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Microwave model for optimizing electro-optical modulation response of the Mach-Zehnder modulator

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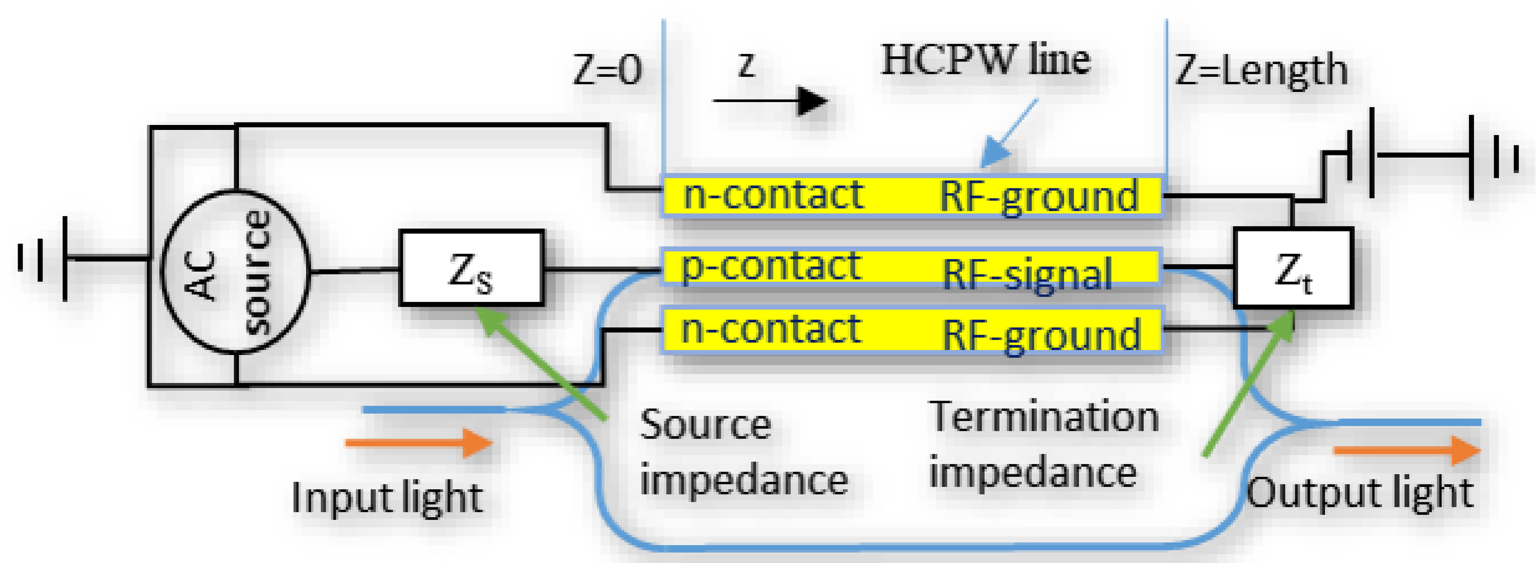
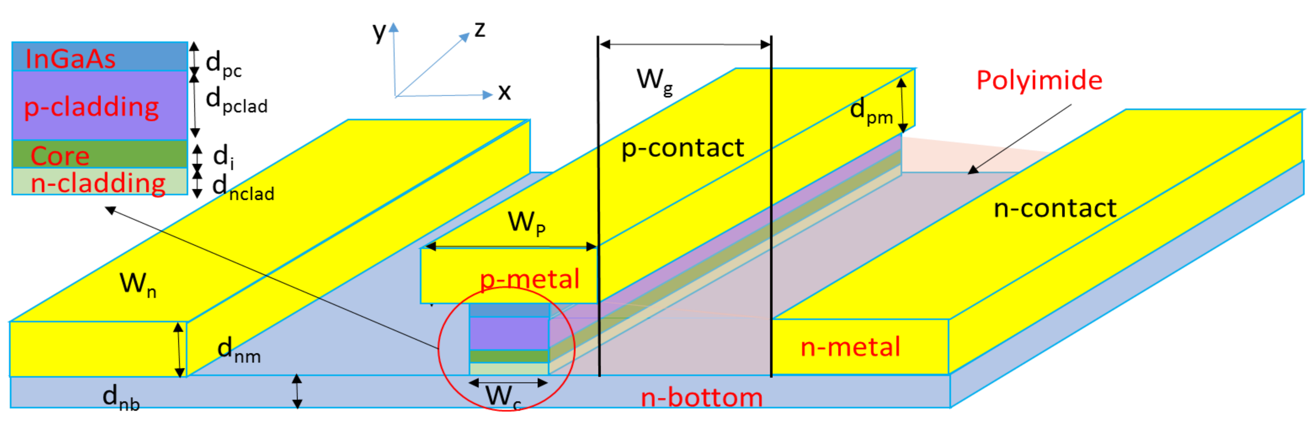
Introduction

Non-iterative electro-optical combined model of the MZM to calculate:

- The frequency-dependent characteristic impedance
- The frequency-dependent propagation constant
- Electro optical frequency response
- The role of impedance matching



Combined Model



Elevated view cross-section of the reference HCPW-MZM

CST Microwave Studio is used to calculate:

- Frequency-dependent electrical complex Propagation constant (γ_m)
- Characteristic impedance of the MZM (Z_m)

small-signal normalized modulation index:

$$M(\omega)=\left|\frac{\Delta\phi(\omega)}{\Delta\phi(0)}\right|=\frac{R_t+R_s}{R_t}\left|\frac{Z_{in}}{Z_{in}+Z_s}\right|\left|\frac{(Z_t+Z_m)F(u_+)+(Z_t-Z_m)F(u_-)}{(Z_t+Z_m)e^{\gamma_m L}-(Z_t-Z_m)e^{-\gamma_m L}}\right|$$

Where:

$$F(u)=\frac{1-exp(u)}{u},\gamma_m=\alpha_m+j\frac{\omega n_m}{c_0},u_{\pm}(\omega)=\pm\alpha_m L+j\frac{\omega}{c_0}(\pm n_m-n_0)L(3)$$

$$Z_{in}=Z_0\frac{Z_t+Z_m tanh(\gamma_m L)}{Z_m+Z_t tanh(\gamma_m L)}$$

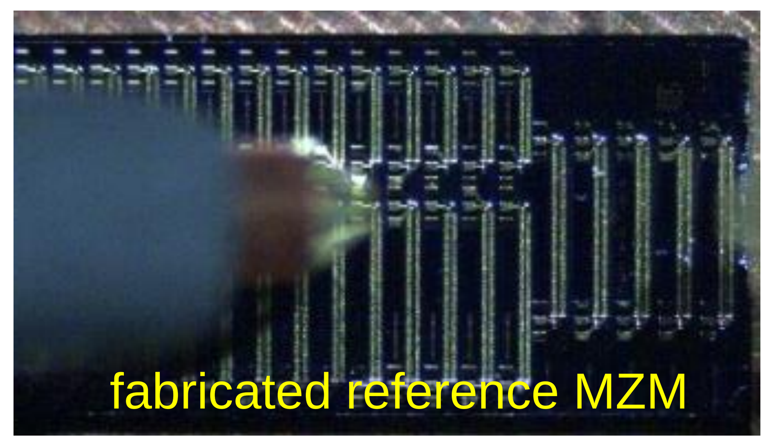
- Δϕ(ω): Frequency dependent cumulative phase modulation over the interaction length L
- Z_s: Source impedance with the real part of R_s
- Z_t: Termination impedance with the real part of R_t
- no: Optical refractive index
- c_0: Speed of light in vacuum
- ω: Angular frequency

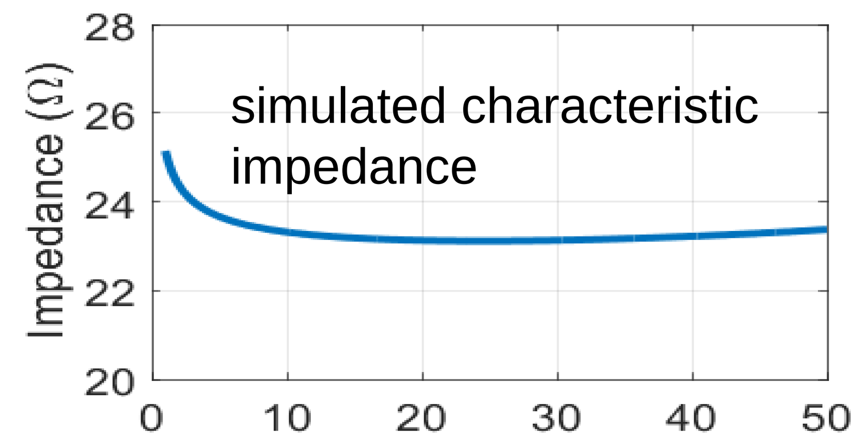
*G. Ghione: Semiconductor devices for high-speed optoelectronics, Cambridge University Press, 382-386 2009

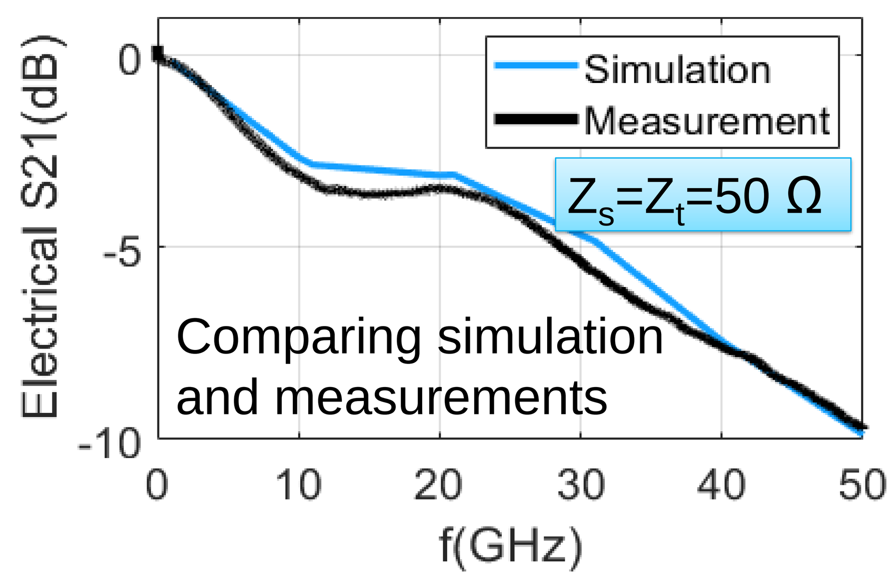
PARAMETERIZATION OF THE REFERENCE HCPW-MZM

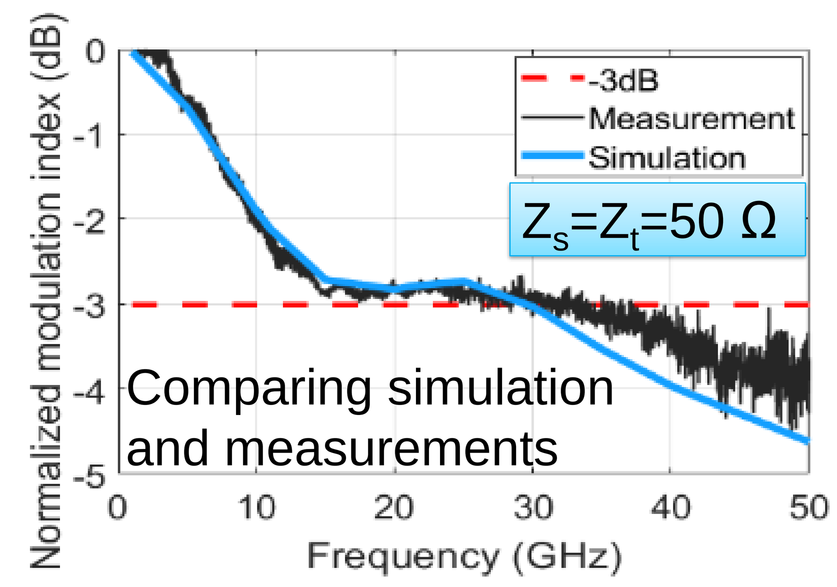
Layer	Doping (cm^{-3})	Thickness (μm)	Width (μm)	Resistivity (Ω.m)
n-metal		d_{mn}=2	w_n=20	ρ_{mn}= 2.5x10^{-8}
p-metal		d_{mp}=2	w_p=9	ρ_{mp}= 2.5x10^{-8}
p-contact	1x10^{19}	d_{pc}=0.28	w_c= 1.4	ρ_{cp}= 4.34x10^{-5}
p-cladding	1x10^{18}	d_{pclad}=1.35	w_c=1.4	ρ_{pclad}=10^{-3}
Intrinsic	n.i.d	d_i=0.21	w_c=1.4	Infinite
n-cladding	6x10^{16}	d_{i2}=0.31	w_c=1.4	ρ_{nclad}=6.097x10^{-5}
n-bottom	5x10^{17}	d_{nb}=1.5		ρ_{nb}= 3.62x10^{-5}

Frequency response and model validation



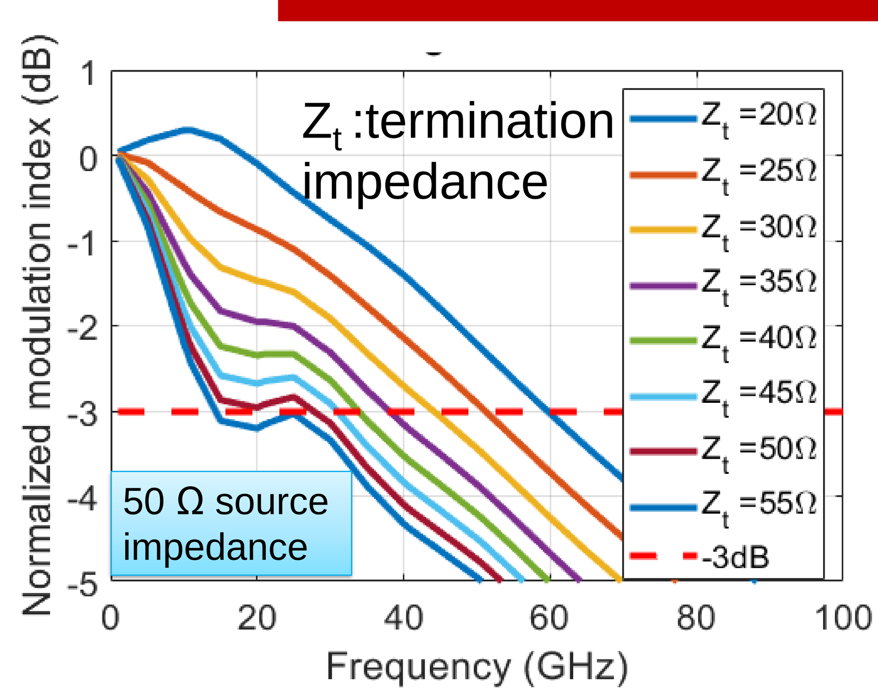


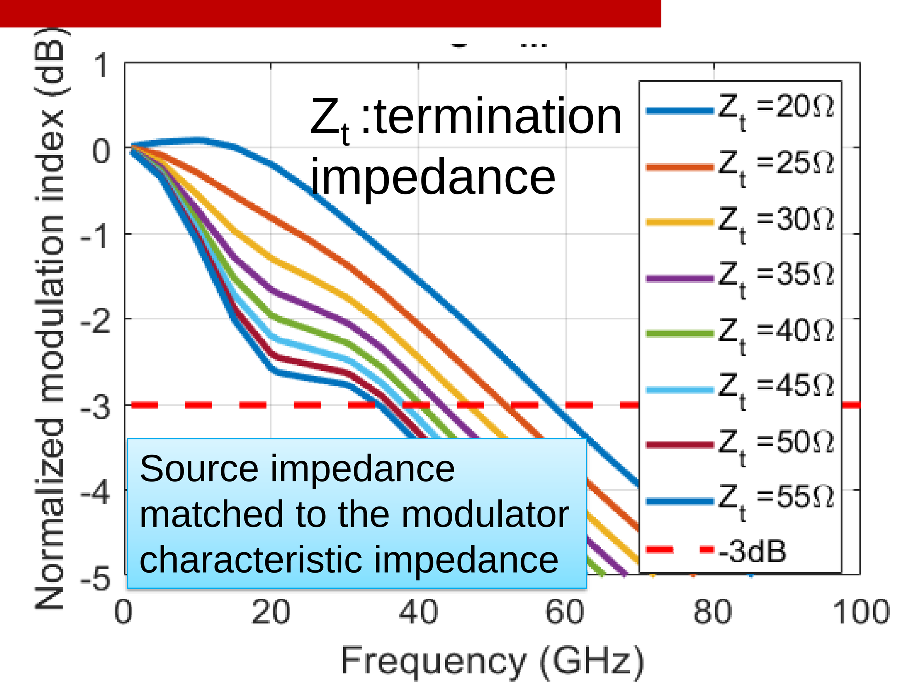




- The measured and 3D-simulated electrical S21 transfer functions are presented with good agreement
- The 3D-simulated characteristic impedance of the reference modulator design is between 23 to 25Ω in the simulated frequency range, indicating a significant mismatch between modulator, source, and termination
- Measured electro-optical-frequency response is overlaps with the calculated modulation index M(ω) of the reference HCPW-MZM when both source and termination impedances are 50 Ω.

The role of impedance mismatch





- Matching termination impedance (Z_t~25Ω) to the characteristic impedance of the HCPW-line, instead of having 50Ω termination, doubles the -3dB EO-bandwidth of the reference MZM
- When the termination is not matched to the modulator impedance (Z_t 50 =Ω), the source impedance matching plays a role, increasing the 3dB bandwidth from 30 GHz to 38 GHz.
- load impedance has a higher impact on the electro-optical bandwidth than the source impedance.

Conclusion

- We have developed a simple and accurate model that combines analytical expressions with line parameters obtained from 3D EM simulators, have shown that it can effectively predict device performance and have validated its output with experimental data
- Matching the termination and source impedances can increase the EO-bandwidth from 30 GHz to 60 GHz

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NWO EFFECT PHOTONICS SMARTPhotonics NXP Fraunhofer Heinrich Hertz Institute