Guided Microwaves

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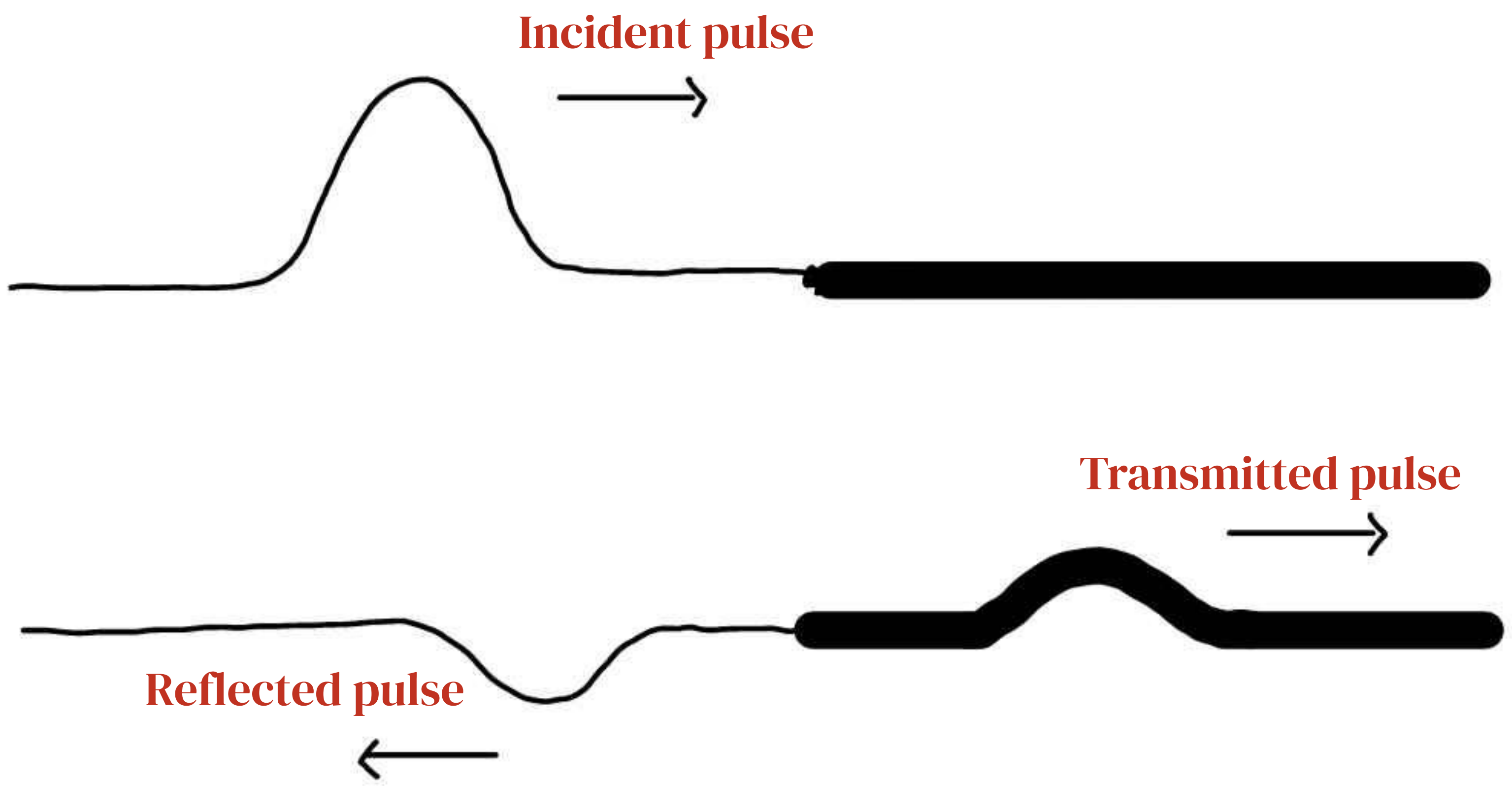
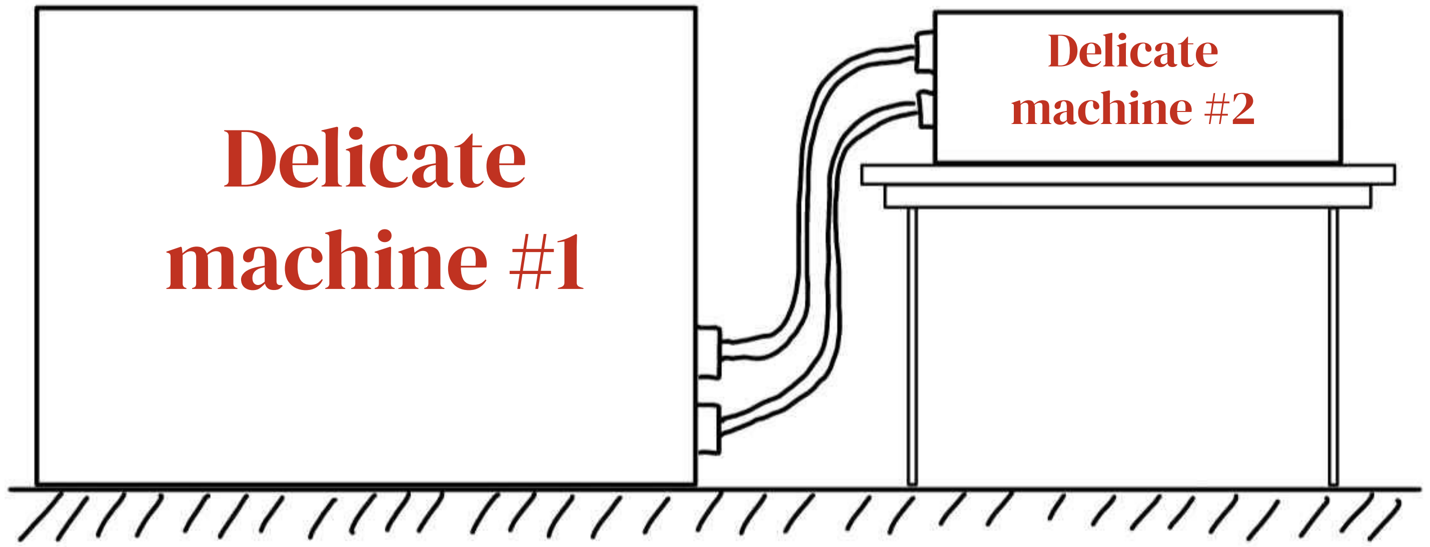
Introduction (1/2)



Application of wave transmission: Power transmission lines carrying electricity

- Wave transmission can be visualized intuitively in rope
- Reflections occur due to varying thickness, or impedance
- The result of this is a loss of energy in the transmitted wave
- Impedance matching is critical for sensitive equipment and efficient power transfer



Application of wave transmission: Delicate machinery that is sensitive to reflected signals

Introduction (2/2)

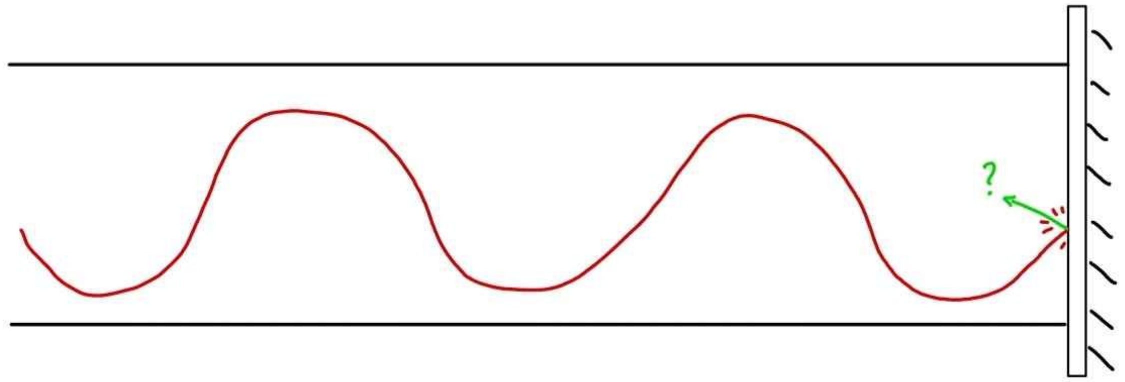
1. Can transmitted and reflected power be measured?
2. How is transmitted power maximized and reflected power minimized?

A waveguide confines waves so they can be measured.

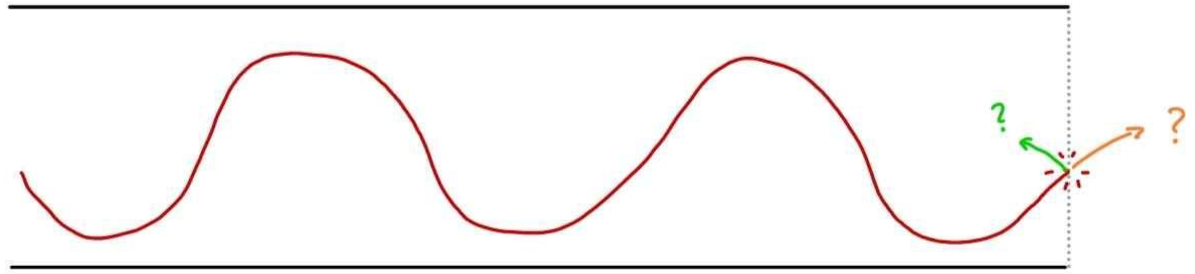
Waveguide ≠ free space.

Changing the interface allows for "matching" of impedances to maximize transmission.

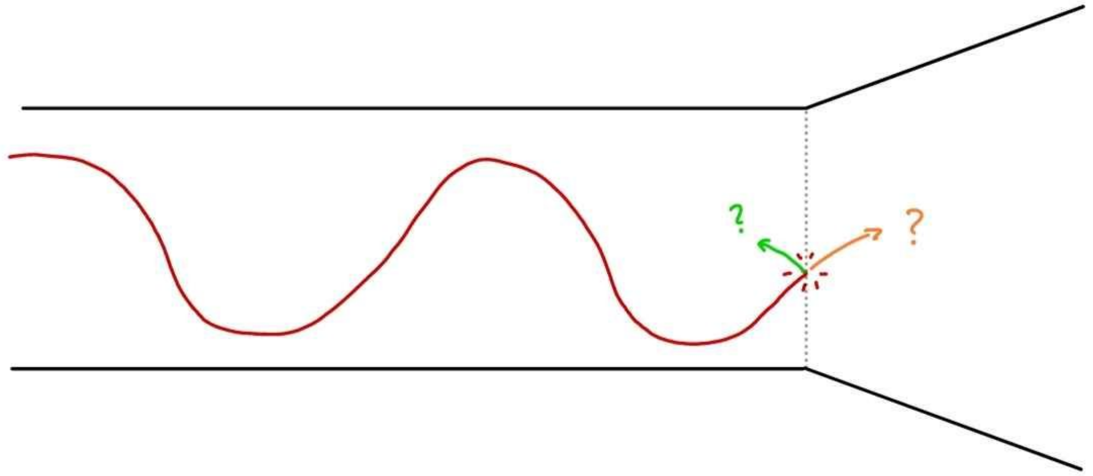
Closed end waveguide



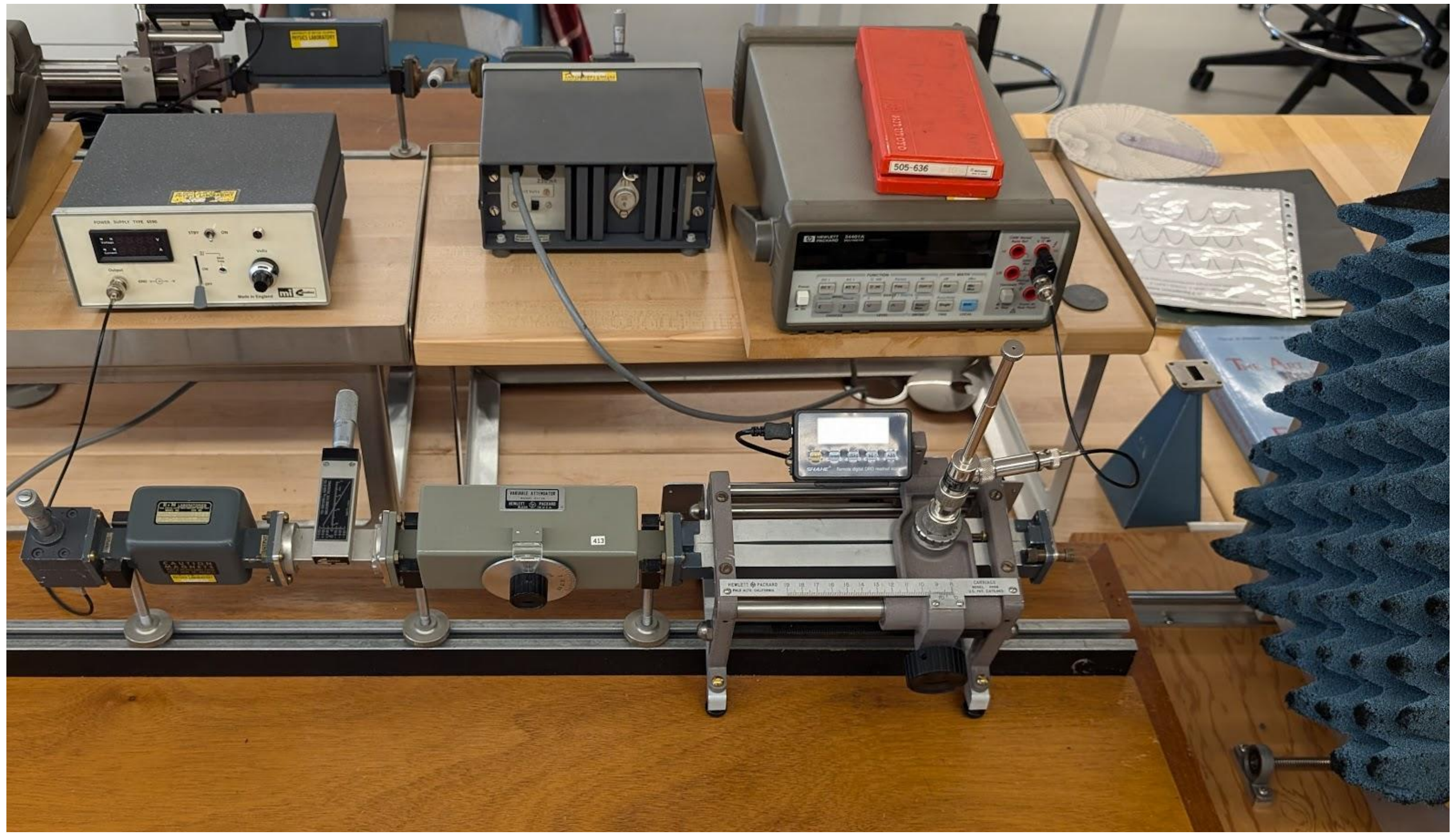
Open end waveguide



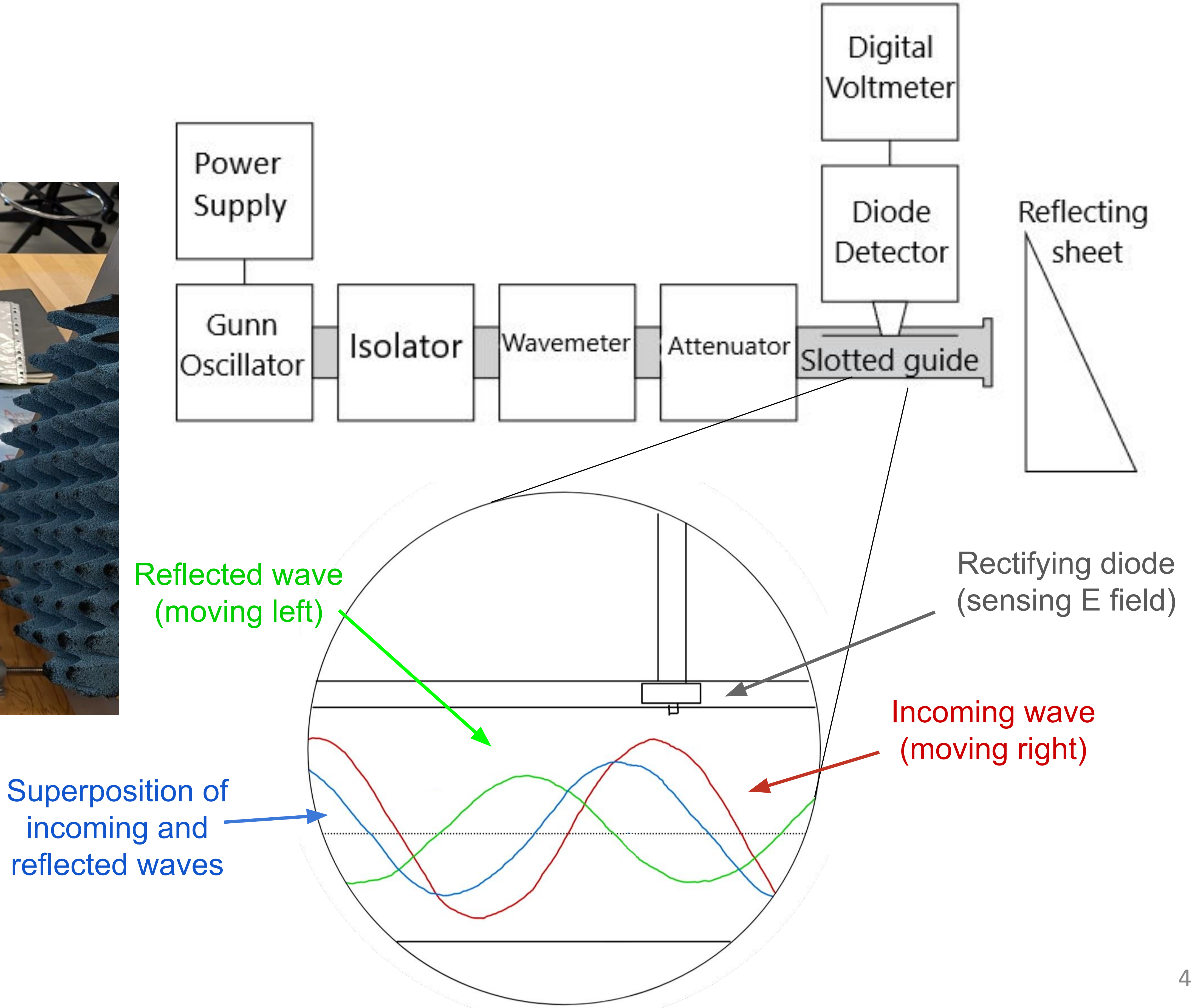
Horn end waveguide



Experiment setup

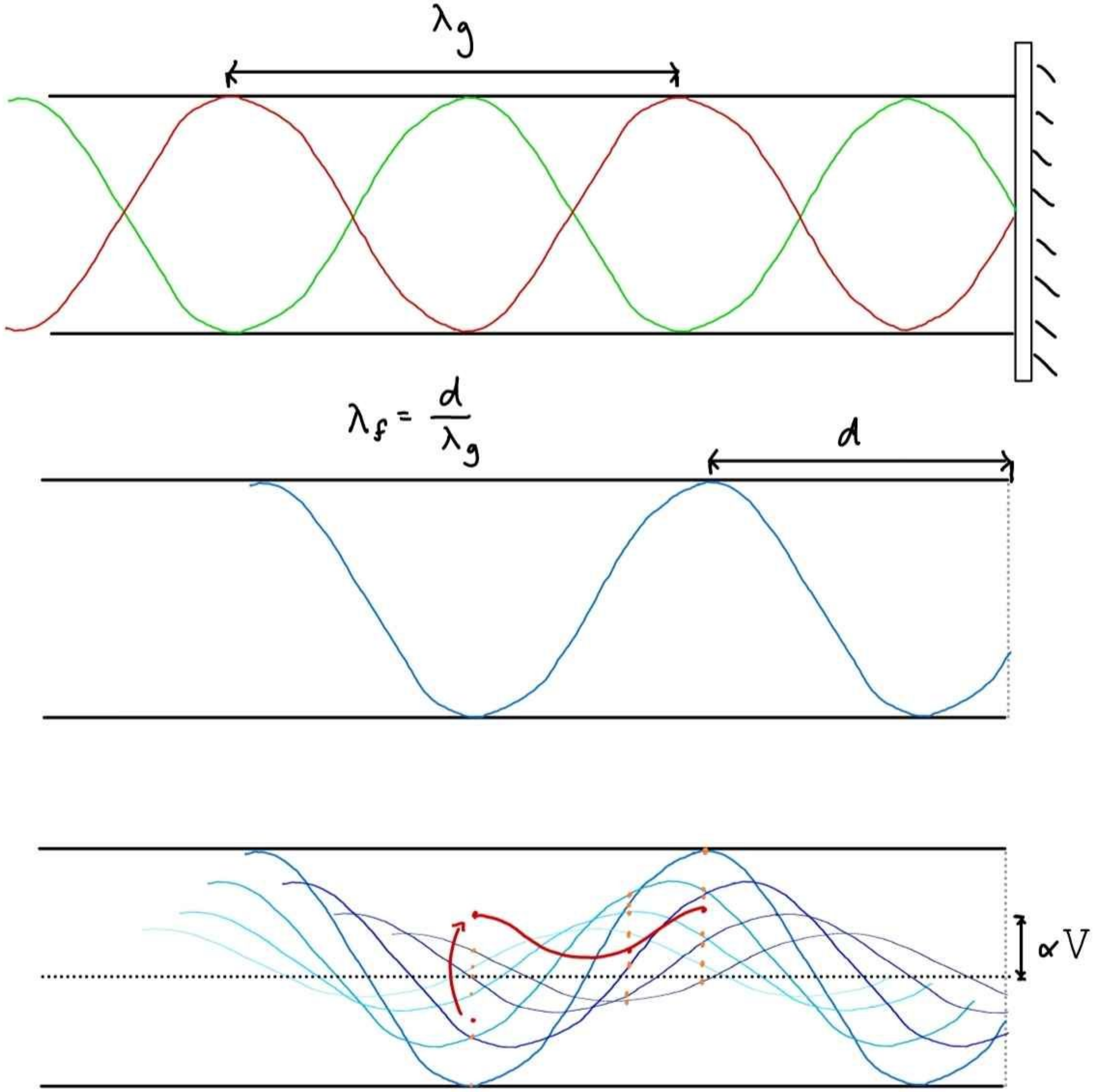


Picture of experiment setup.

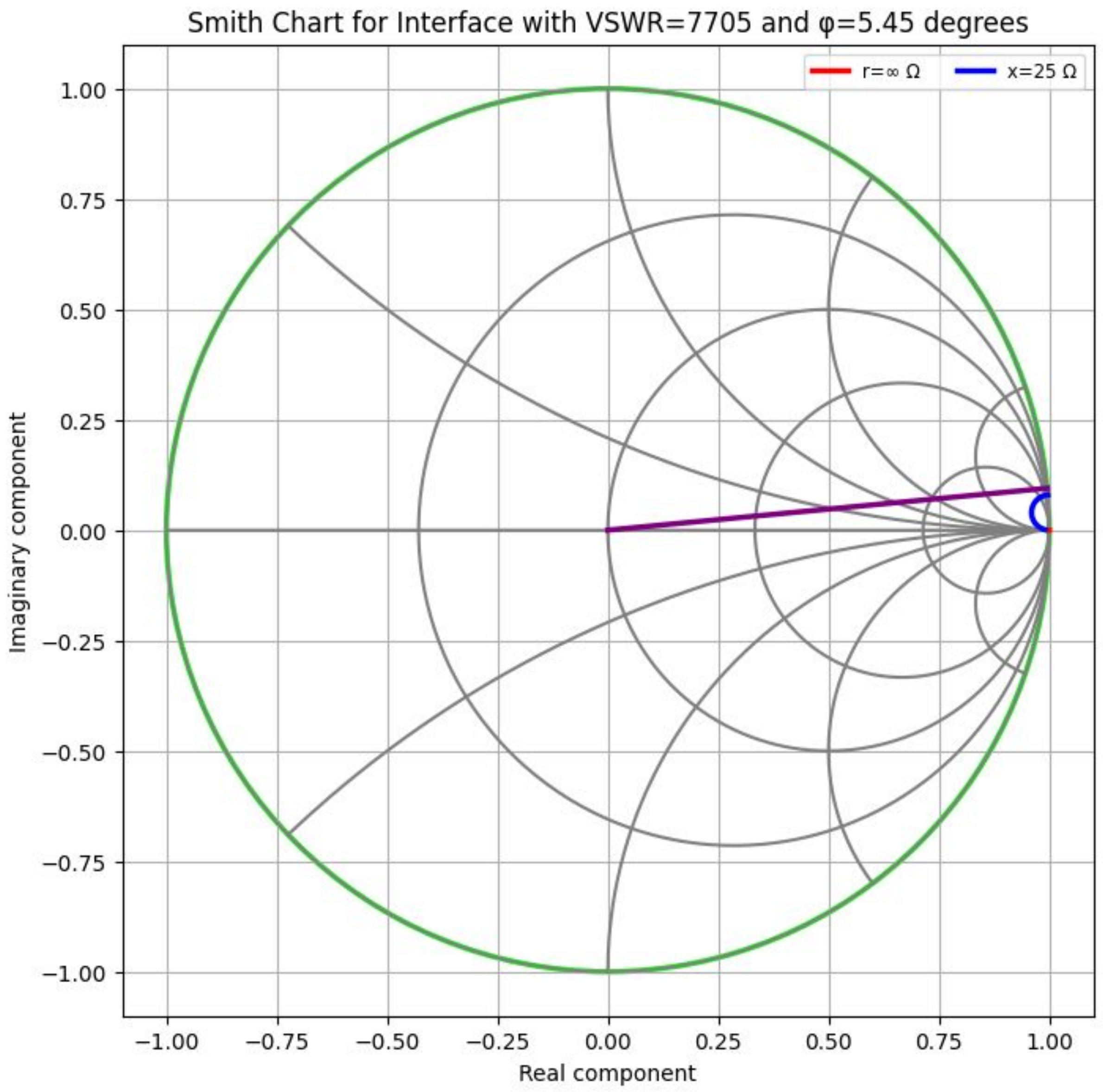


Procedure

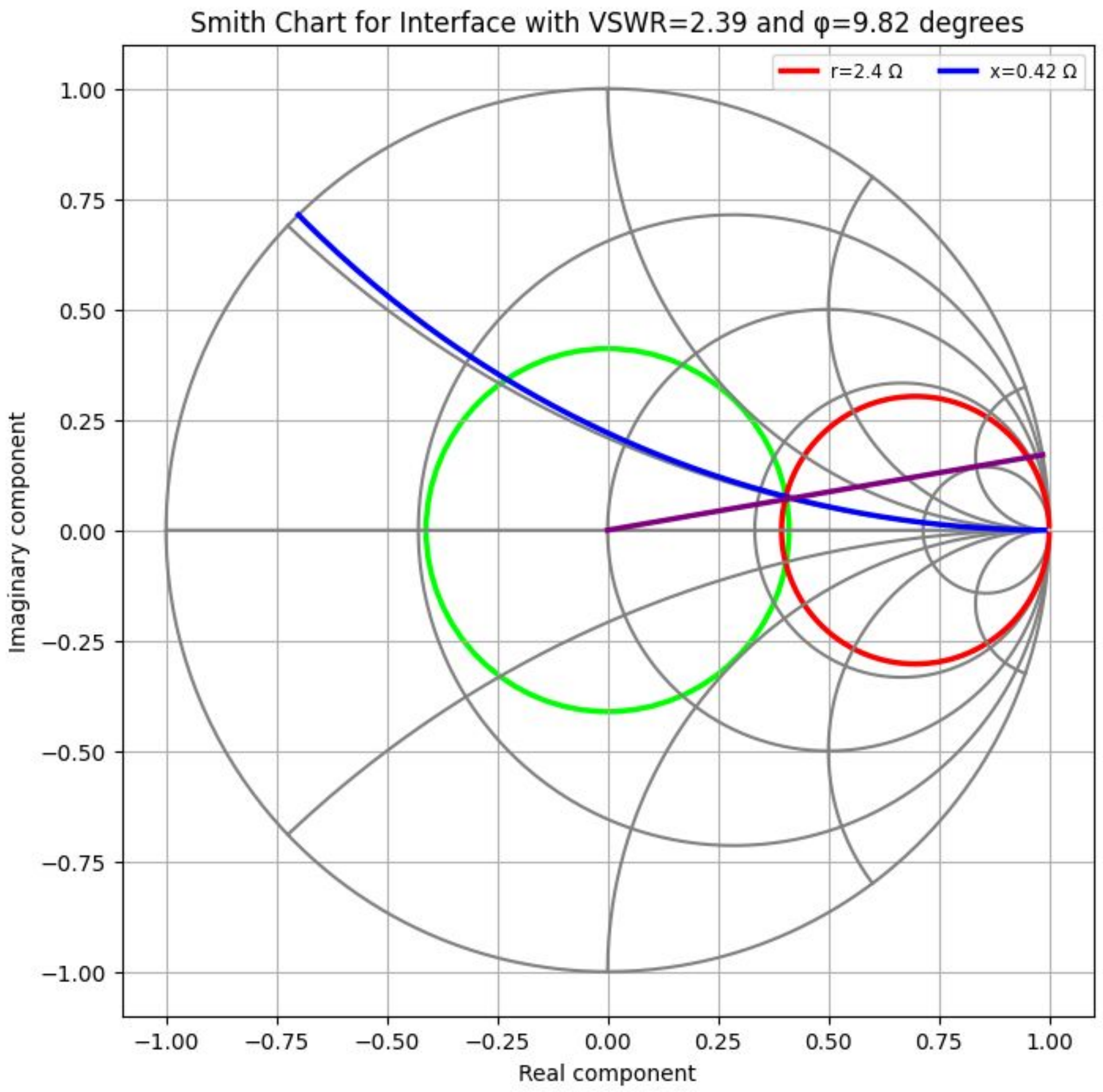
1. Find the wavelength in the guide λ_g
2. Find the fractional wavelength from the end to the nearest maxima λ_f
3. Measure and calculate the Voltage Standing Wave Ratio (VSWR)
4. Calculate the reflection coefficient Γ, and the phase of the reflected wave φ
5. Plot (Γ, φ) on the Smith Chart and determine the impedance
6. Repeat steps 2-5 for each waveguide termination



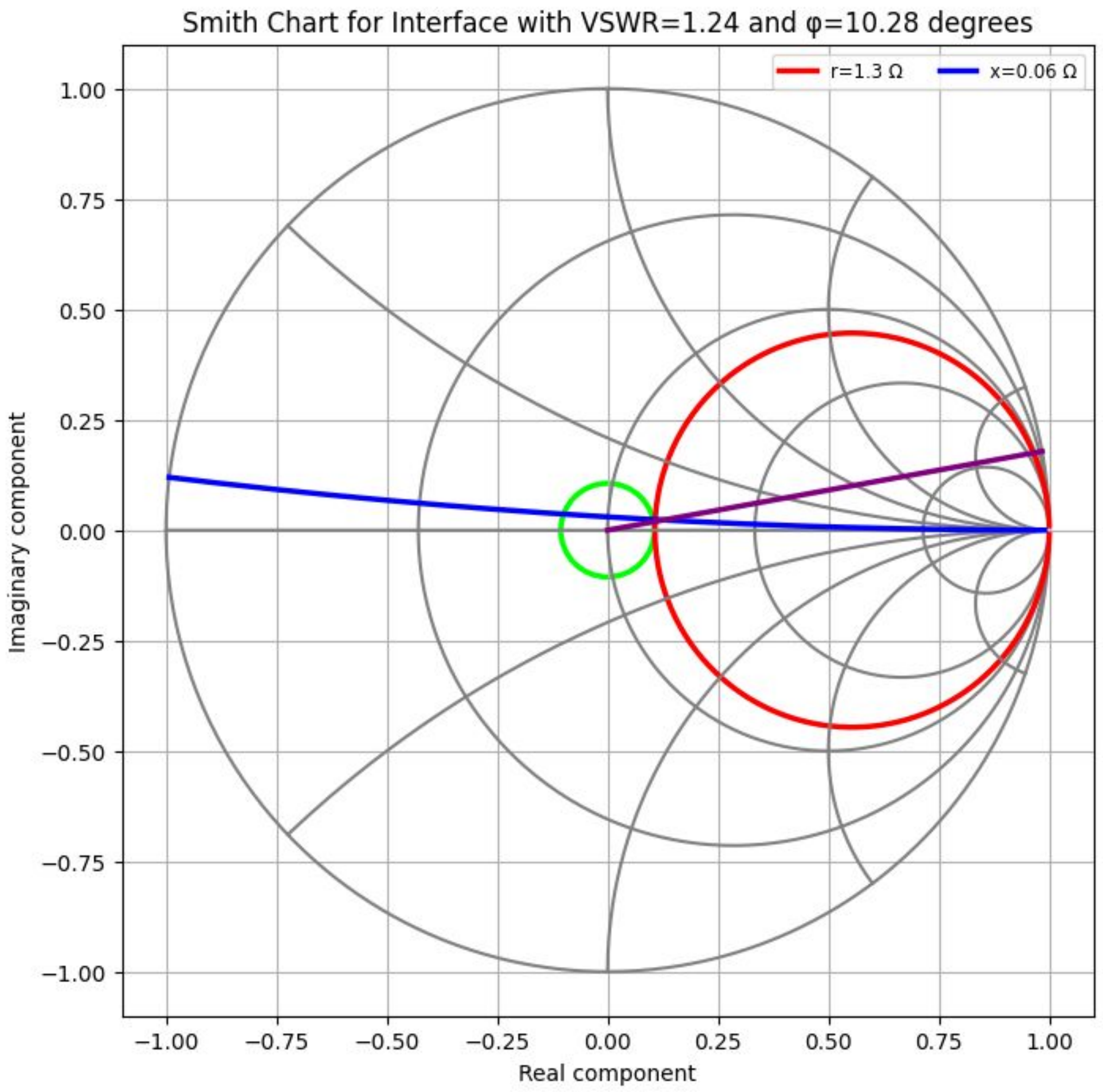
Results (1/2)



Closed end waveguide Smith Chart plot



Open end waveguide Smith Chart plot



Horn end waveguide Smith Chart plot

Results (2/2)

	VSWR	Reflection Coeff.	Phase Angle (°)
Closed end	7705 ± 294	1.00 ± 0.05	5.450 ± 0.009
Open end	2.39 ± 0.01	0.411 ± 0.002	9.32 ± 0.02
Horn end	1.24 ± 0.01	0.106 ± 0.001	10.48 ± 0.02

Table 1. Table of measured VSWR, Reflection Coefficient, and Phase Angle values for each guide termination.

	Rel. Resistance (Ω)	Rel. Reactance (Ω)	Abs. Resistance (Ω)	Abs. Reactance (Ω)	Mag. Impedance (Ω)
Closed end	$\infty \pm$?	25 ± 3	$\infty \pm$?	11700 ± 1400	$\infty \pm$?
Open end	2.4 ± 0.1	0.42 ± 2	1124 ± 47	197 ± 94	1141 ± 65
Horn end	1.3 ± 0.1	0.05 ± 0.03	609 ± 47	23 ± 14	609 ± 48

Table 2. Table of relative and absolute resistance and reactance, and impedance magnitude of each guide termination.

$Z_{abs} = Z_{rel} * Z_0$, Z_0 = guide impedance = 468.52 (Ω)

Improvements (only one!)

1. More reference theory beforehand

Summary & Next Steps

Summary

- Impedance matching is very important for efficient power transfer
- Impedance of open, closed and horn end are determined by measuring the E field in the guide
- Plotting using the Smith Chart translates between voltages and distance to impedance
- Horn end provides best transition (impedance match) from the guide to free space

Next Steps

- Redo with proper phase φ calculation
- Track measurement uncertainty in addition to instrument uncertainty

Appendix: Table of Relevant Formulas

Formula	Description
$Z_0 = 120\pi\lambda_g/\lambda_0$ (Ω)	Guide impedance - obtained by solving Maxwell's equations for the B and E fields, and using the result for the TE_{10} mode. λ_g = guide wavelength, λ_0 = free space wavelength
$\Gamma = (VSWR - 1)/(VSWR + 1)$	Reflection coefficient - how much of the wave is reflected by the impedance discontinuity in the transmission medium
$\varphi = 2kd_{min} - \pi$ $\varphi = 2kd_{max}$	Phase angle - on the Smith Chart the maximum and min from the end of the guide are off by rotations of π, seen in the formulas for the phase angle