Microwave Experiment: Week 3

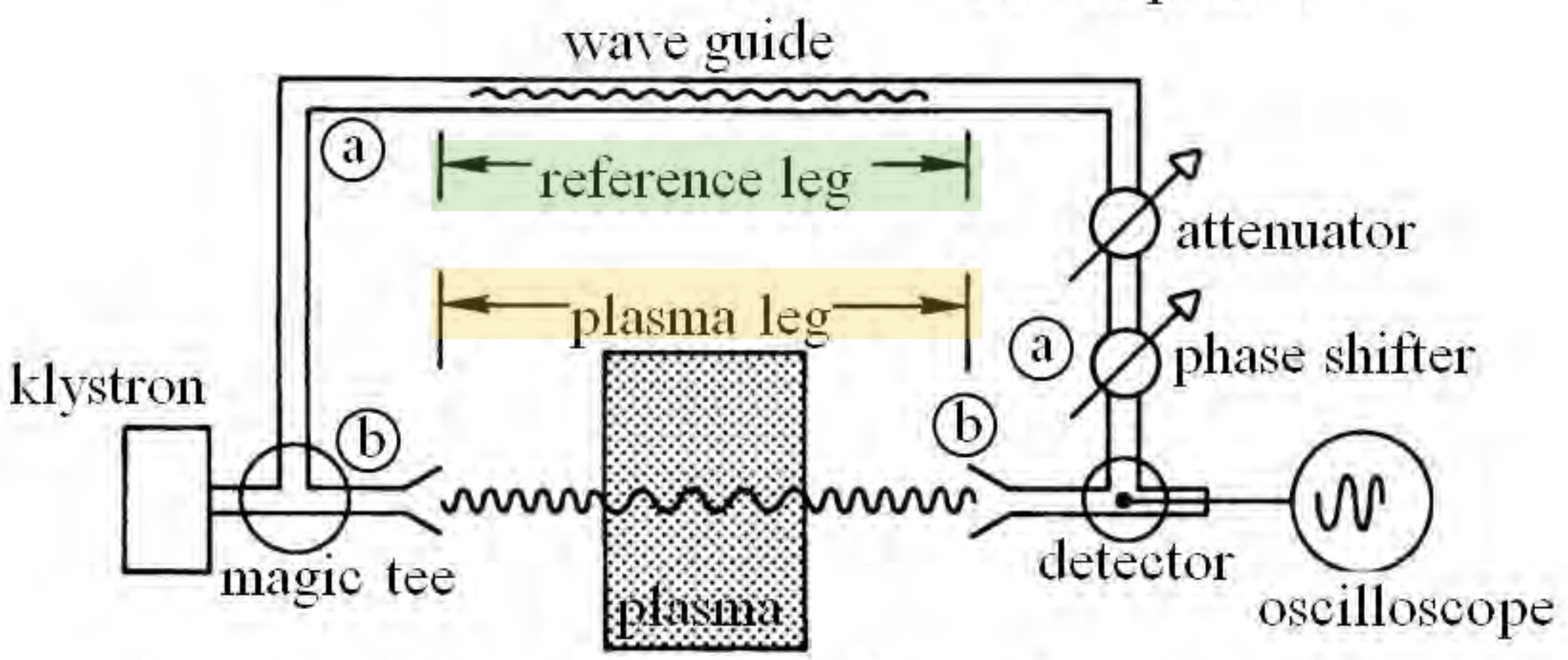
AP 4018
Columbia University

Objective

- Measure the complex dielectric constant of materials with a microwave interferometer

- Microwave interferometer for plasma density measurement

index of refraction $\tilde{n} = \frac{c}{v_{ph}} = \frac{ck}{\omega}$ >1 in glass; $=1$ in vacuum; <1 in plasma

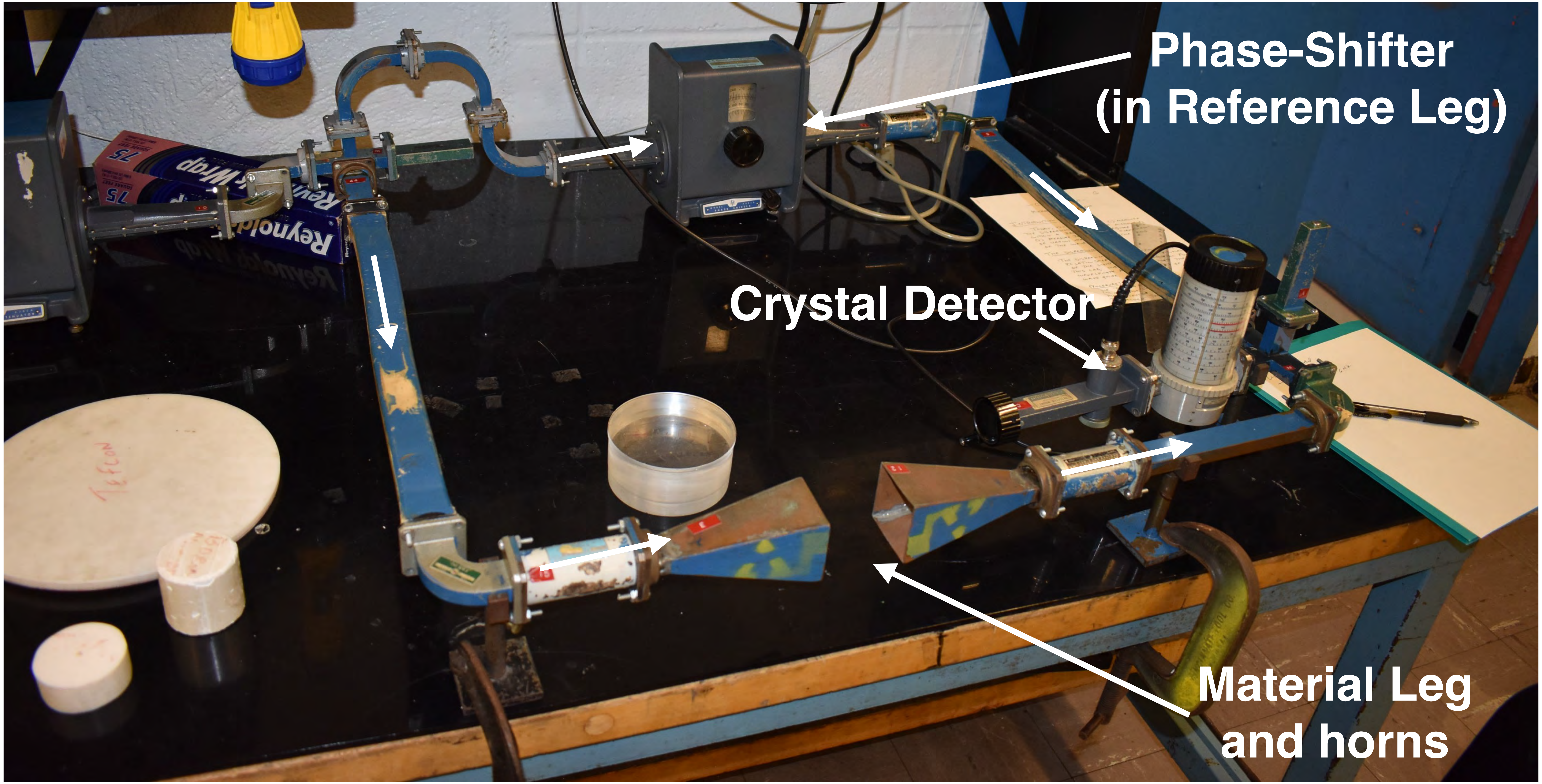


A microwave interferometer for plasma density measurement.

1.without plasma, signals from path ⓐ and ⓑ are 180° out of phase.

2.with plasma, the phase in ⓑ changed as λ↑, (by higher plasma density).

Components of a Microwave Interferometer



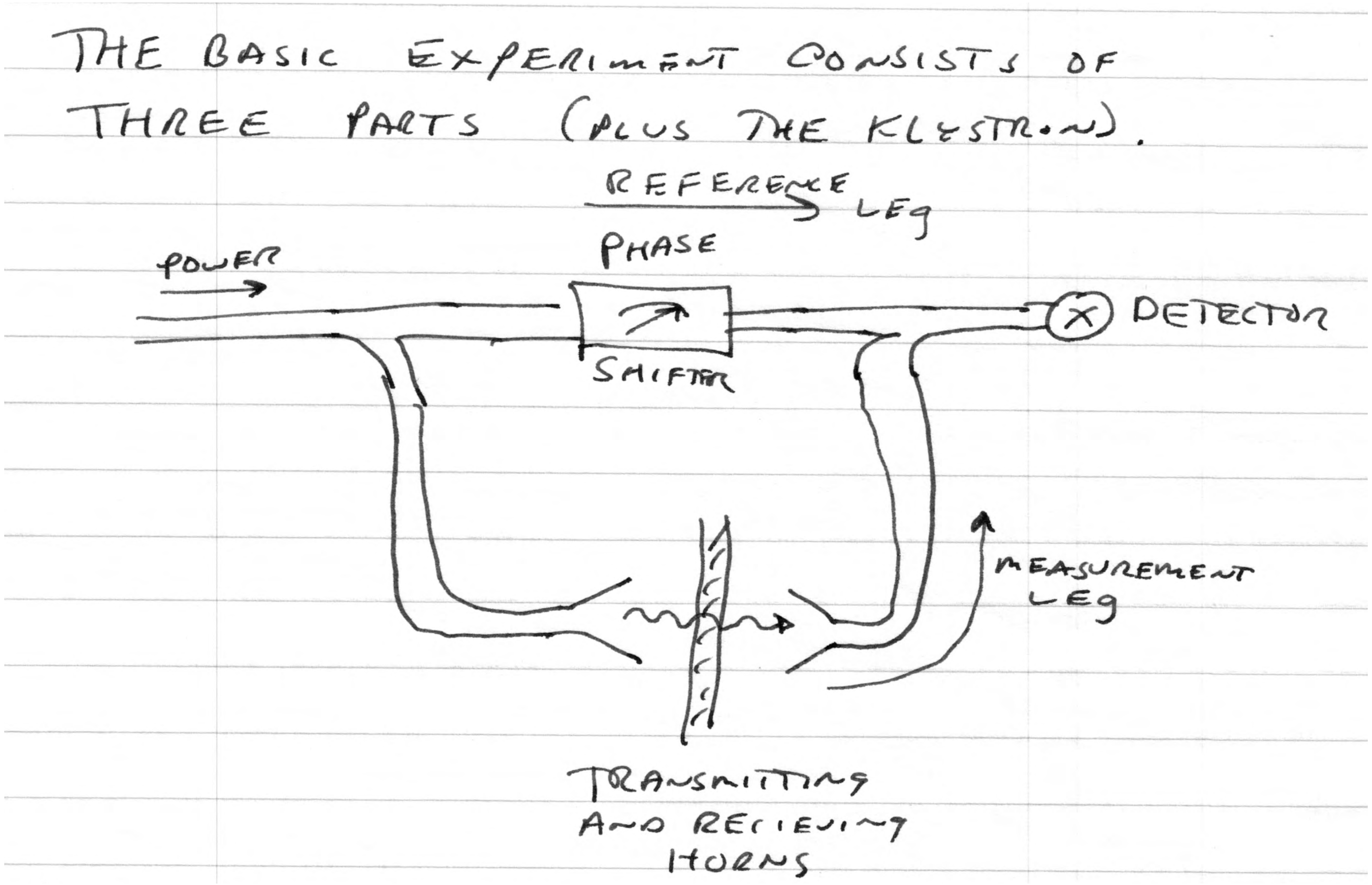
What you can measure?

- Microwave interferometer detects the change in the wavelength and attenuation of microwaves (light) as it passes through a material *relative* to the passage through free space

- The phase changes and

- The amplitude changes

Schematic: Diagram



Schematic: Function

1) A PHASE-SHIFTER (NOT PERFECT, BUT CLOSE) INSIDE THE <u>REFERENCE</u> LEG

2) A SQUARE-LAW DETECTOR (WHICH COMBINES THE SIGNALS FROM THE <u>MEASUREMENT</u> AND <u>REFERENCE</u> LEGS)

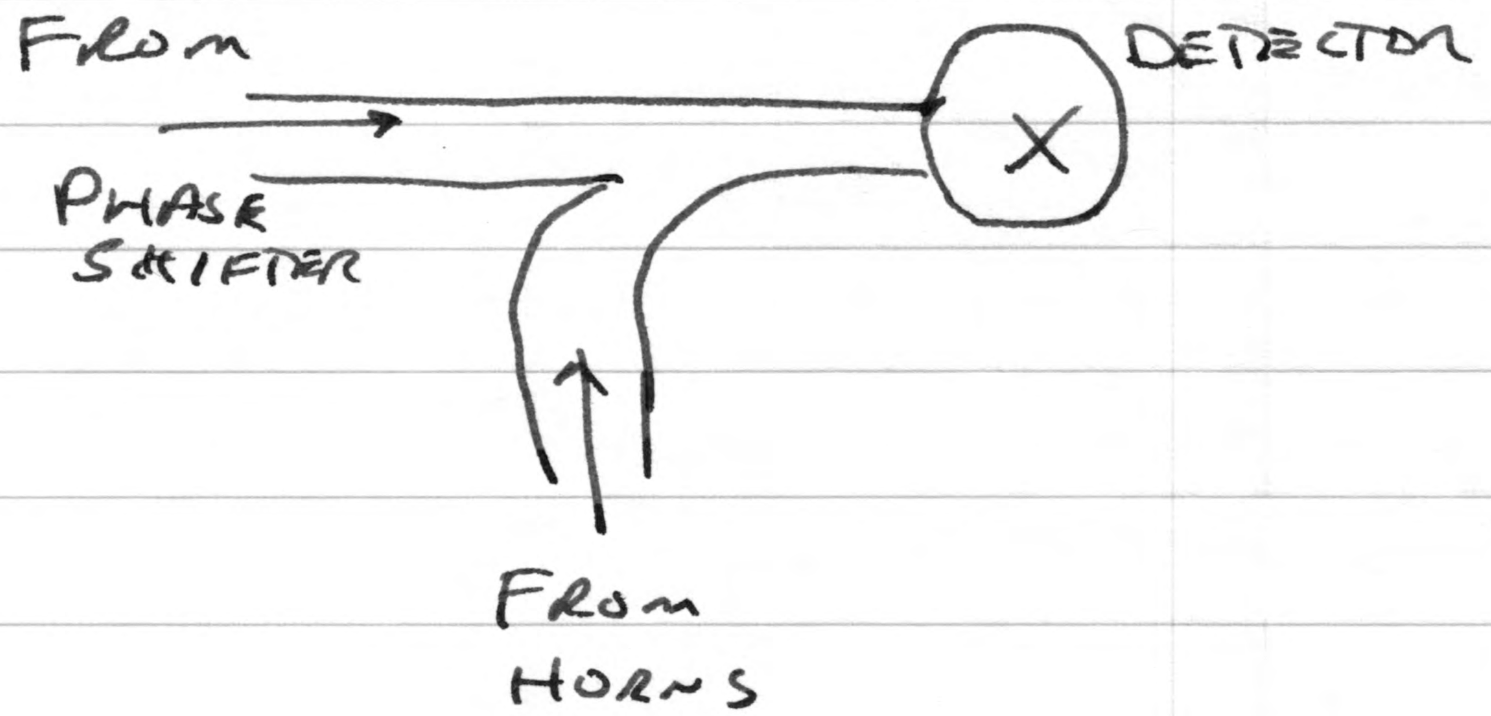
3) THE <u>TRANSMITTING</u> AND <u>RECEIVING</u> HORNS

DIFFERENT MATERIALS CAN BE PLACED BETWEEN THE HORNS.

Procedure

YOUR EXPERIMENTAL PROCEDURE IS USED TO MEASURE THE DIFFERENCE BETWEEN LIGHT PROPAGATION THROUGH AIR (CLOSE TO VACUUM) AND THROUGH VARIOUS MATERIALS.

WHAT HAPPENS WHEN THERE IS NOTHING PLACED BETWEEN THE HORNS?



VOLTAGE AT DETECTOR $\propto |E|^2$

$$E = E_{REF} + E_{HORNS}$$

$$= E_R e^{-j\omega t} + E_H e^{-j\omega t + i\phi}$$

WHERE ϕ IS THE PHASE DIFFERENCE BETWEEN THE SIGNAL FROM THE HORNS AND THE SIGNAL FROM THE REFERENCE! ϕ CHANGES AS YOU ADJUST THE PHASE SHIFTER!!

Procedure (continued)

$$V_{DET} = \left|E_R + E_H e^{i\phi}\right|^2$$
$$= \left(E_R + E_H e^{i\phi}\right)\left(E_R + E_H e^{-i\phi}\right)$$
$$= E_R^2 + E_H^2 + E_R E_H\left(e^{i\phi} + e^{-i\phi}\right)$$
$$= E_R^2 + E_H^2 + 2E_R E_H \cos(\phi)$$

THUS, YOU CAN MEASURE V_{DET} VS. ϕ AND IDENIFY

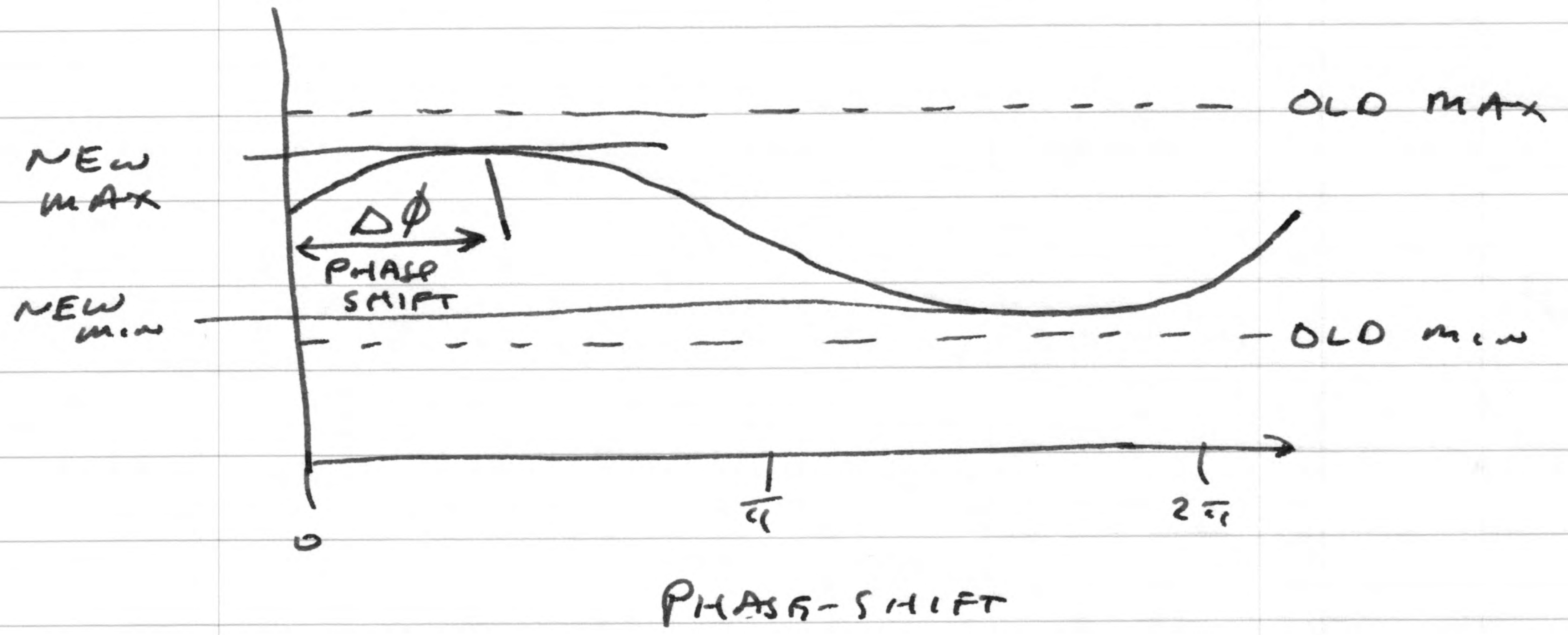
$$V_{DET}\ \text{MAX} = (E_R + E_H)^2$$
$$V_{DET}\ \text{MIN} = (E_R - E_H)^2$$

AND THE READINGS OF THE PHASE SHIFTER CORRESPONDING TO MIN AND MAXIMUM.

What happens when material is placed between horns?

ANSWER:

WHEN A MATERIAL IS PLACED BETWEEN THE HORNS, THE PHASE WILL CHANGE AND THE AMPLITUDE WILL CHANGE...



FROM THE NEW MIN / MAX YOU CAN CALCULATE THE ATTENUATION THROUGH THE SLAB

$$\frac{E_H'}{E_H} = e^{-\alpha d}$$

α = ATTENUATION COEFFICIENT

d = THICKNESS OF SLAB

FROM THE PHASE SHIFT, YOU CAN CALCULATE THE CHANGE IN WAVELENGTH

$$\Delta\phi = (k' - k)d$$

(d ← THICKNESS OF SLAB)

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{\text{FREE-SPACE WAVELENGTH}}$$

$$k' = \frac{2\pi}{\lambda'} = \frac{2\pi}{\text{WAVELENGTH IN MATERIAL}}$$

YOU SHOULD CHECK THAT IF YOU DOUBLE THE THICKNESS OF THE MATERIAL, THEN THE ATTENUATION AND PHASE-SHIFT WILL INCREASE.

What happens when material is placed between horns?

REMEMBER,

$k' = \sqrt{\epsilon}\, k'$ WHERE ϵ = RELATIVE DIELECTRIC CONSTANT

$= n k'$ WHERE n = INDEX OF REFRACTION.

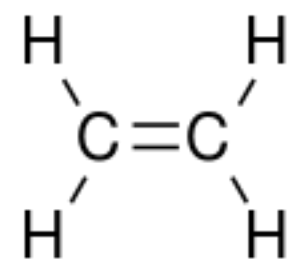
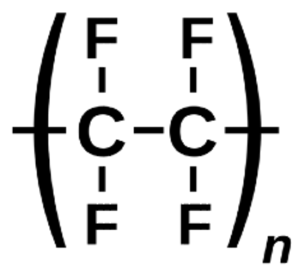
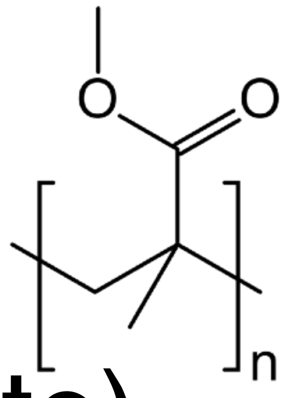
NOTE THE WAVELENGTH WILL BE SMALLER INSIDE THE MATERIAL THAN OUTSIDE.

THUS, THE SIGNAL IN THE HORNS WILL HAVE A GREATER PHASE SHIFT WITH A MATERIAL THAN WITHOUT MATERIAL.

What is Contained in Data File?

Microwave-Week-3-Data.csv

- Measured @ frequency = 9.430 GHz
- Recorded the phase of *minimum* and *maximum* electric field intensity
- Recorded the magnitude of the *minimum* and *maximum* (as $V_{det} \propto |E_r + E_m|^2$)

- ***For the following cases:***
  - Air
  - 3 cm thick Polyethene 
  - 2 cm thick Teflon
  - 0.9 cm thick Teflon 
  - 4.5 cm thick Lucite (or Poly(methyl methacrylate)) 

Summary: Week 3

- Measure the propagation of microwaves through materials using a microwave interferometer.