Ringing Test for 1.5 GHz Transmission Lines using Nichols Charts

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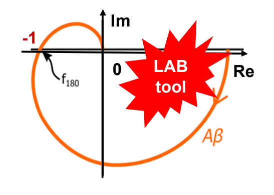
1. Research Objective

Solving the stability test problems:

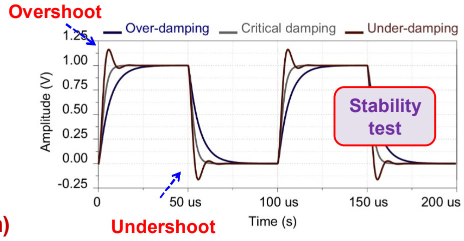
- Overshoot in high-speed transmission lines
- Limitations of loop gain and Nyquist diagram

Nyquist plot of loop gain



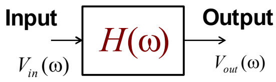
(Unclear operating region)

Ringing in electronic systems



2. Research Background

High-order system



Transfer function

$$H(\omega)=\frac{V_{out}(\omega)}{V_{in}(\omega)}=\frac{A(\omega)}{1+L(\omega)}$$

$V_{in}(\omega)$, $V_{out}(\omega)$: periodic signals with angular frequency variable

$A(\omega)$: Numerator function

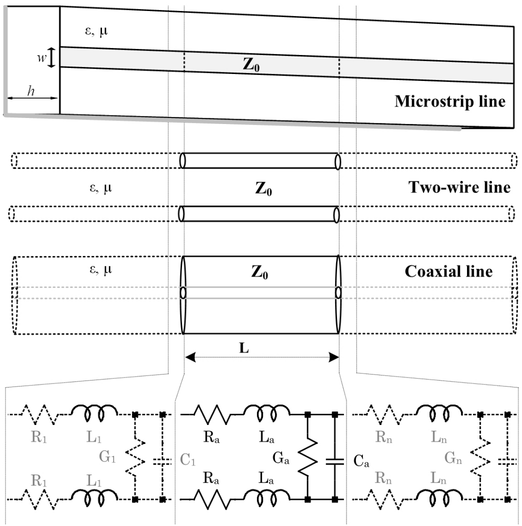
$L(\omega)$: Self-loop function

$$L(\omega)=\frac{A(\omega)}{H(\omega)}-1$$

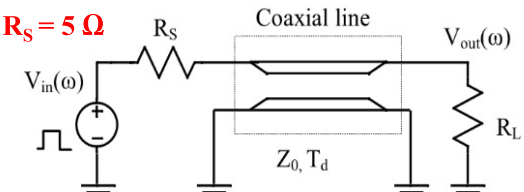
- ○Polar chart → Nyquist chart
- ○Magnitude-frequency plot
- ○Angular-frequency plot } Bode plots
- ○Magnitude-angular diagram → Nichols diagram

3. Ringing test for coaxial line

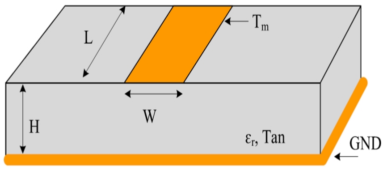
Simplified model of transmission lines



Schematic of the coaxial line



Physical model of transmission line



Parameters of the schematic model

Variable	Value	Variable	Value
L_a	0.25 nH	Z_0	50 Ω
R_a	1.82 mΩ	Loss	1.6 mdB
C_a	0.1 pF	Skin depth	1.7 um
G_a	6.81 uM/Ω	Delay	0.2 ns

Parameters of the physical model

Parameter	Value	Parameter	Value
Metal width (W)	0.71 mm	Substrate thickness (H)	2
Trace length (L)	40 mm	Dielectric constant (ε_r)	4.6
Metal thickness (T_m)	35 mm	Loss tangent (Tan)	0.01
Metal resistivity	17.2 nΩ	Frequency	1.5 GHz
Surface roughness	0.1 um	Characteristic Impedance	50 Ω

Apply superposition at the node X_{out},

$$V_{out}(\omega)\left(\frac{1}{R_S+Z_0}+\frac{1}{R_L}\right)=V_{in}(\omega)\frac{1}{R_S+Z_0};$$

Characteristic impedance

$$Z_0=\sqrt{\frac{R_a+j\omega L_a}{G_a+j\omega C_a}}\approx\sqrt{\frac{L_a}{C_a}};$$

Matching impedance

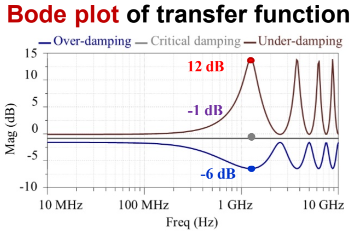
$R_L = 50\ \Omega$,

Transfer function and self-loop function

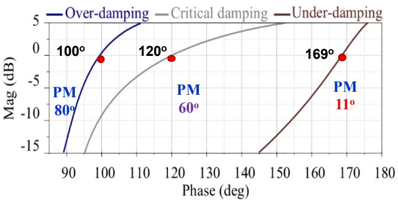
$$H(\omega)=\frac{V_{out}(\omega)}{V_{in}(\omega)}=\frac{1}{1+L(\omega)};\quad L(\omega)=\frac{R_S+\sqrt{\frac{R_a+j\omega L_a}{G_a+j\omega C_a}}}{R_L};$$

4. Simulation Results

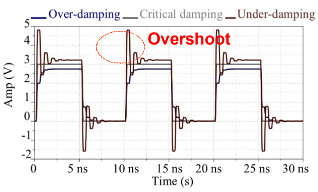
Bode plot of transfer function



Nichols plot of self-loop function



Transient response



Case	Over-damping	Critical damping	Under-damping
Magnitude (transfer function)	-6 dB	-1 dB	12 dB
Phase margin (self-loop function)	80° (observed at 100°)	60° (observed at 120°)	11° (observed at 169°)

5. Conclusion

- Limitations of loop gain in stability test of physical systems.
- Ringing test for transmission lines using Nichols charts

→ Observation of self-loop function can help us optimize the behaviors of transmission lines easily.

Future work:

Stability test for parasitic components in printed circuit boards, physical layout layers, floating load systems…

References

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[2] J. Lin, M. Su, Y. Sun, X. Li, S. Xie, G. Zhang, F. Blaabjerg, "*Accurate Loop Gain Modeling of Digitally Controlled Buck Converters*," IEEE Trans. on Indus. Elec., pp. 1-1, Jan. 2021.
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