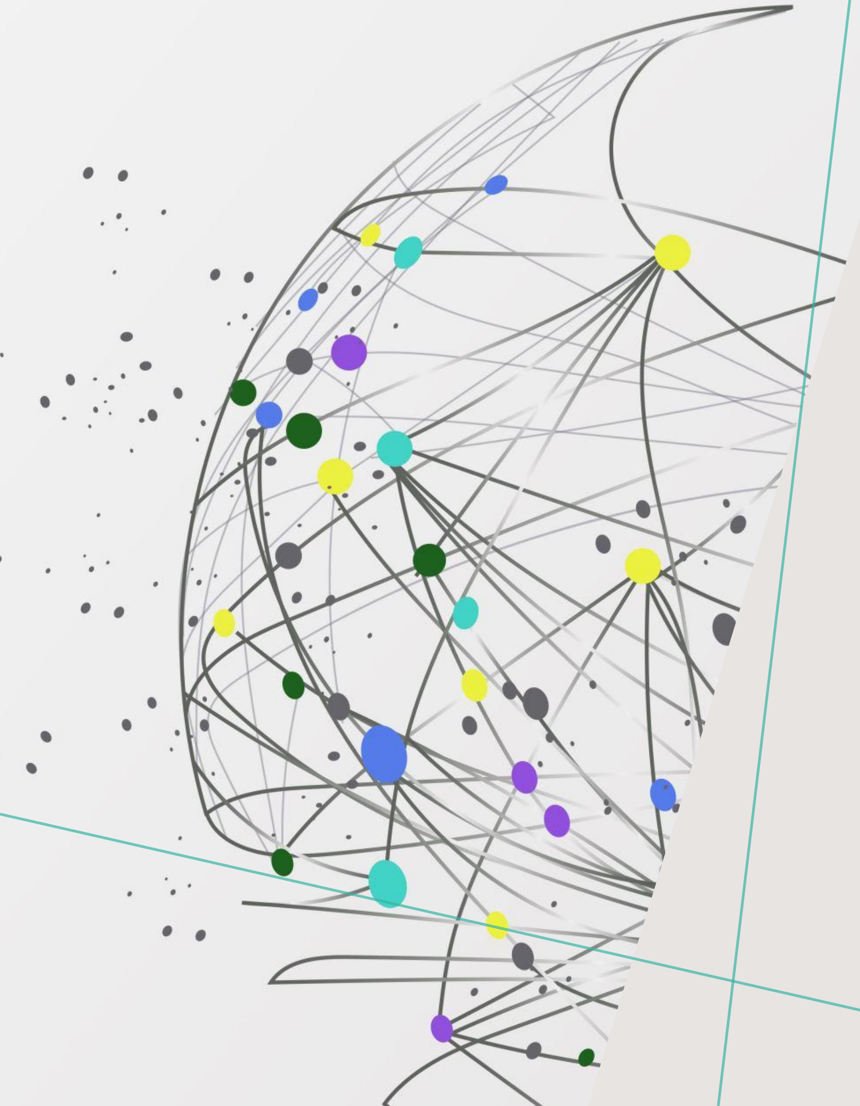
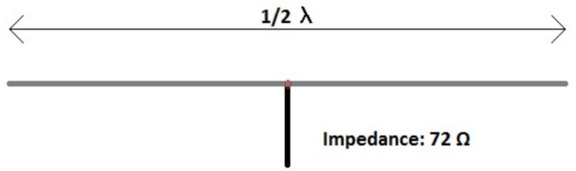


DEC 9, 2021

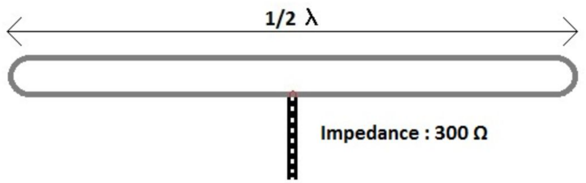
TRANSMISSION LINES WITHOUT TEARS

SAIED SEGHATOLESLAMI AD2CC
GREG MAURO K3EA

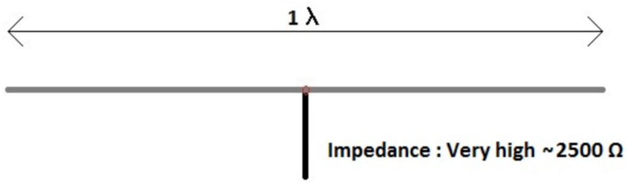
DIFFERENT ANTENNAS...



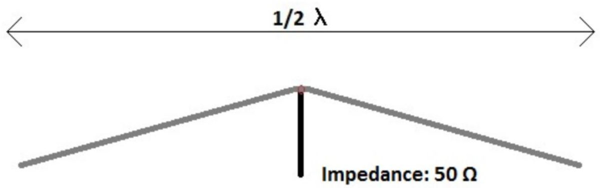
Open half wave dipole antenna



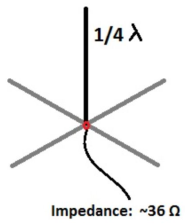
Closed half wave dipole antenna



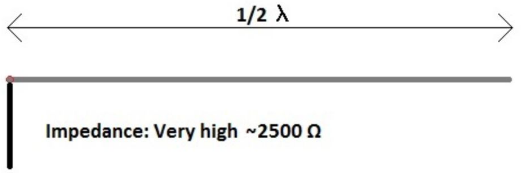
Open whole wave dipole antenna



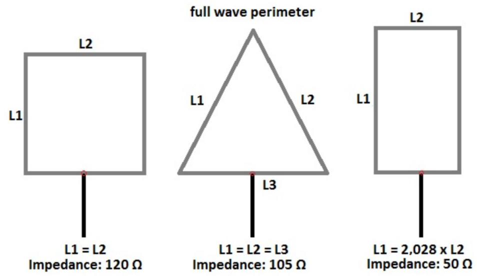
Inverted V dipole antenna

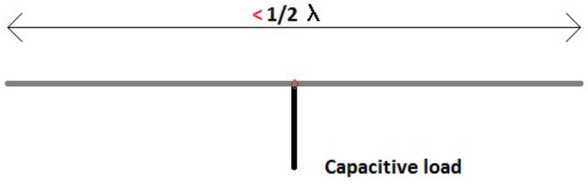


Quadrant wave vertical

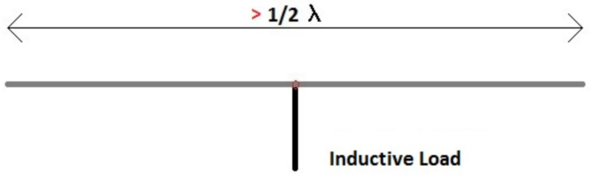


End fed half wave antenna





Dipole antenna too short



Dipole antenna too long

GOAL

- Learn what makes transmission lines transmission lines
- Gain some insights into how they work
- Build efficient antenna/feedline systems
- ...with just arithmetic...
- We can do higher math at a different time

THINGS TO TAKE AWAY

- A 50 Ohm coax (feedline) terminated in other than 50 ohms changes the coax impedance at its input.
- Coax (feedline) construction, material, length, and frequency all impact the above answer (your milage will vary as you change these factors)
- The input impedance to the feedline, in most cases, will have a reactive (capacitive or inductive) component
- Power input to the feedline (into the resistive part of the input impedance) is equal to the power delivered to the load at the termination of the feedline

RECALL THE TECHNICIAN EXAM?

Question	Answer
How fast does a radio wave travel through free space	At the speed of light
What is the approximate velocity of a radio wave as it travels through free space	300,000,000 meters per second (299,792,458)
What is the name for the distance a radio wave travels during one complete cycle	Wavelength
What is the formula for converting frequency to approximate wavelength in meters	Wavelength in meters equals 300 divided by frequency in megahertz

One more thing: in RG8X, radio waves propagate at 79% of the speed in free space or 236,800,000 meters per second

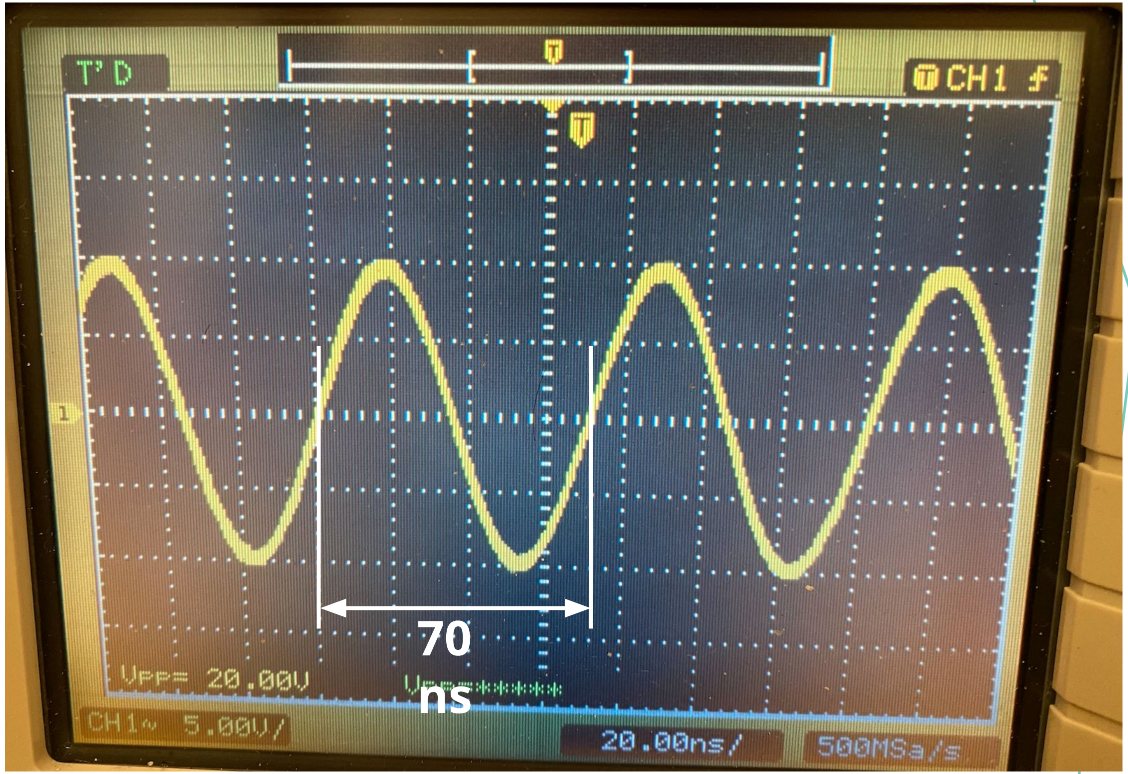
SO, LET'S JUST PICK A FREQUENCY

$$Frequency = 14.250\ MHz$$

$$Period = \frac{1}{Frequency} \cong 70.18\ nanoseconds$$

Electrical wavelength in RG8X @ 14.25 MHz

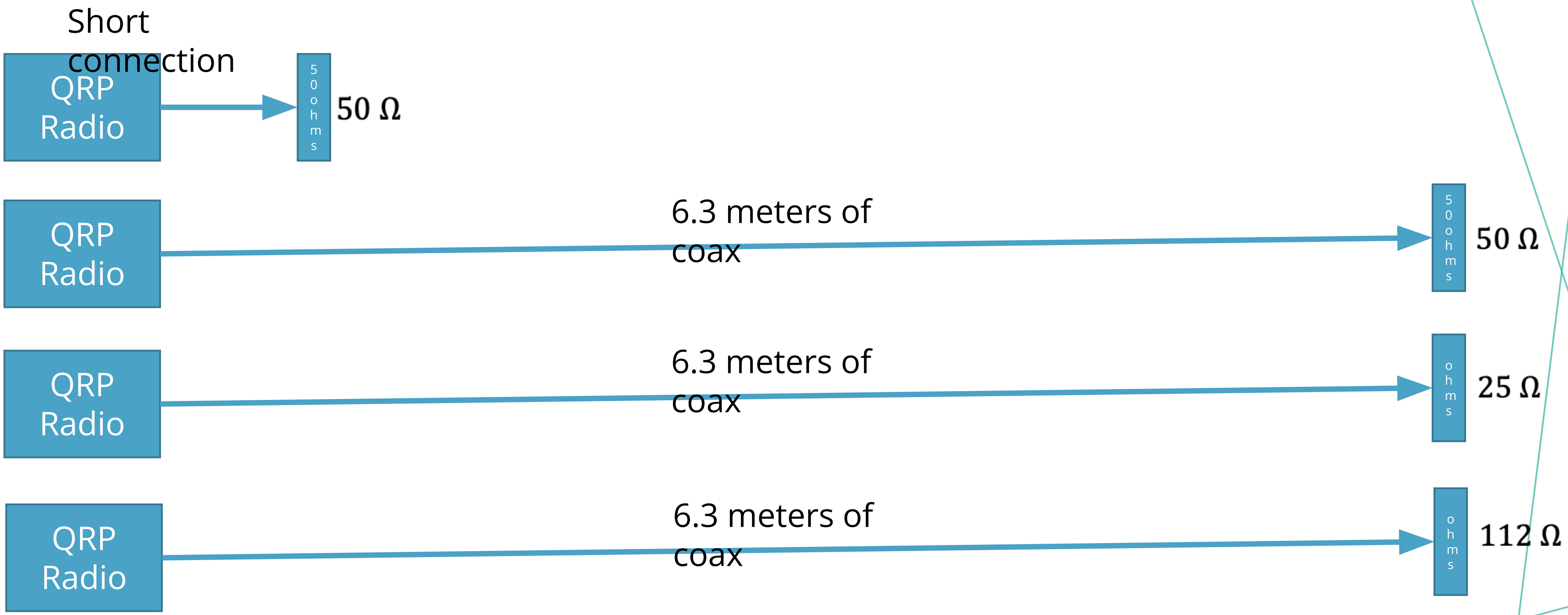
$$Wavelength = \frac{Speed\ of\ propagation}{Frequency} = \frac{237}{14.250} = 17.3\ meters$$



…AND A COAXIAL CABLE

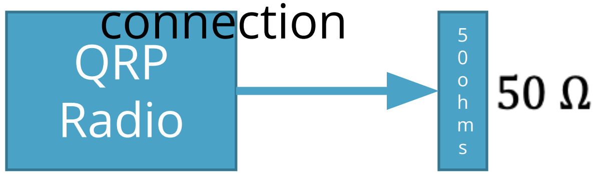
- Coax type: RG8X
- Length: 20’ 7” feet = 6.3 meters
- Velocity factor: 79% (velocity in cable as a percent of velocity in vacuum)
- Impedance: 50 Ohms (resistive)
- Loss: ”lossless” at HF frequencies
- Ratio of cable length to wavelength: 37%
- Cable length is an “appreciable” fraction of the wavelength

THE EXPERIMENTS



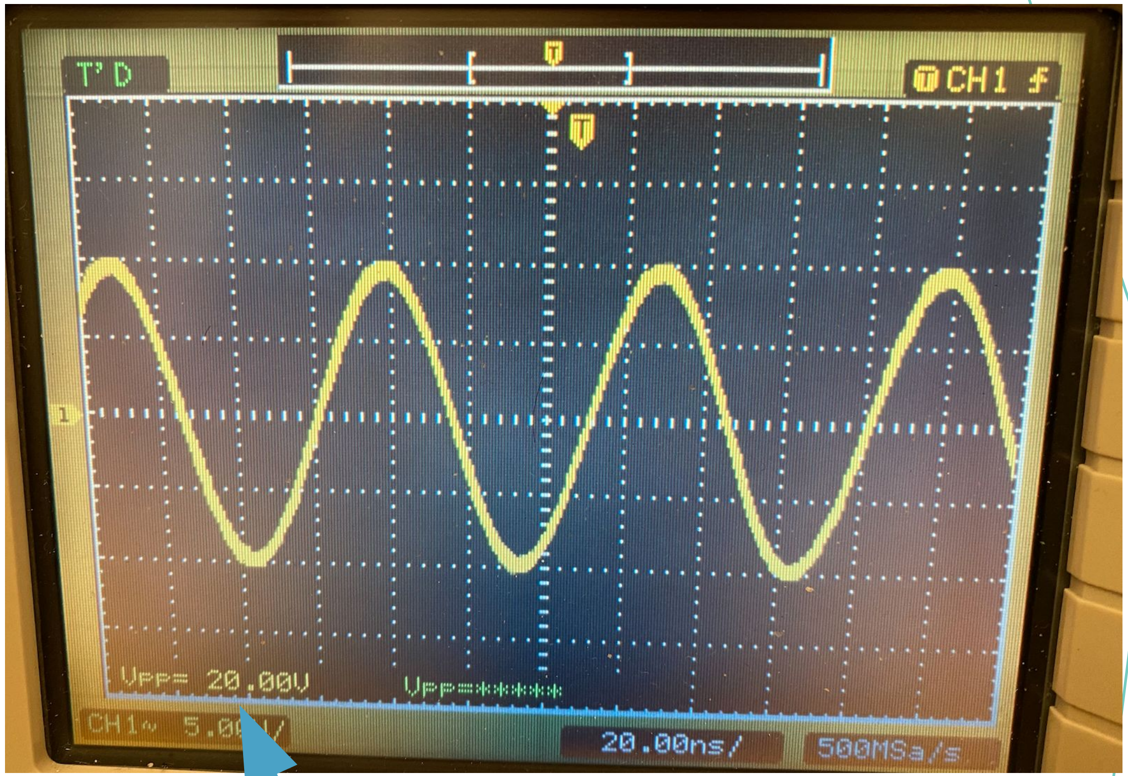
EXPERIMENT 1 - VOLTAGE

“Short” (1.8 meter) connection



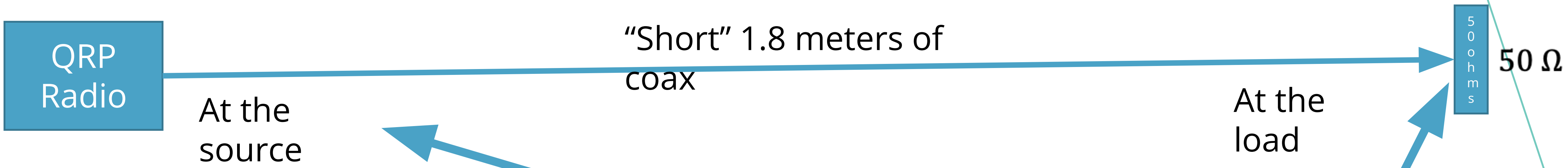
We have already calculated period and wavelength, let’s calculate the power delivered to the load.

$$P_{load} = \frac{V_{rms}^2}{R_{load}} = \left(\left(\frac{20}{2}\right) \times \left(\frac{1}{\sqrt{2}}\right)\right)^2 \times \frac{1}{50} = 1.0 \text{ Watts}$$



20 Volts Peak to Peak

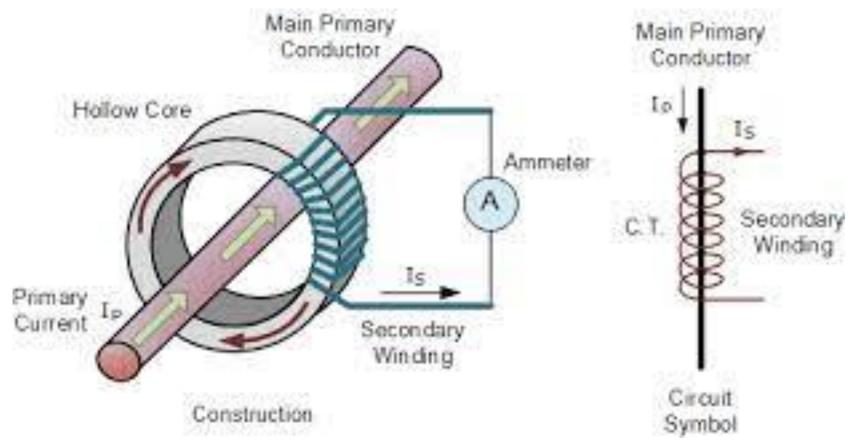
EXPERIMENT 1 TIME

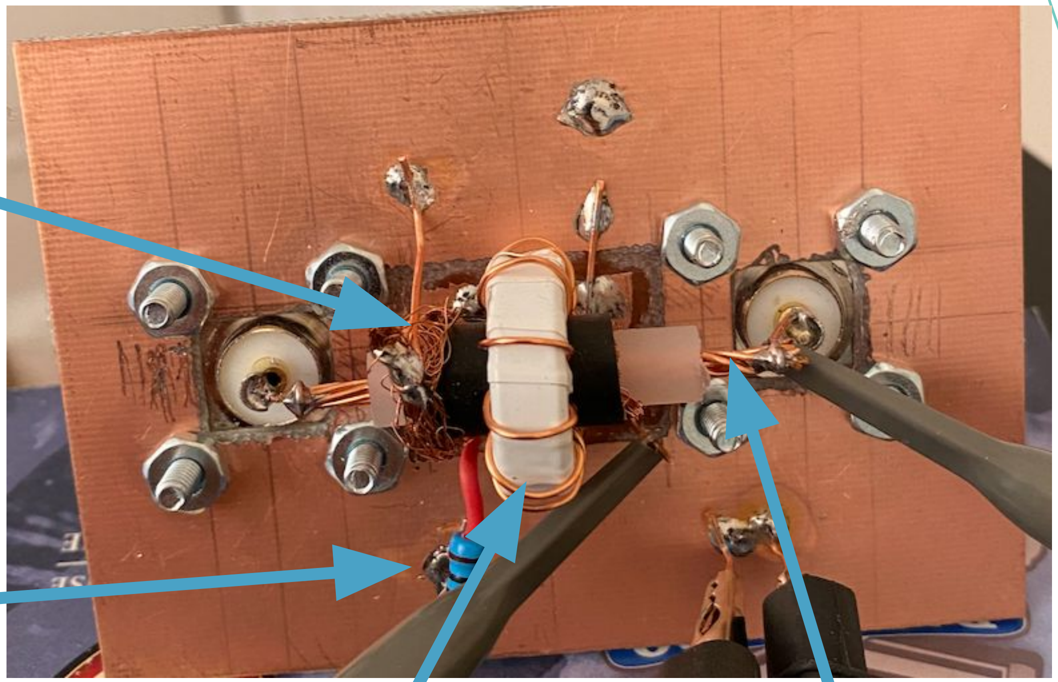


- RG8X propagation velocity: 236,800,000 m/s
- 1.8 m / 236,800,000 m/s = 7.6 ns

Voltage is delayed about 8 ns at the load from the source

SIDETRACK: MEASURING CURRENT





Shiel
d

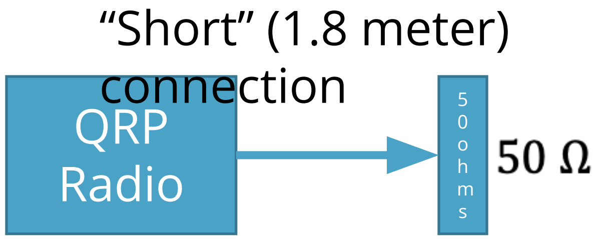
100
Ohms

11 turn
secondary

1 turn
primary
(coax
cable)

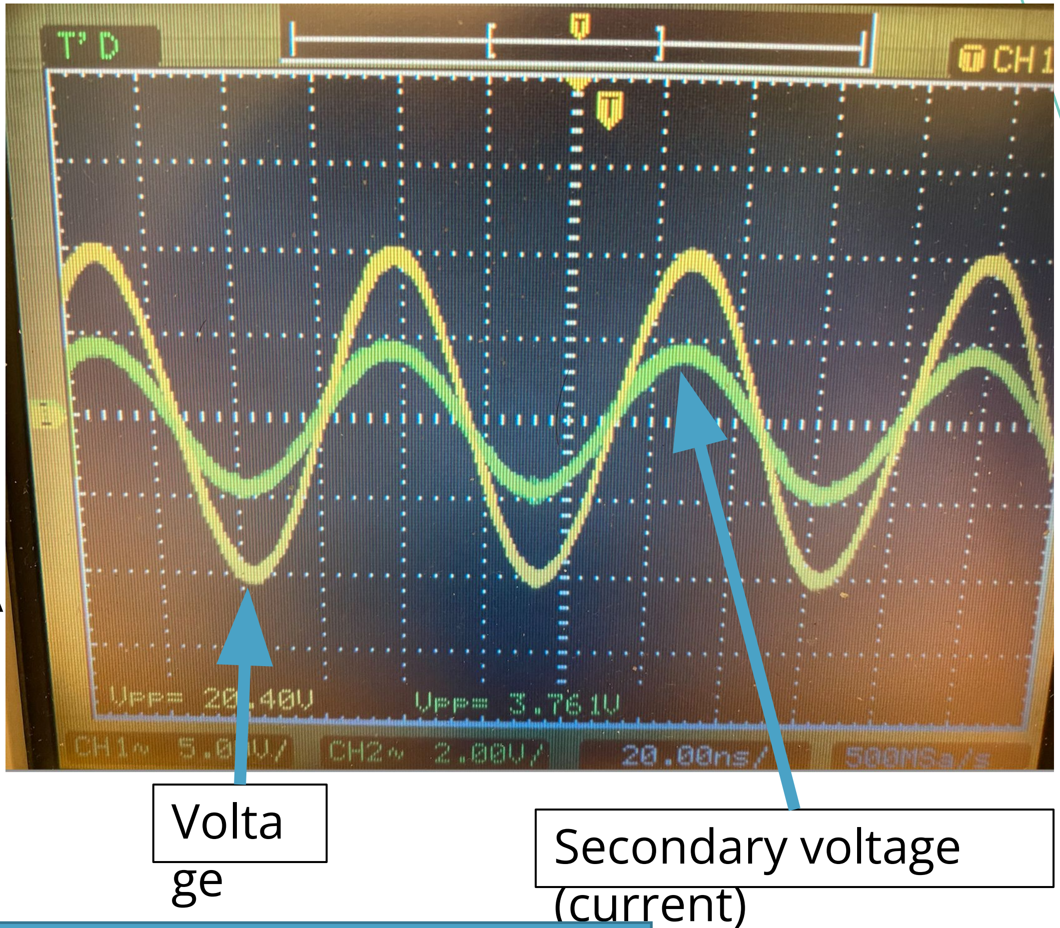
Instead of measuring current in the secondary, we put 100 ohms across the secondary and measure voltage

EXPERIMENT 1 – CURRENT



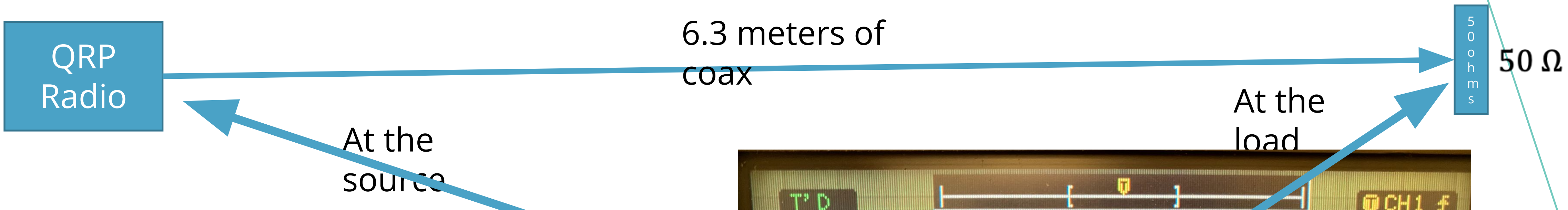
- Note: current is in phase with voltage indicating resistive load
- 3.76 volts peak to peak / 2 = 1.88 volts peak
- 1.88 volts / 100 ohms = 18.8 mA peak
- 18.8 mA peak (secondary) x 11 turns ratio = 206.8 mA peak (primary)
- 206.8 mA / 1000 = 0.2068 A peak in primary

$$P_{load} = (I_{rms})^2 R_{load} = \left(0.2068 \frac{1}{\sqrt{2}}\right)^2 \times 50 = 1.07 \text{ Watts}$$

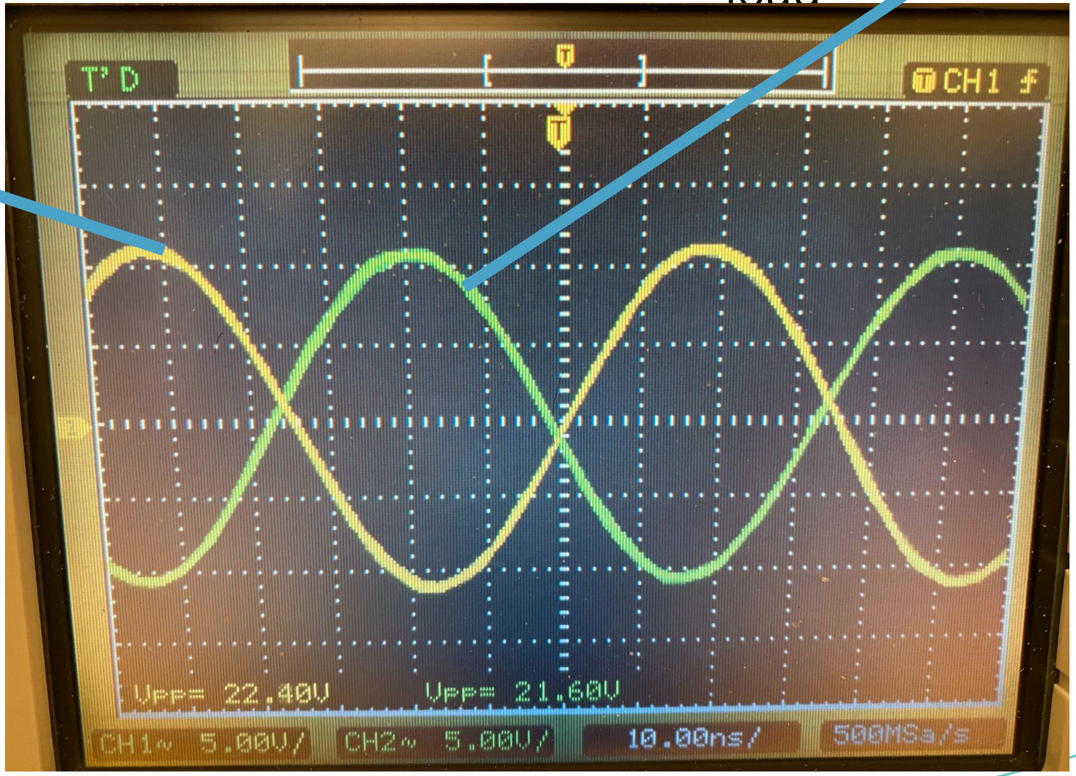


Using the voltage or the current formula for power, we get the same

EXPERIMENT 2 - VOLTAGE



- ~1 Watt into the cable
- ~1 Watt delivered to the load



There is a delay between voltage at the load and the source

EXPERIMENT 2 TIME

QRP Radio

6.3 meters of coax

50 oohms

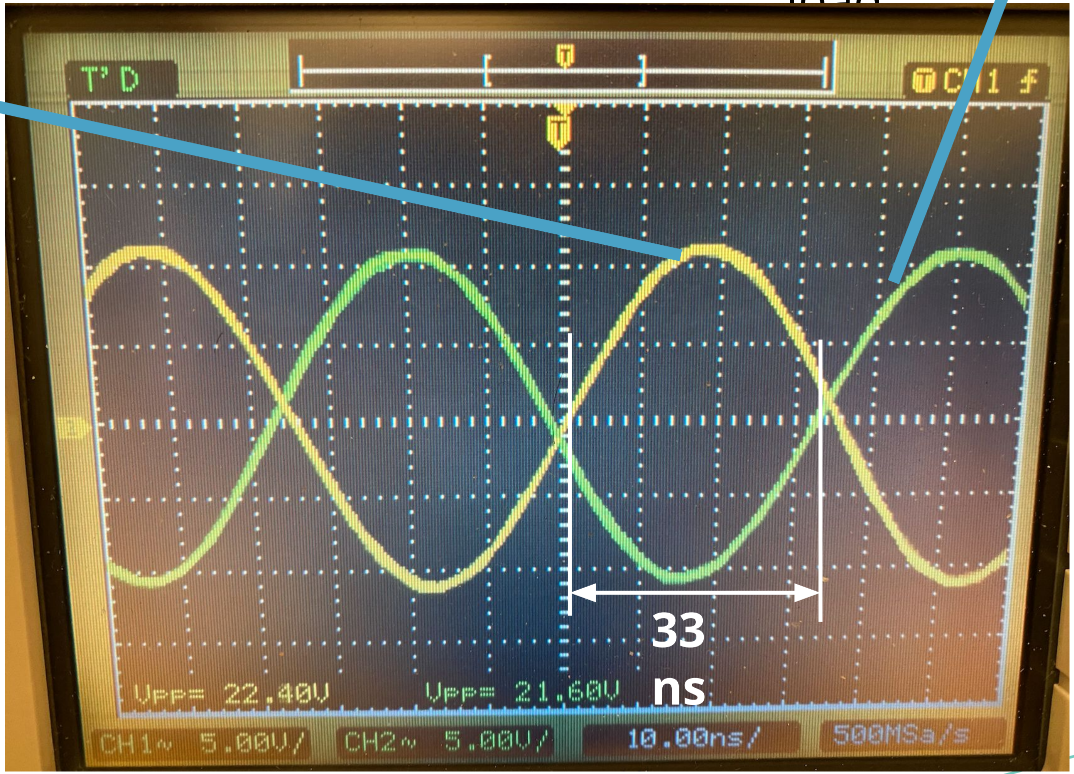
$50\ \Omega$

At the source

At the load

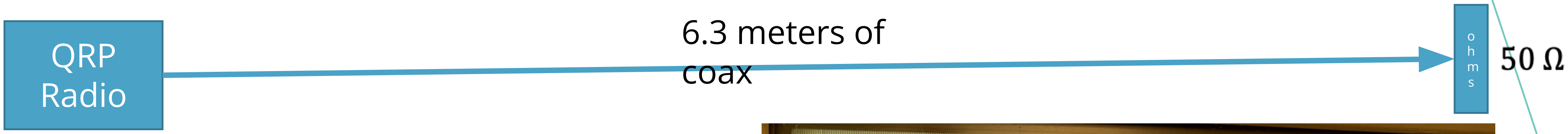
$$\frac{6.3\ meters}{236.8\ million\ m/s} = 26.6\ nano\ seconds$$

- What causes the difference?
- Stray inductance and capacitance?
- Measurement error?
- The RG8X used has a velocity of 191 million miles per second
- …or a little bit of all the above…



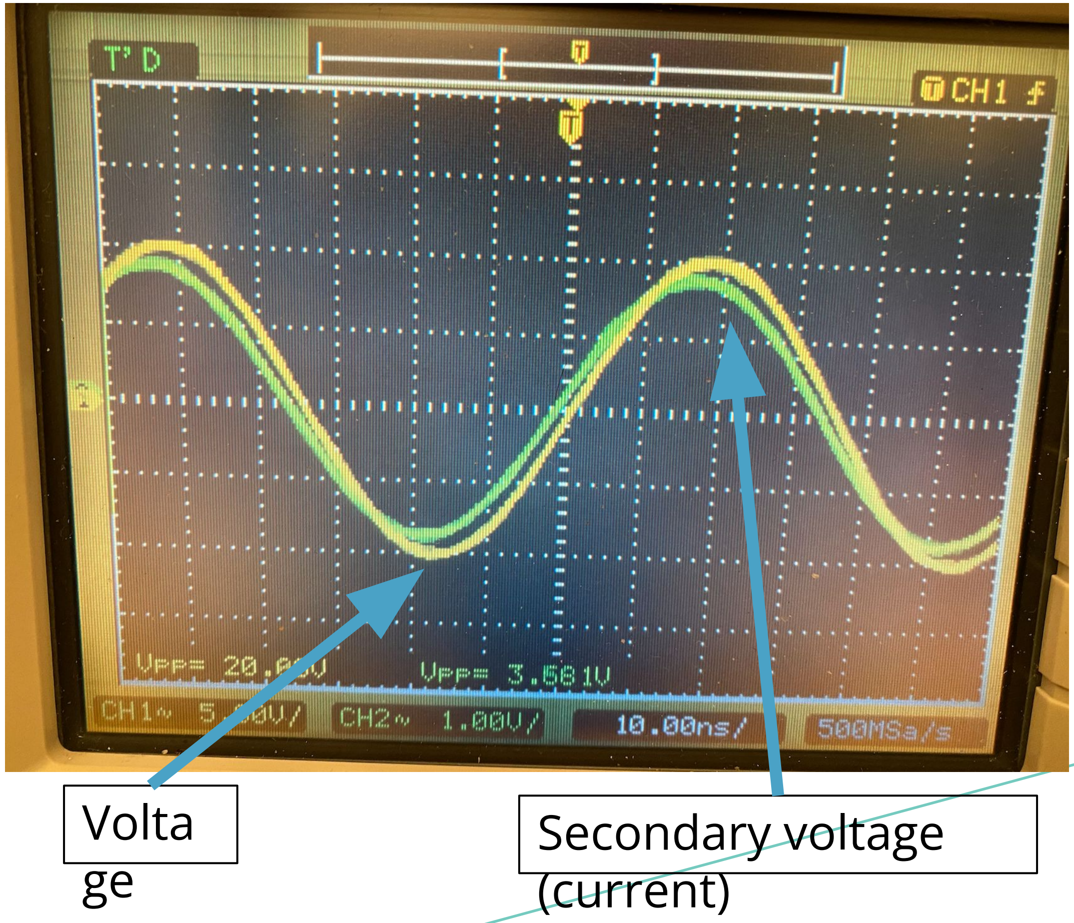
There is a delay 33 ns between voltage at the load and the source

EXPERIMENT 2 CURRENT



- Note: current is in phase with voltage indicating resistive load
- 3.68 volts peak to peak / 2 = 1.84 volts peak
- 1.88 volts / 100 ohms = 18.4 mA peak
- 18.4 mA peak in secondary x 11 = 202.4 mA peak in primary
- 202.4 mA / 1000 = 0.2024 A peak in primary

$$P_{load} = (I_{rms})^2 R_{load} = \left(0.2024 \frac{1}{\sqrt{2}}\right)^2 \times 50 = 1.02 \text{ Watts}$$



EXPERIMENT 3 VOLTAGE

QRP Radio

6.3 meters of coax

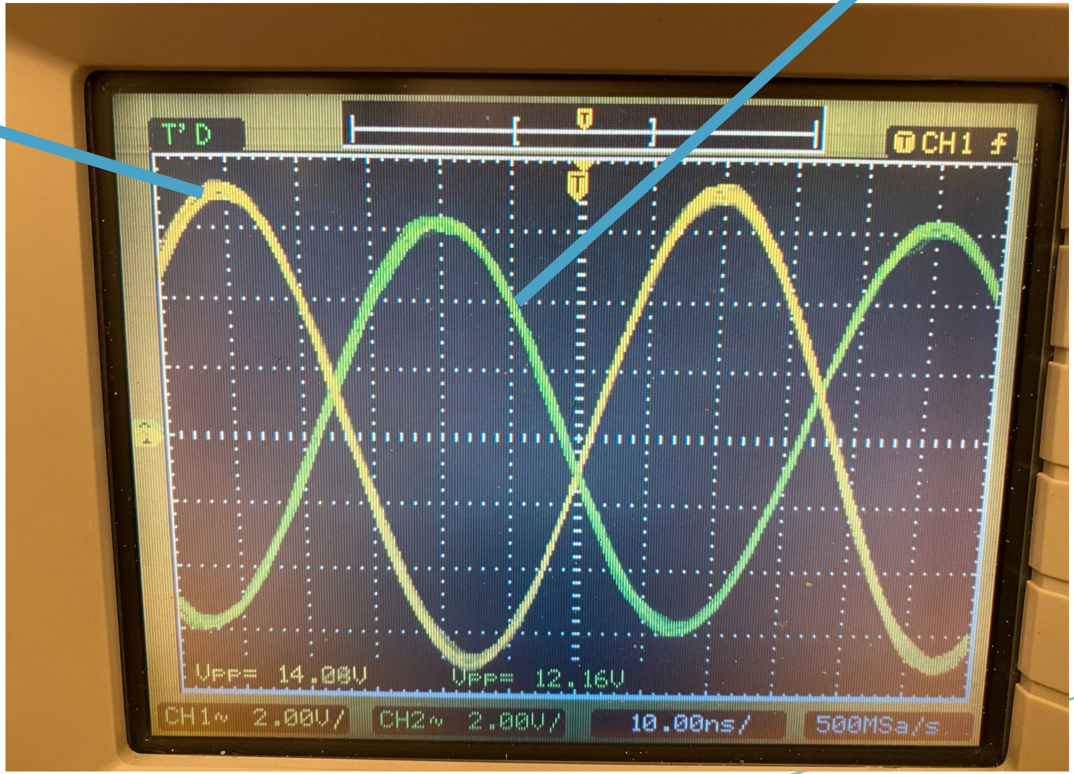
25 Ω

ohms

At the source

At the load

What happened, where does 14.00 volts and 12.16 volts come from?



Power delivered to the load (remember this number):

$$P_{load} = \frac{V_{rms}^2}{R_{load}} = \left(\frac{12.16}{2} \times \frac{1}{\sqrt{2}}\right)^2 \times \frac{1}{25} = 744\ mW$$

EXPERIMENT 3 VOLTAGE

QRP Radio

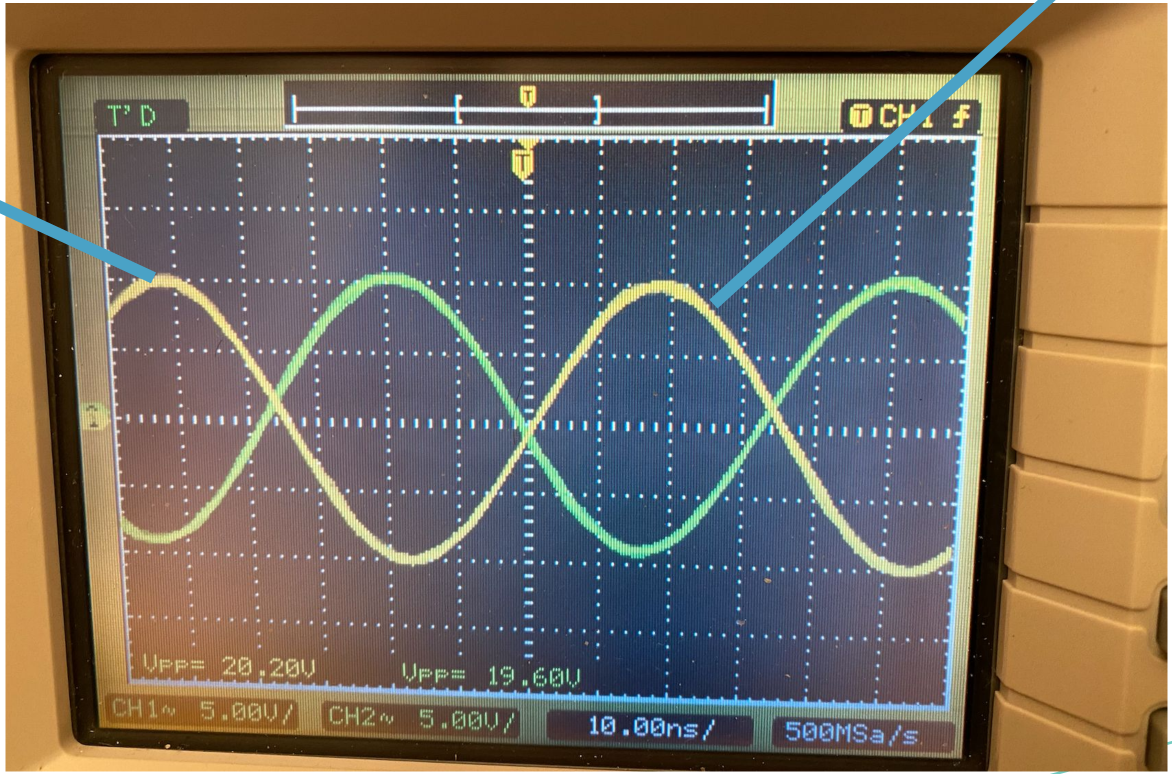
6.3 meters of coax

ohms

50 Ω

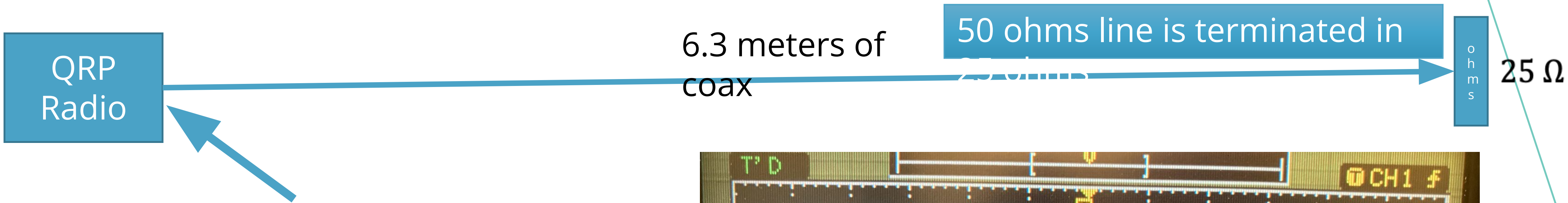
At the source

At the load



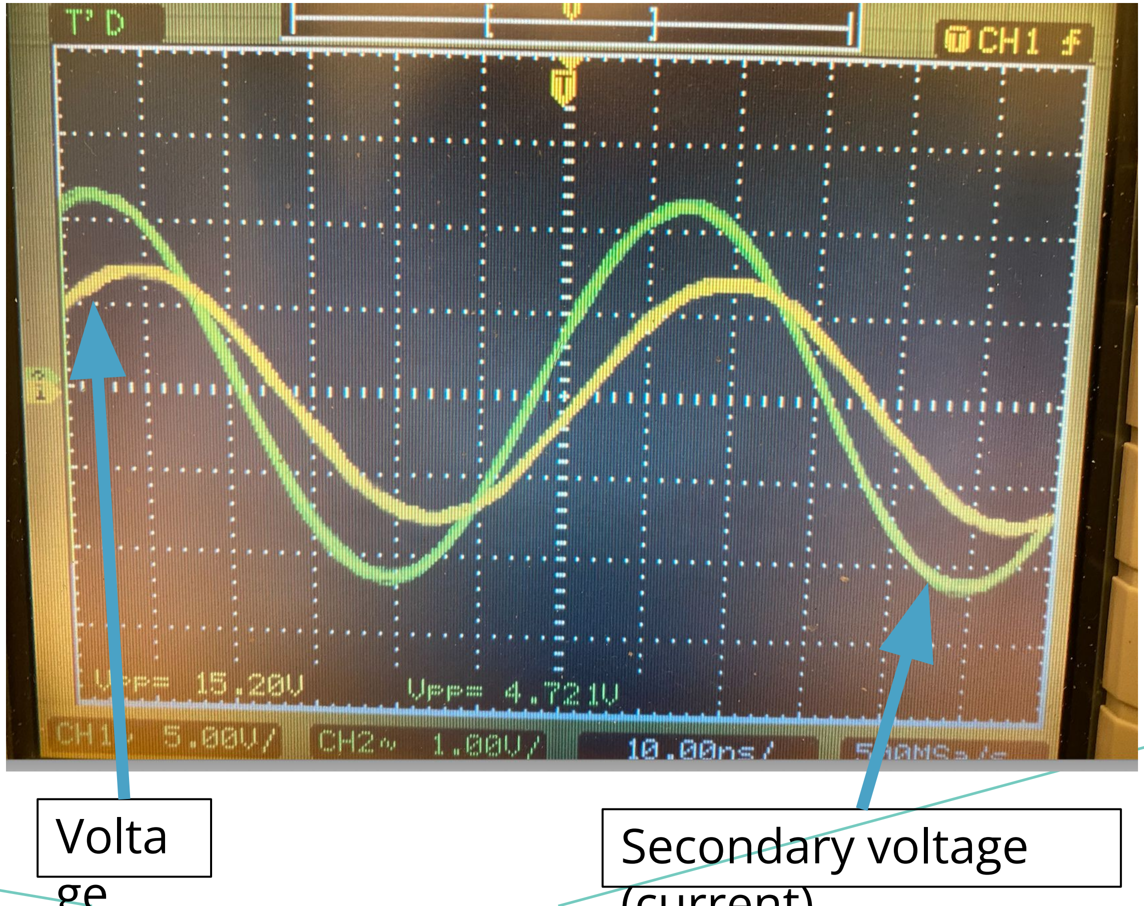
Insight
Terminating a transmission line with other than its characteristic impedance

EXPERIMENT 3 CURRENT



<u>At the input to the line:</u>

- Current leads voltage by 7 ns (10% of period)
- Load has a capacitive component
- ELI the ICE man
  - Voltage leads current in an inductor
  - Current leads voltage in a capacitor



EXPERIMENT 3 THE MATH

- Voltage at the input 15.2 volts peak to peak
- Voltage across the current sensing resistor 4.72 volts peak to peak
- 4.72 / 100 = 47.2 mA peak to peak
- 47.2 mA x 11 = 519.2 mA peak to peak
- 519.2 mA / 1000 = 0.5192 A
- 15.2 volts / 0.5192 A = 29.3 Ohms (23.7 ohms resistive and 17.2 ohms capacitive)

$$P = \left(\frac{0.5192}{2} \times \frac{1}{\sqrt{2}}\right)^2 \times 23.7 = 0.788 \text{ W} = 798 \text{ mW}$$

EXPERIMENT 4 VOLTAGE

QRP Radio

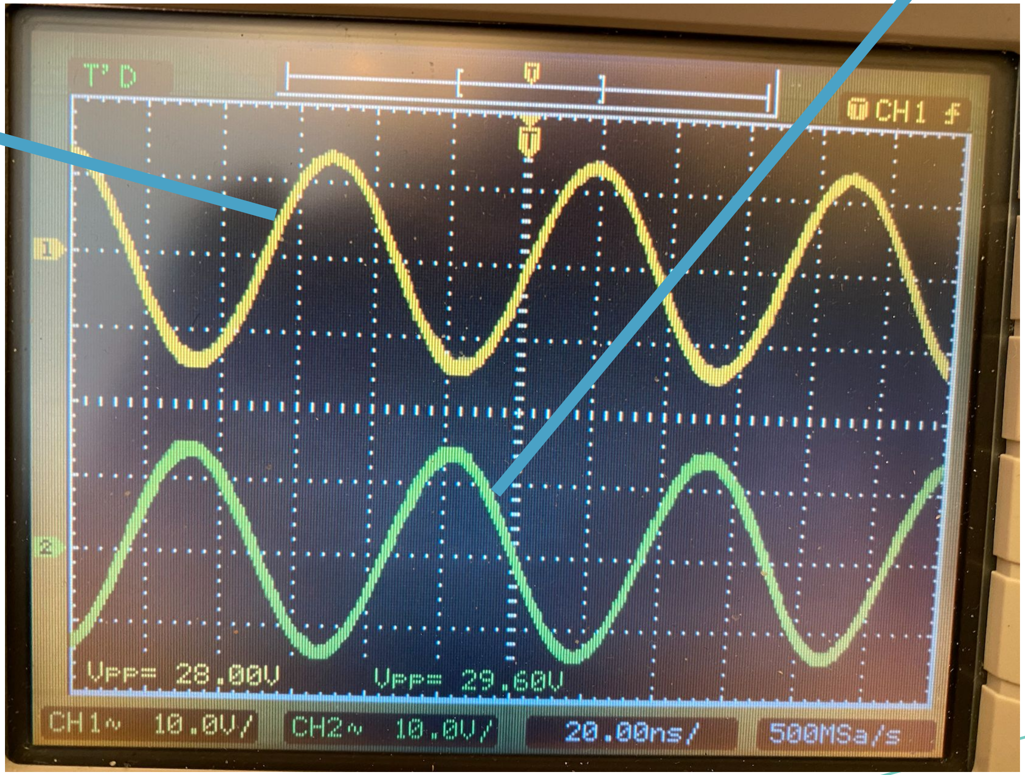
6.3 meters of coax

ohms

112 Ω

At the source

At the load



…the same story, the 28 volts and 29.6 volts are related to the 20 volts with a 50 ohm load the same way as the 14.00 volts and 12.16 volts form the 25 ohms case?

Power delivered to the load (remember this number):

$$P_{load} = \frac{V_{rms}^2}{R_{load}} = \left(\frac{29.6}{2} \times \frac{1}{\sqrt{2}}\right)^2 \times \frac{1}{112} = 978\, mW$$

EXPERIMENT 4 CURRENT

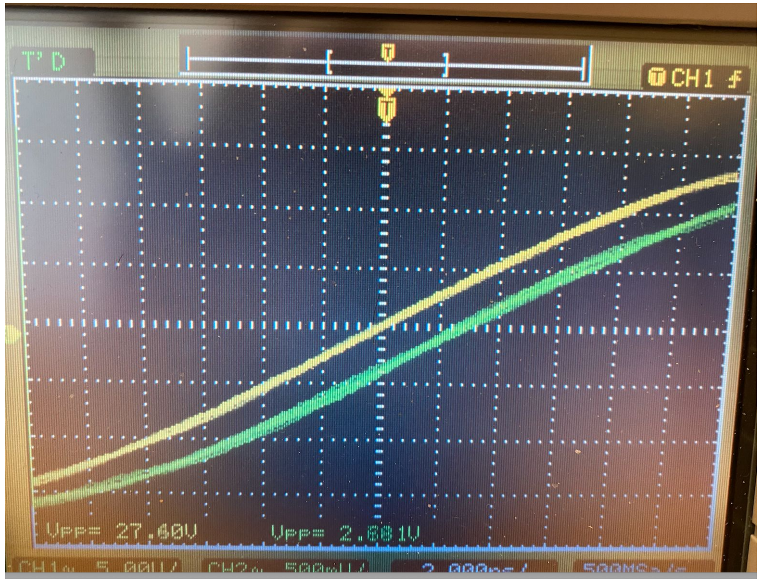
QRP Radio

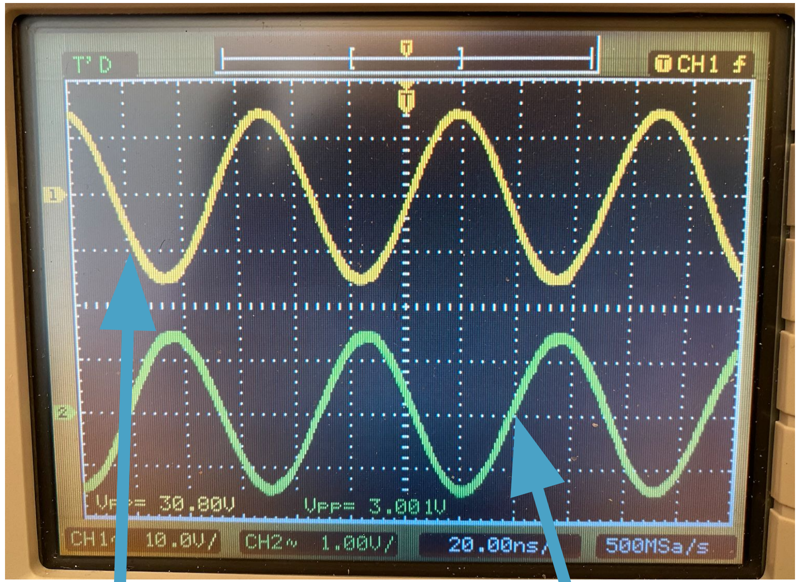
6.3 meters of coax

50 ohms line is terminated in

ohms

112 Ω





Voltage

Secondary voltage (current)

<u>At the input to the line:</u>

- Voltage leads current by 3 ns (4.3% of period)
- Load has an inductive component
- FU the ICE man

EXPERIMENT 4 THE MATH

- Voltage at the input 27.7 volts peak to peak
- Voltage across the current sensing resistor 2.68 volts peak to peak
- 2.68 / 100 = 26.8 mA peak to peak
- 26.8 mA x 11 = 294.8 mA peak to peak
- 294.8 mA / 1000 = 0.2948 A peak to peak
- 27.7 volts / 0.2948 A = 94.0 Ohms (90.6 ohms resistive and 24,9 ohms inductive)

$$P = (I_{rms})^2 R = \left(\frac{0.2948}{2} \times \frac{1}{\sqrt{2}}\right)^2 \times 90.6 = 0.956 \text{ W} = 984 \text{ mW}$$

INSIGHTS

- This data is for one length of cable, one frequency, and three terminations
- Other situations will give different results, but it gives you an idea what is at work
- Terminating a line in its characteristic impedance makes it appear as if it is not there (except for the wave travel time)
- Terminating a line in a different impedance changes the input impedance of the line (and often with a reactive, capacitance or inductance, component)
- The change depends on the cable, the frequency, the length and the termination

WHAT DO YOU DO, PRACTICALLY

- Your radio is designed for best performance with 50 Ohms load
- …but who has a pure 50 ohms resistive antenna?
- Build or buy as good an antenna as you can (consult Greg)
- Your feedline impedance is most likely 50 ohms
- So, you radio will see a different impedance and that depends…
- At an SWR of 2, you will lose 10% of your power output and at an SWR of 3, about 25% of power, so keep your SWR close to 2 or less…

Additional Reference Material

REFLECTION

- When a wave (of any kind) hits a mismatch in its traveling medium, some of the wave will reflect back
- As we have seen, when the line is terminated with a matching impedance, the full power of the wave is delivered to the load and that is the end of the story
- ...But what if it is not? Let's dig into that.

$$reflection\ coefficient = \frac{reflected\ voltage}{forward\ voltage} = \frac{load\ impedance\ - line\ impedance}{load\ impedance + line\ impedance}$$

$$reflection\ coefficient(at\ 25\Omega) = \frac{reflected\ voltage}{forward\ voltage} = \frac{25\ - 50}{25 + 50} = -.333$$

$$reflection\ coefficient(at\ 112\Omega) = \frac{reflected\ voltage}{forward\ voltage} = \frac{112\ - 50}{112 + 50} = .383$$

REFLECTION

$$reflection\ coefficient = \frac{reflected\ voltage}{forward\ voltage} = \frac{load\ impedance\ - line\ impedance}{load\ impedance + line\ impedance}$$

$$reflection\ coefficient = \frac{reflected\ voltage}{forward\ voltage} = \frac{25\ - 50}{25 + 50} = -0.333$$

$$reflected\ voltage = -0.333 \times forward\ voltage$$

$$load\ voltage = forward\ voltage + reflected\ voltage = 12.16\ volts$$

$$forward\ voltage = 18.23\ volts$$

$$reflected\ voltage = -6.1\ volts\ (-sign\ indicates\ 180\ degree\ phase\ shift)$$

And just for reference:

$$SWR(at\ 25\Omega) = \frac{1 + absolute\ value\ of\ reflection\ coefficient}{1 - absolute\ value\ of\ reflection\ coefficient} = \frac{1 + .333}{1 - .333} = 2$$

$$SWR(at\ 112\Omega) = \frac{1 + .383}{1 - .383} = 2.2$$

$$absolute\ value\ of\ reflection\ coefficient = \frac{SWR - 1}{SWR + 1}$$