-X^2)\Gamma}{1-\Gamma^2 X^2}$$

$$X = e^{-\gamma d} \qquad Z_c = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$$

$$\Gamma = \frac{Z_c - Z_o}{Z_c + Z_o} \qquad \gamma = \sqrt{(R+j\omega L)(G+j\omega C)}$$

TL Extraction Formulas

$$X = e^{-\gamma d} = e^{-j\beta d} e^{-\alpha d}$$

$$X = e^{-\gamma d} = \frac{\left(S_{11} + S_{21}\right) - \Gamma}{1 - \left(S_{11} + S_{21}\right)\Gamma}$$

$$\Gamma = Q \pm \sqrt{Q^2 - 1}$$

$$Q = \frac{\{S_{11}^2 - S_{21}^2\} + 1}{2S_{11}}$$

$$R = \mathrm{Re}\{\gamma Z_c\}$$

$$G = \mathrm{Re}\{\frac{\gamma}{Z_c}\}$$

$$L = \frac{1}{\omega}\mathrm{Im}\{Z_c \gamma\}$$

$$C = \frac{1}{\omega}\mathrm{Im}\{\frac{\gamma}{Z_c}\}$$

Low-Loss Approximation

If we assume $R << \omega L$

and $G << \omega C$

$$Z_c \cong \sqrt{\frac{L}{C}}$$

$$\gamma \cong \frac{R}{2}\sqrt{\frac{C}{L}} + j\omega\sqrt{LC} = \frac{\mathrm{R}}{2\mathrm{Z_c}} + j\frac{\omega}{v_p}$$

$$\alpha \cong \frac{\mathrm{R}}{2\mathrm{Z_c}} \qquad \beta \cong \frac{\omega}{\mathrm{v_p}}$$

TL Extraction Formulas

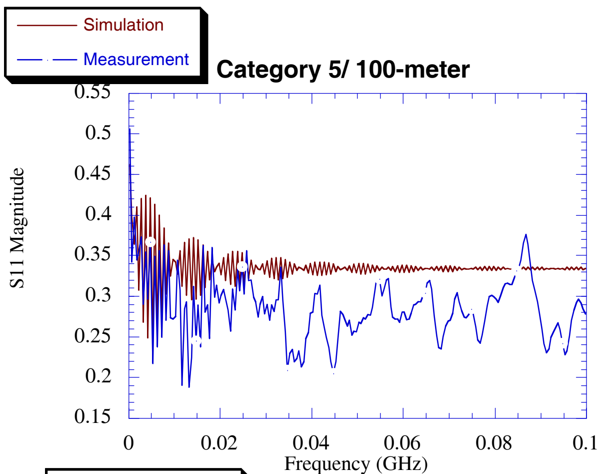
$$\alpha = -\frac{\ln\left(\left|X\right|\right)}{d}$$

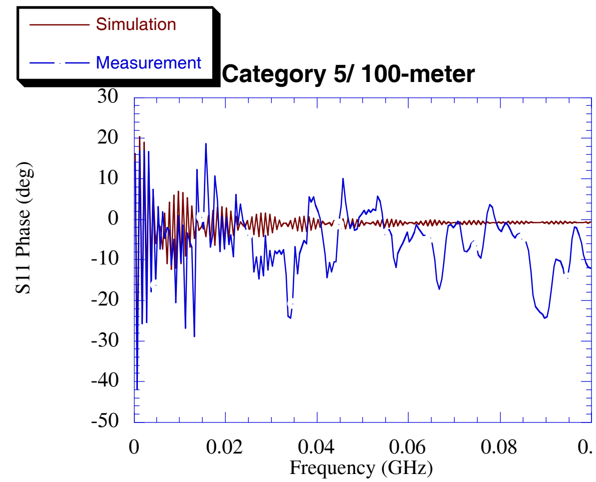
$$R = -\frac{2Z_c \ln\left(\left|X\right|\right)}{d}$$

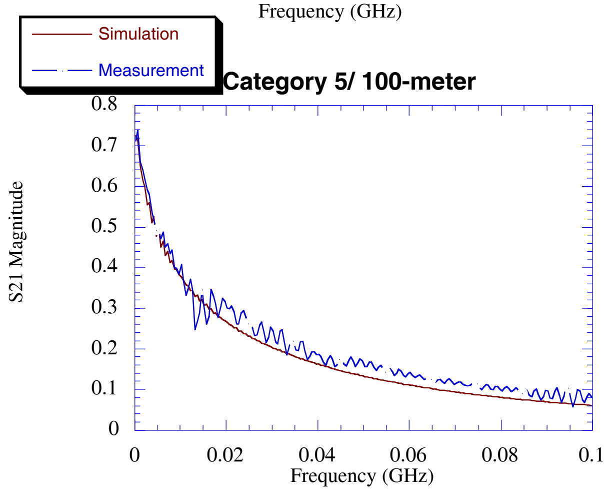
$$\frac{\Delta\phi}{\Delta\omega} = -\frac{d}{v_p}$$

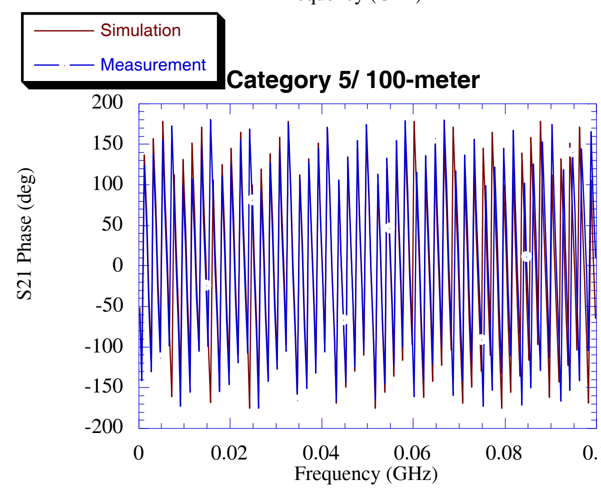
$$v_p = -\frac{d}{\dfrac{\Delta\phi}{\Delta\omega}}$$

Example: Category-5 Cable (long)

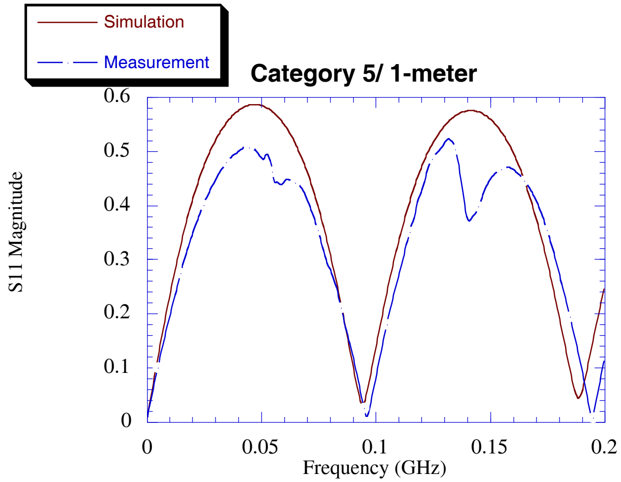


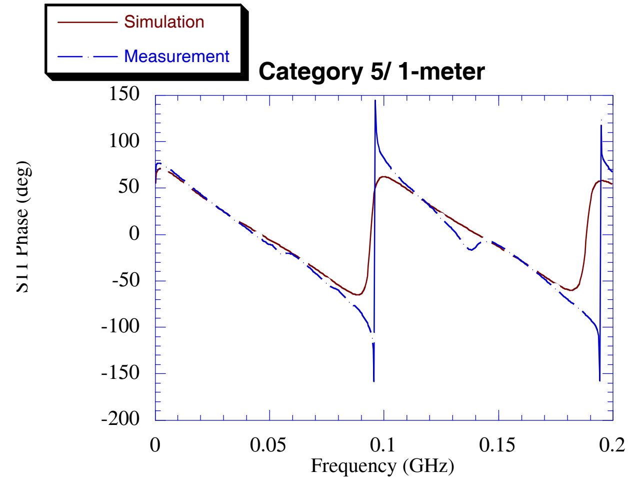


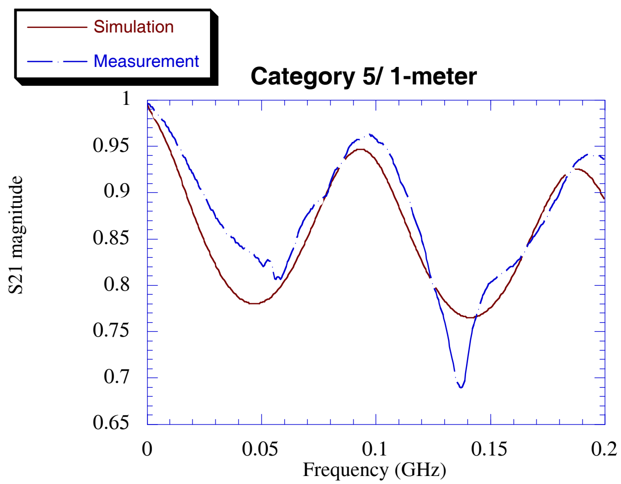


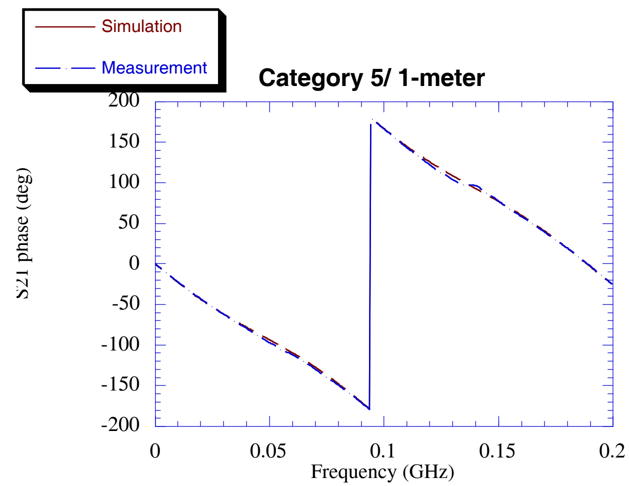


Example: Category-5 Cable (short)

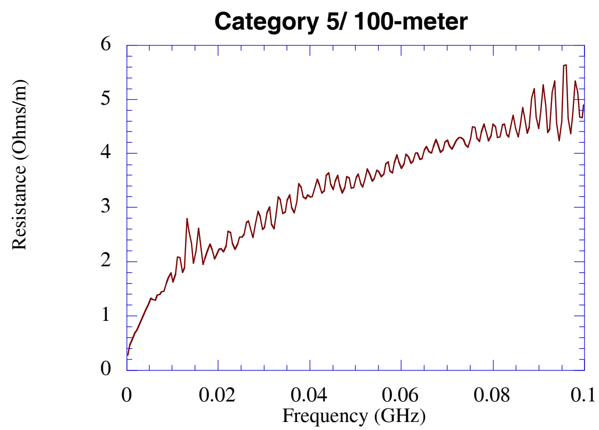


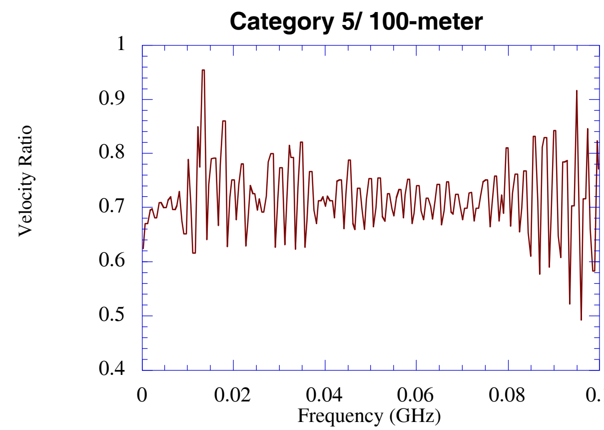






Category-5 Cable – Loss Characteristics





Cable Loss Model

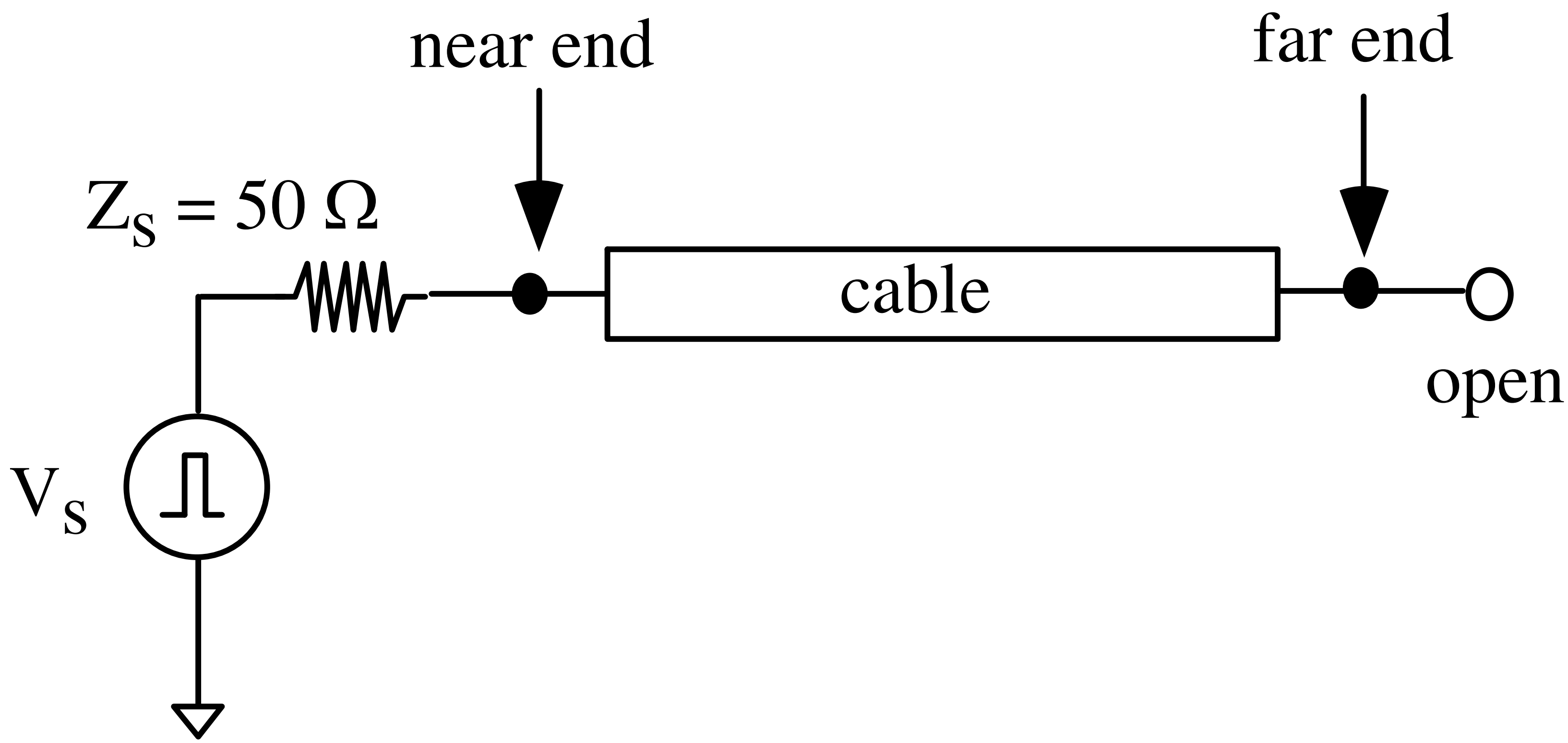
$$R(f) = R_s * f^p$$

$$v_r = v_{ro} + v_{rs} * f$$

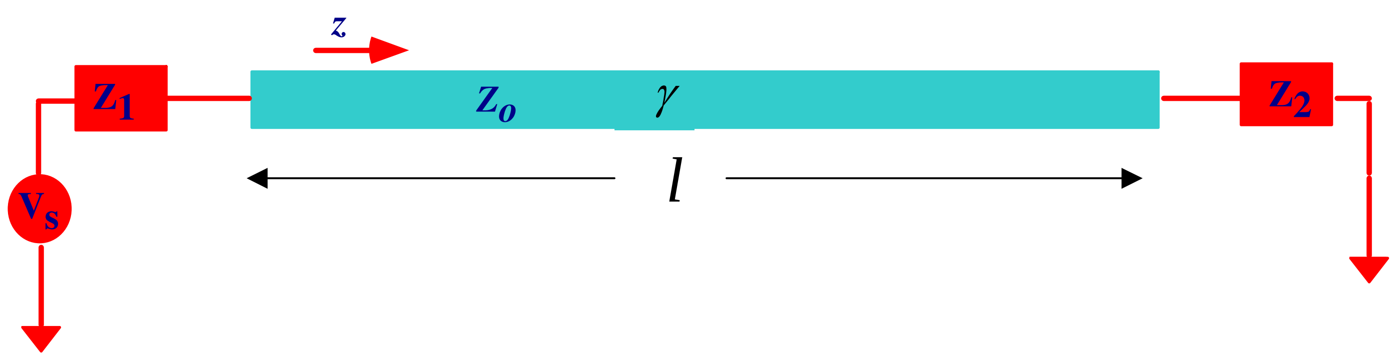
$$Z = R(f) + j\omega L = R_{skin} + j(R_{skin} + \omega L)$$

	Z_o (Ω)	v_{ro} (m/ns)	v_{rs} (m/ns-GHz)	R_s (Ω/m-GHz^p)	p	f_{max} (GHz)
Category 5	100	0.724	-0.165	15.38	0.482	0.2
24-Ga	100	0.678	1.157	29.03	0.593	0.1
Category 3	100	0.705	11.06	12.31	0.473	0.01
SMA	50	0.700	0.113	7.94	0.415	0.2

Time-Domain Simulations



Lossy Transmission Line

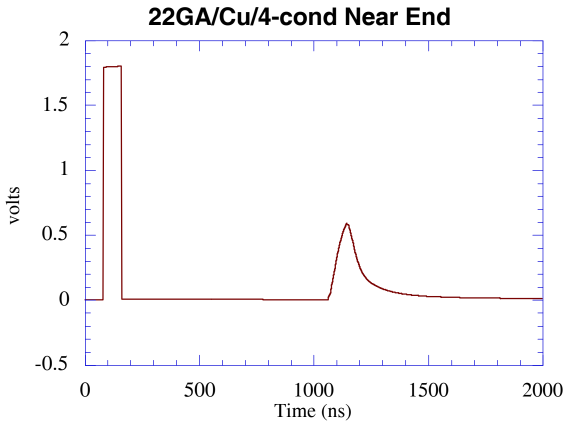


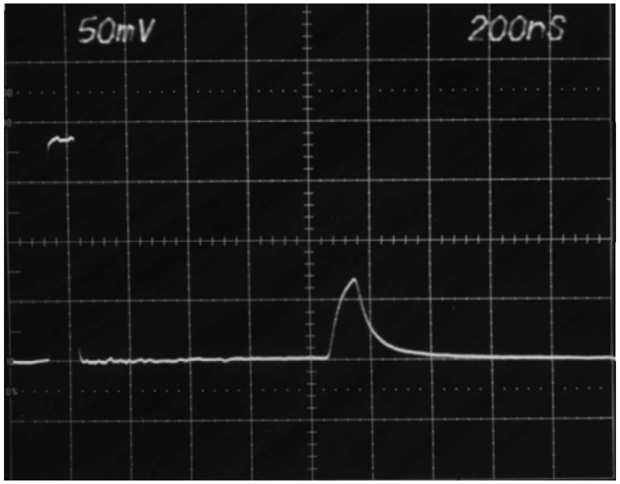
$$V(z) = Ae^{-\alpha z}e^{-j\beta z} + Be^{+\alpha z}e^{+j\beta z}$$

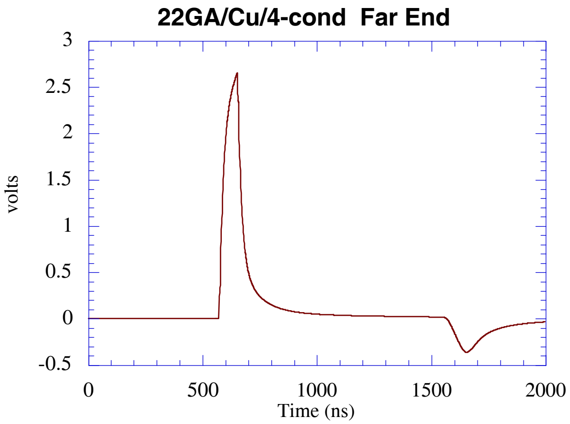
$$I(z) = \frac{1}{Z_o}\left[Ae^{-\alpha z}e^{-j\beta z} - Be^{+\alpha z}e^{+j\beta z}\right]$$

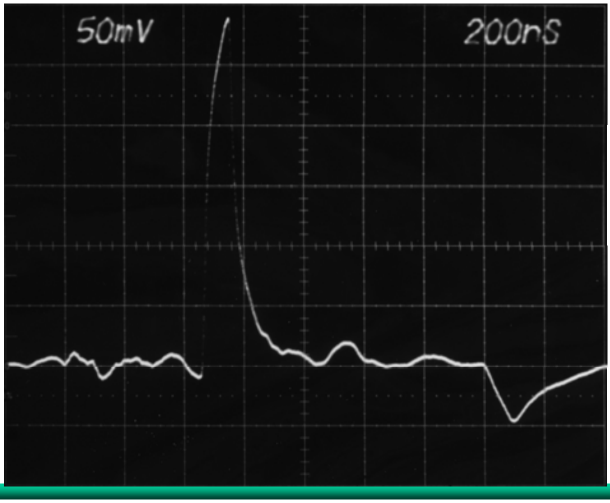
$$Z_o = \sqrt{\frac{\left(R(\omega) + j\omega L\right)}{\left(G + j\omega C\right)}} \qquad \gamma = \alpha + j\beta = \sqrt{\left(R(\omega) + j\omega L\right)\left(G + j\omega C\right)}$$

Pulse Propagation (CAT-5)

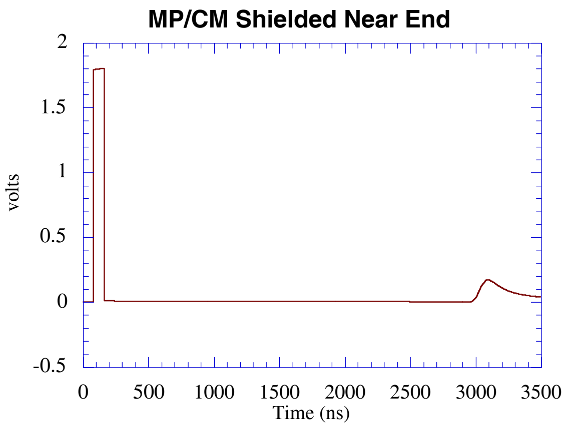


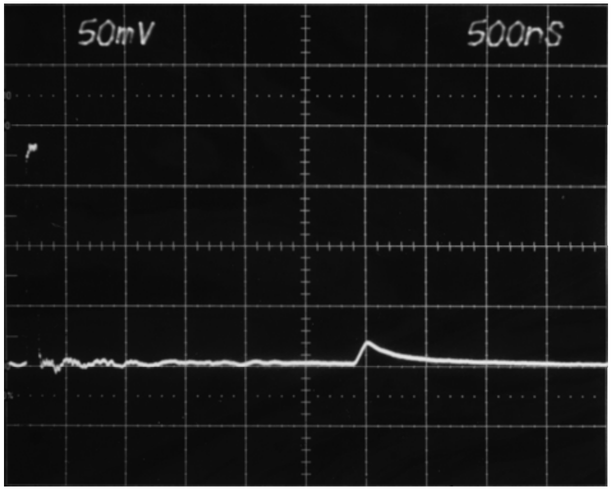


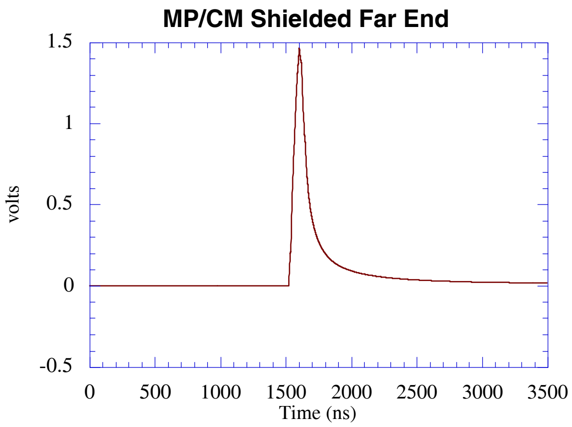


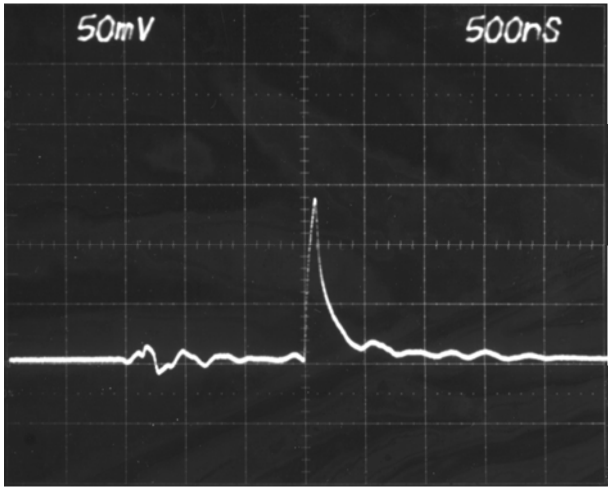


Pulse Propagation (MP/CM)

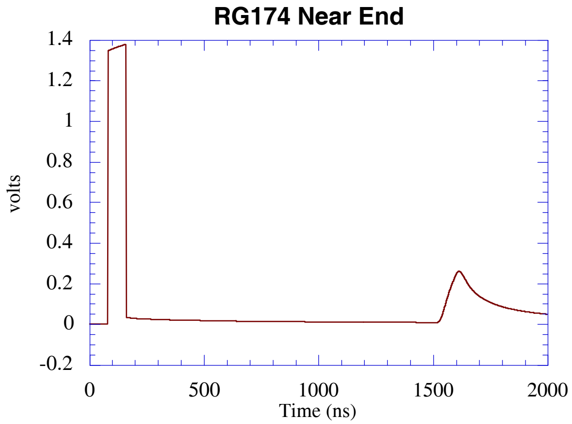


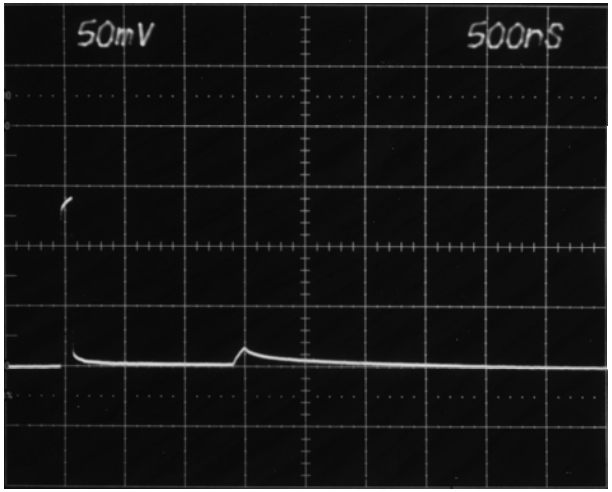


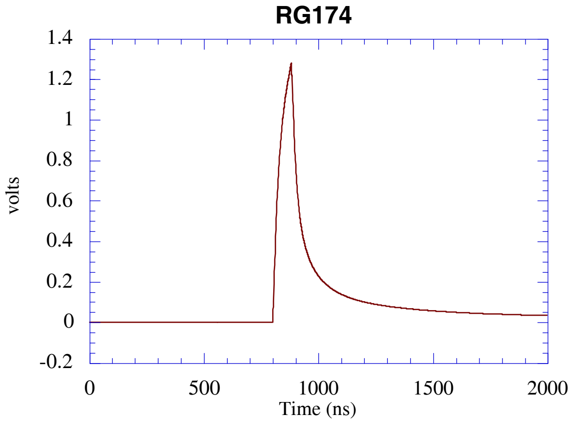


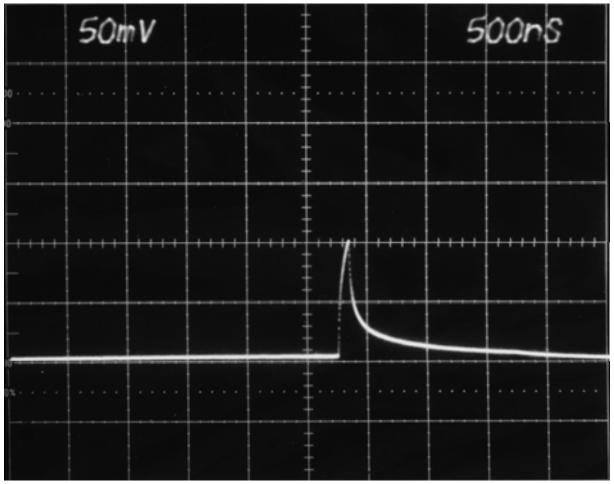


Pulse Propagation (RG174)







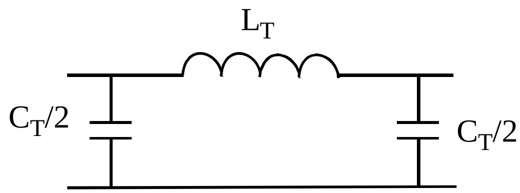


Modeling Interconnections

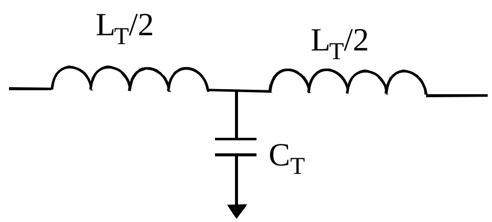
Low Frequency

Short

Mid-range Frequency

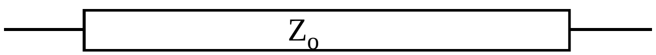


or



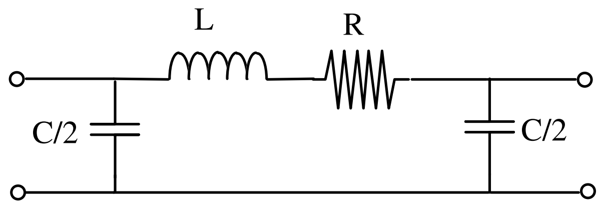
Lumped Reactive CKT

High Frequency



Transmission Line

Low-Frequency TL Approximation



$$P = (R + j\omega L)(1 + j\omega C Z_o/2)$$

$$Y = j\omega C Z_o/2$$

$$S_{11} = \frac{P - 2YZ_o - YP}{2Z_o + P + 2YZ_o + YP} \qquad S_{21} = \frac{2Z_o}{2Z_o + P + 2YZ_o + YP}$$

$$A = 2Z_o(1 - S_{21})$$

$$Y = \frac{A - 2S_{11}S_{21}Z_o - S_{11}A}{4S_{21}Z_o + 2S_{11}S_{21}Z_o + S_{11}A + A} \qquad P = A - 2YS_{21}Z_oS_{21}(1 + Y)$$

Low-Frequency Model for Microstrip

- Lumped Model
- Use extraction algorithm