TAPPING TRANSFORMERS

DAVE VE3OOI

FEBRUARY 2023

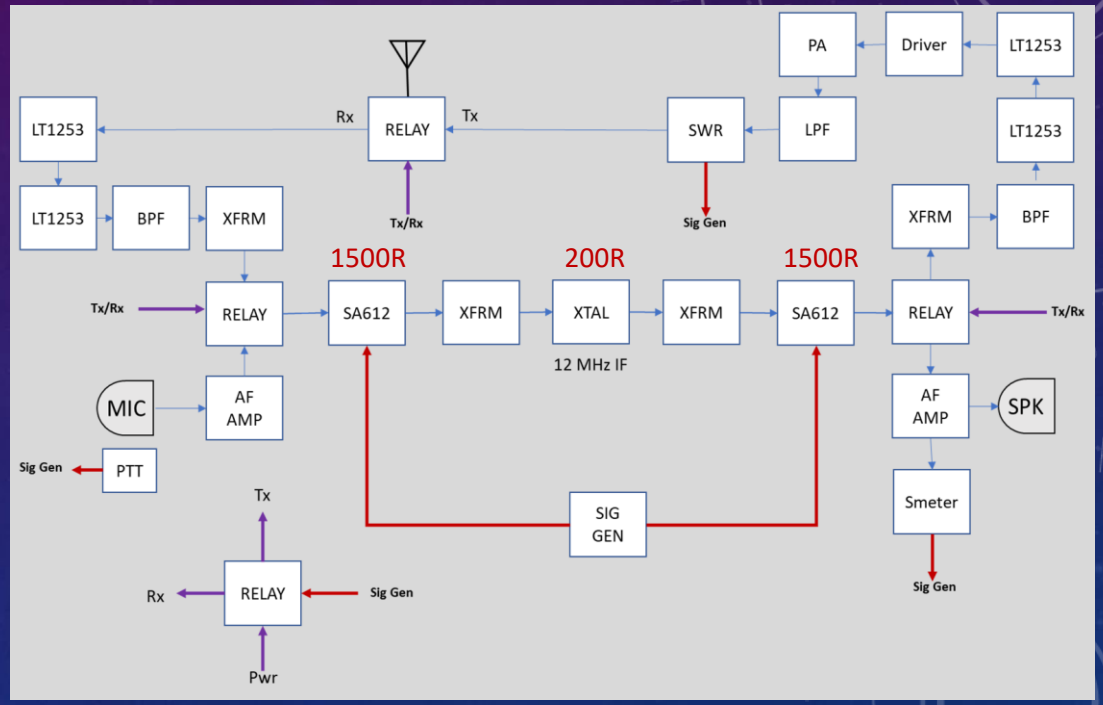
"Went outside the envelope -- faster than the speed for which it was designed." - Chuck Yeager

The speed was so great that Yeager lost control and the aircraft tumbled about 50,000 feet -- turning wildly. Yeager banged his helmeted head so hard on the "canopy" of the cockpit that he dented it. Yet he saved himself and the plane.

THE PROBLEM

Background

- Peter and I build the Dueling 612 Transceiver
- SA612 has impedance of 1500R and Crystal Filter has impedance of the order of 200R
- Had issues measuring performance of mixer and crystal filter using Spectrum Analyzer
- We discussed methods of measuring performance
  1. Tap coupling transformers
  2. Using a resistor divider
- The resistor divider was “off the cuff” suggestion

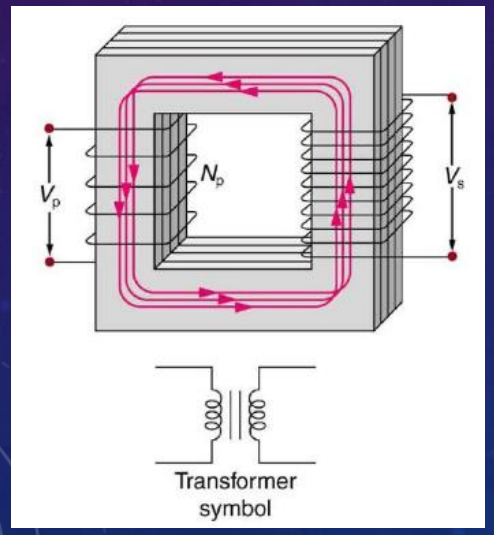


AGENDA

This is not a tutorial on transformers

- Its not about how transformers work
- Its not about transformers equations. Just accept the equations

This is about simple physics



$$\frac{Vs}{Vp} = \frac{Ns}{Np}$$

$$\frac{Ip}{Is} = \frac{Ns}{Np}$$

$$\left(\frac{N_P}{N_S}\right)^2 = \frac{Z_P}{Z_S}$$

Power in a Transformer

$$\text{Power}_{\text{Primary}} = \text{Power}_{\text{Secondary}}$$

$$P_p = I_p V_p = I_s V_s = P_s$$

PHYSICS

Simple Physics

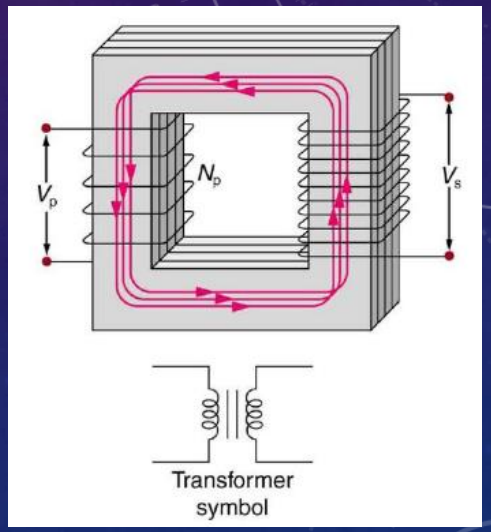
- ✓ The power output to a transformer MUST be equal or less than the power input into a transformer. If not, you can make a perpetual motion machine and the world is flat and JFK was shot by aliens
- ✓ This is governed by the laws of thermodynamics

The Laws of Thermodynamics

1st Law of Thermodynamics - Energy cannot be created or destroyed.

2nd Law of Thermodynamics - For a spontaneous process, the entropy of the universe increases.

3rd Law of Thermodynamics - A perfect crystal at zero Kelvin has zero entropy.



As we now know that energy is the capacity to do work, with the standard unit used for energy (and work) being the **Joule**. A joule of energy is defined as the energy expended by one ampere at one volt, moving in one second. Electric current results from the movement of electric charge (electrons) around a circuit, but to move charge from one node to another there needs to be a force to create the work to move the charge, and there is: *voltage*.

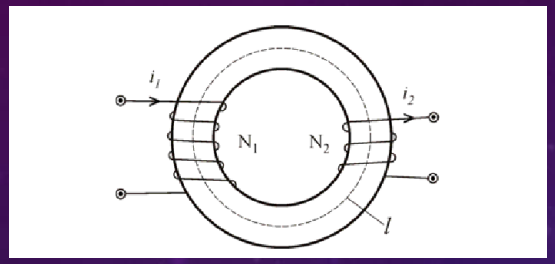
What is Electric Power?

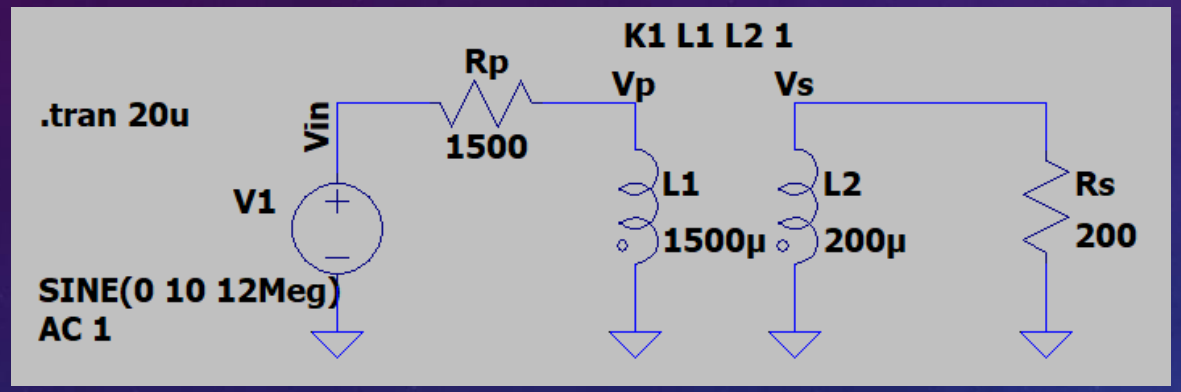
Electric power Definition – It is the rate at which work is done or energy is transformed in an electrical circuit. Simply put, it is a measure of how much energy is used in a span of time.

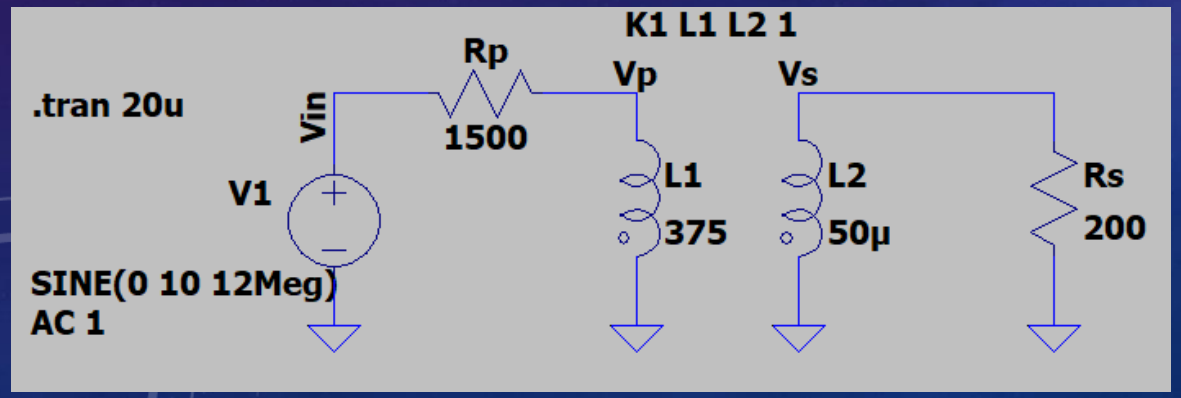
In physics, the rate of transfer of electrical energy by an electrical circuit per unit time is called electrical power. Here electrical energy can be either kinetic energy or potential energy. In most of the cases, potential energy is considered, which is the energy stored due to the relative positions of charged particles or electric fields. Electrical power is denoted by P and measured using Watt.

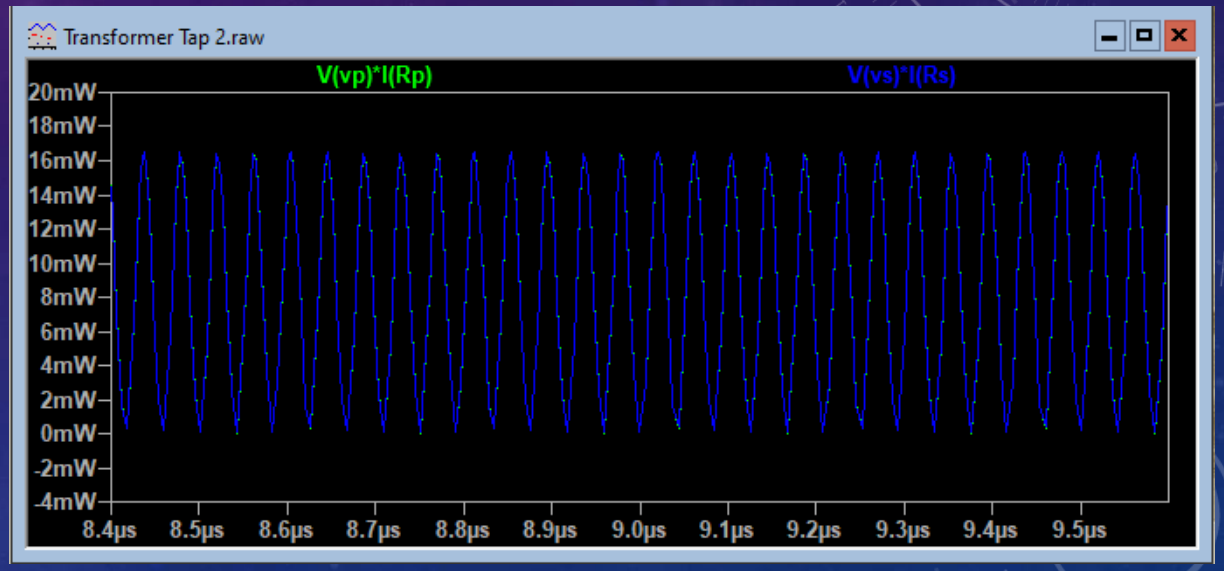
WHAT DOES THIS MEAN?

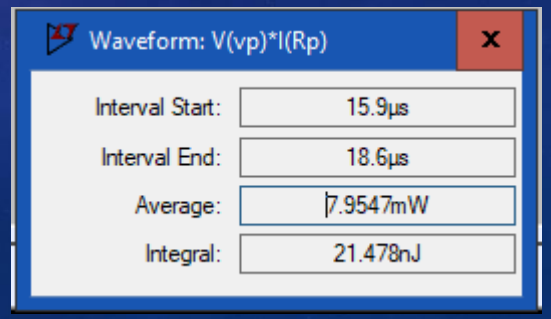
Simple Physics: Power Transfer – 1st Law of Thermodynamics

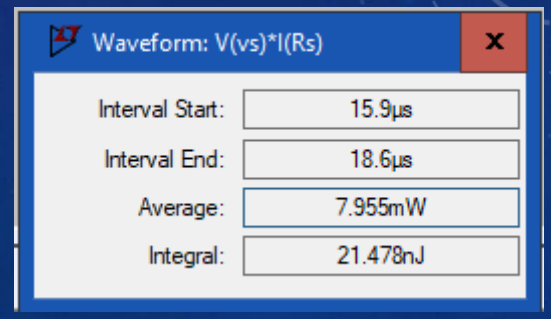






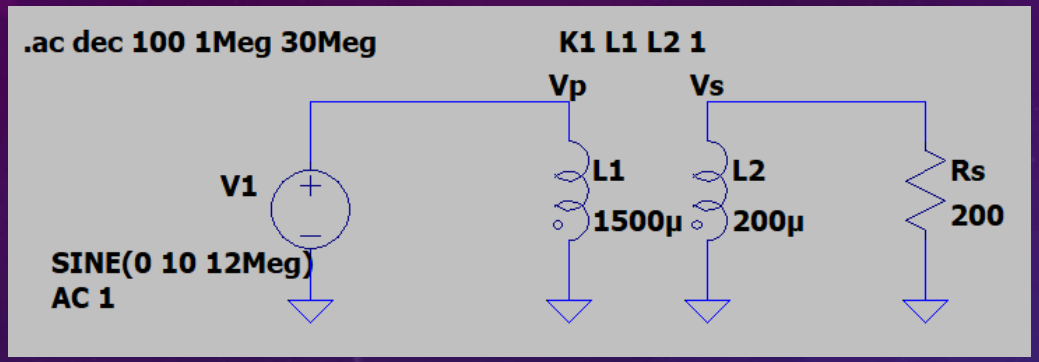


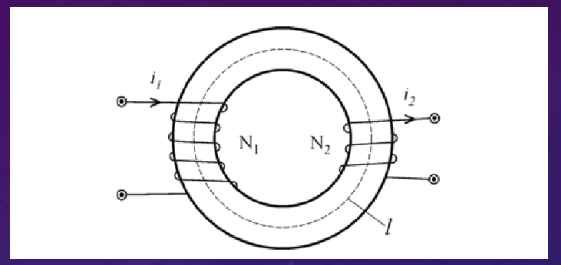


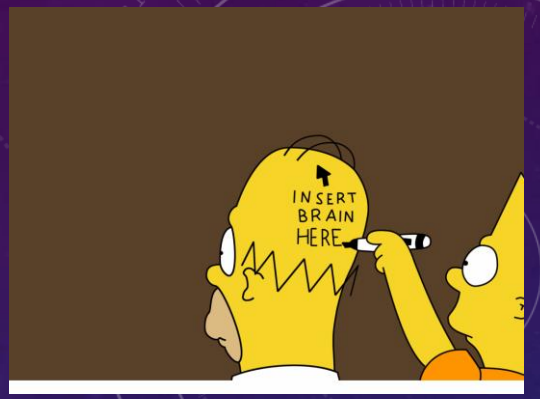


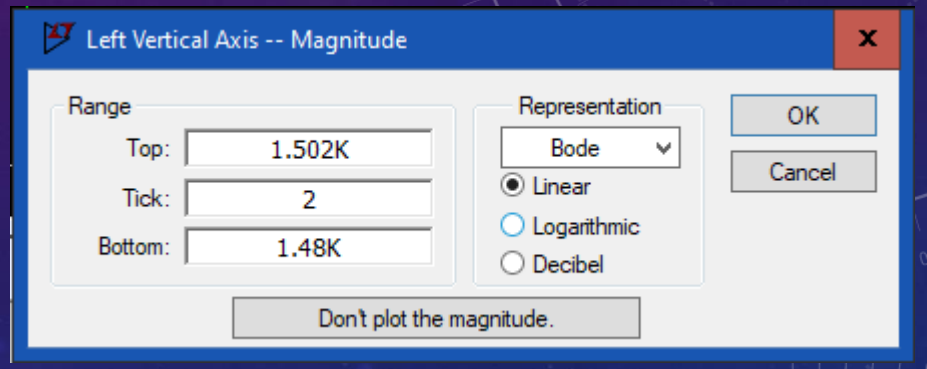
WHAT DOES THIS MEAN?

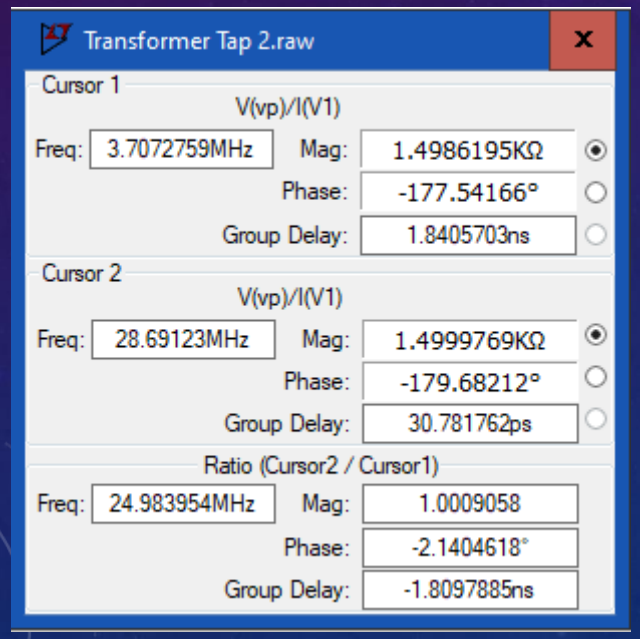
Simple Physics: Impedance Transformation

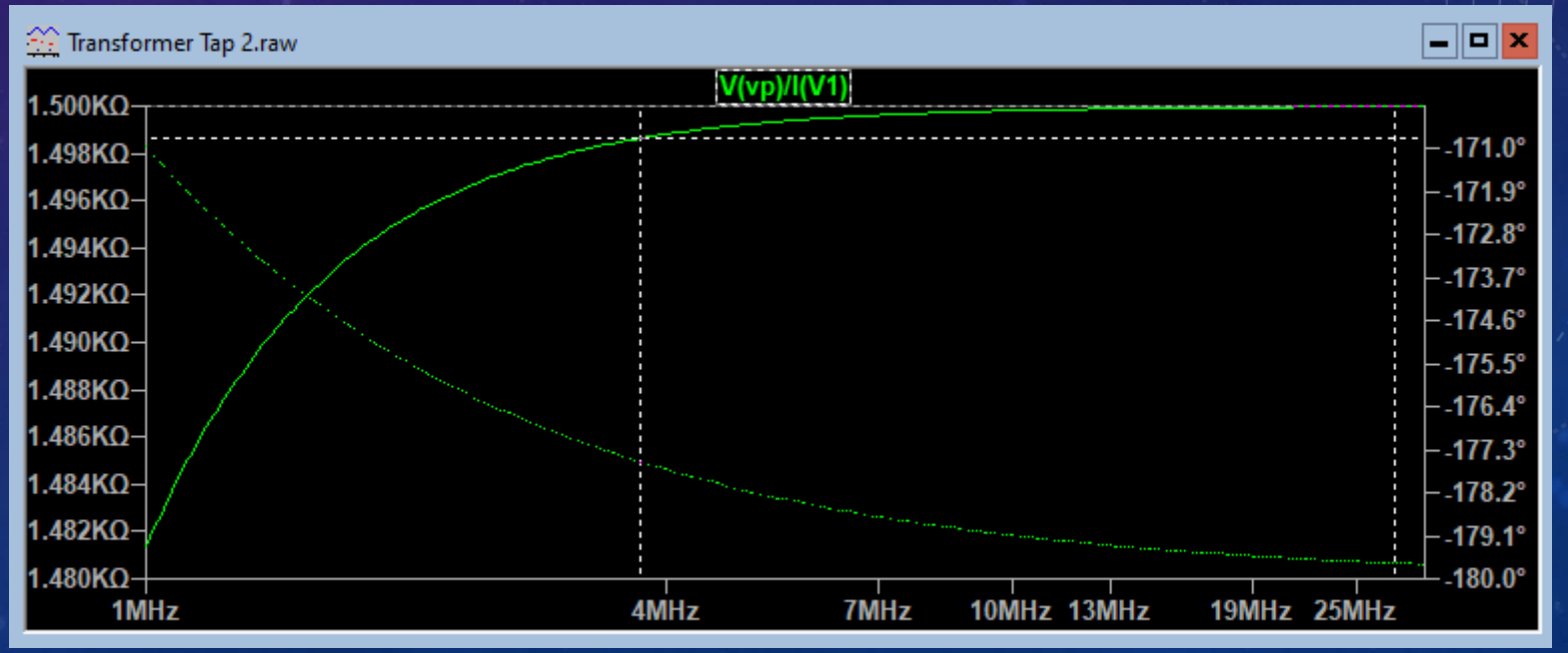












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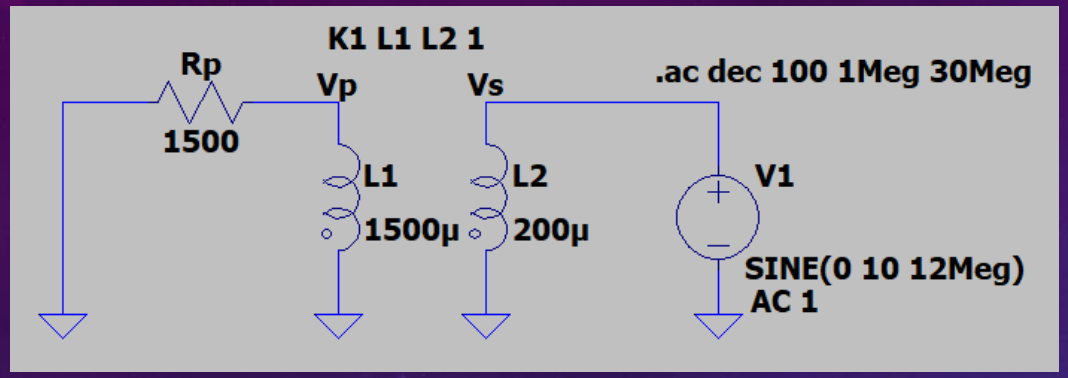
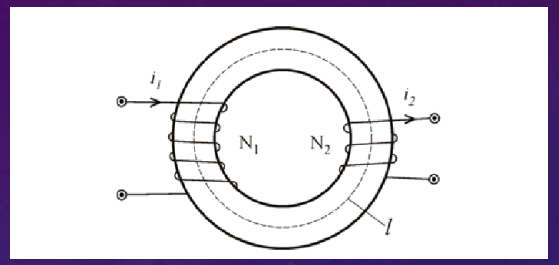
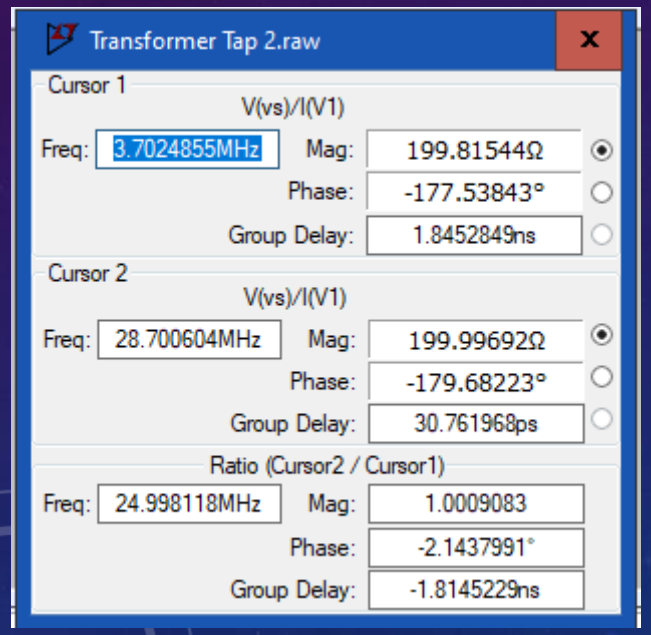
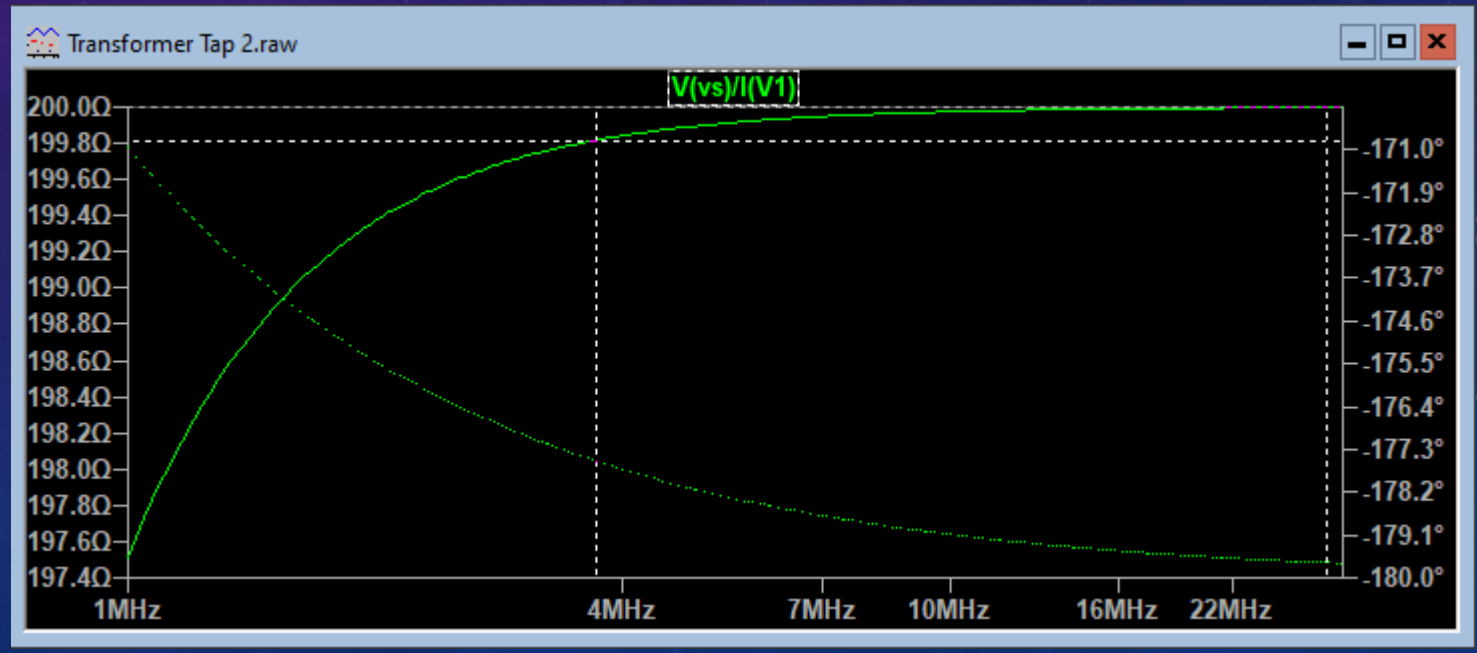


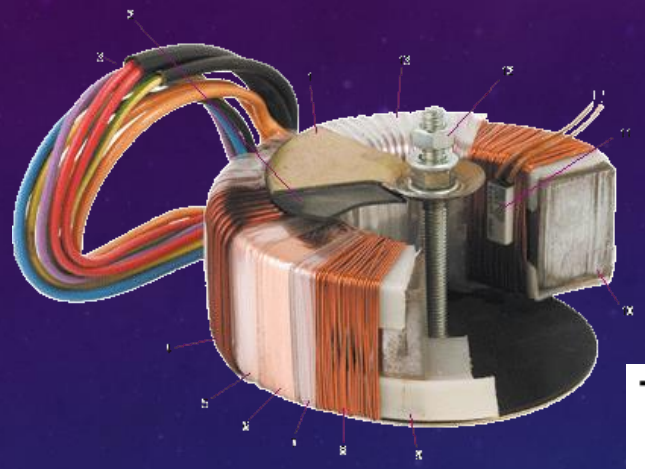


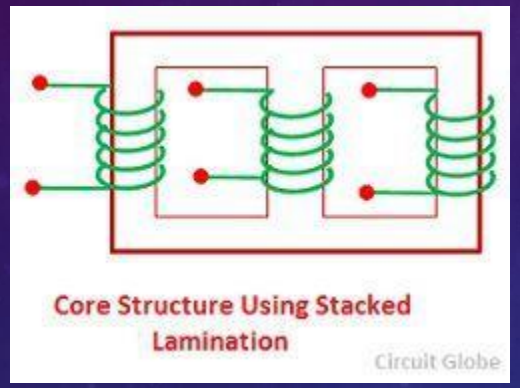


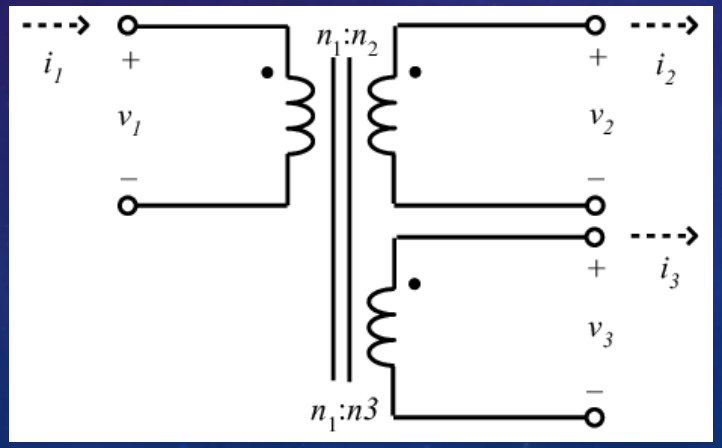


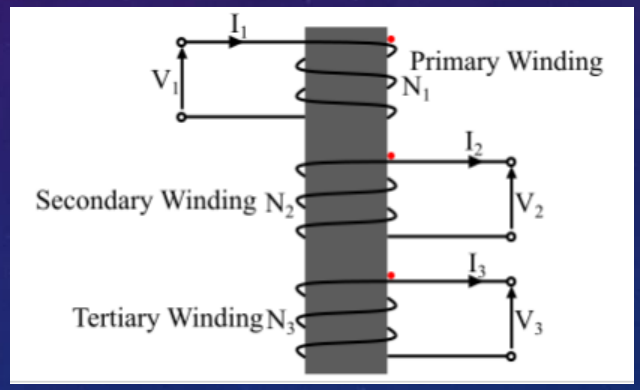
WHAT HAPPENS IF YOU ADD A TAP?

- ✓ 1st Law of Thermodynamics: Power in = Power out (for ideal transformer)
- ✓ Impedance reflected is based on turns ratio of **all turns and taps**









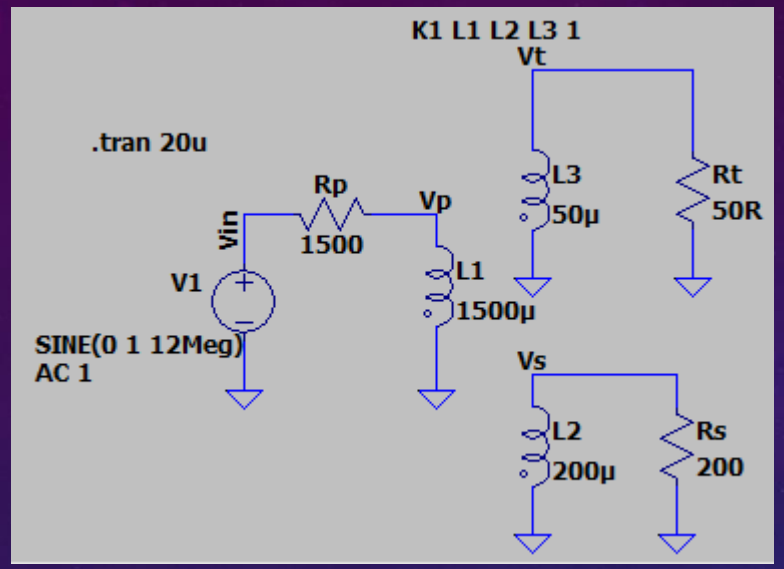
$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

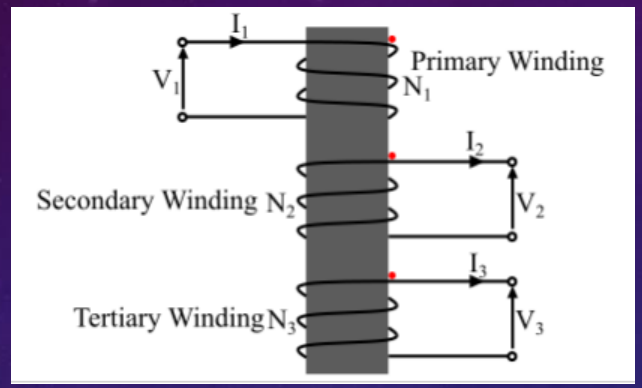
$$\frac{V_3}{V_1} = \frac{N_3}{N_1}$$

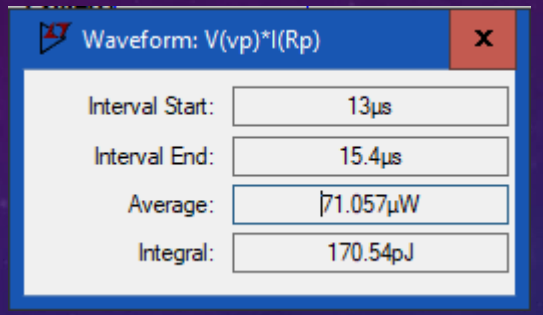
$$N_1 I_1 = N_2 I_2 + N_3 I_3$$

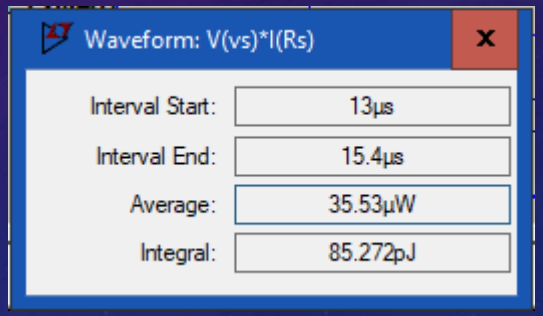
ADDING 50R TAP

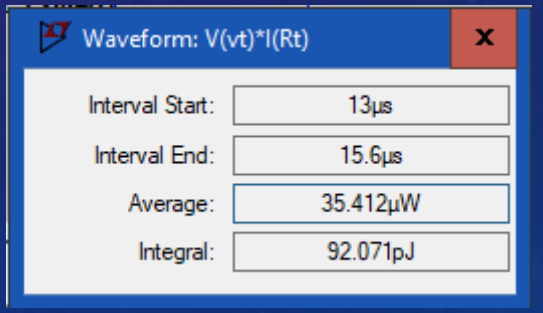
SIMPLE/COMPLEX Physics: Power Transfer – 1st Law of Thermodynamics

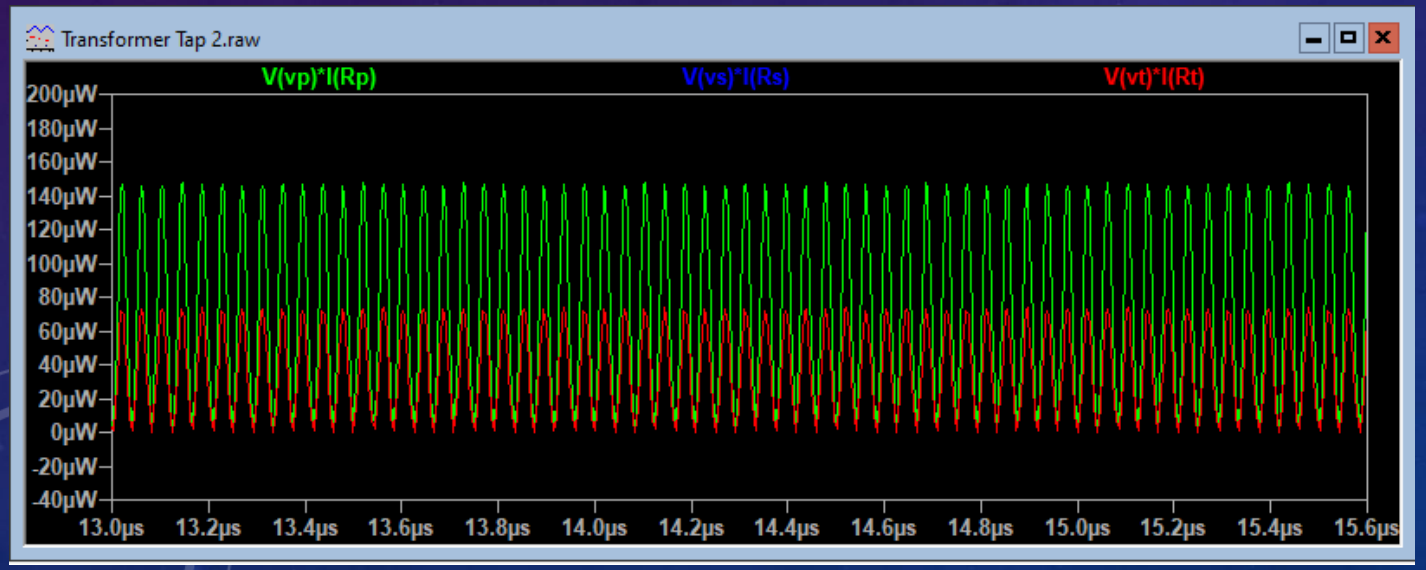








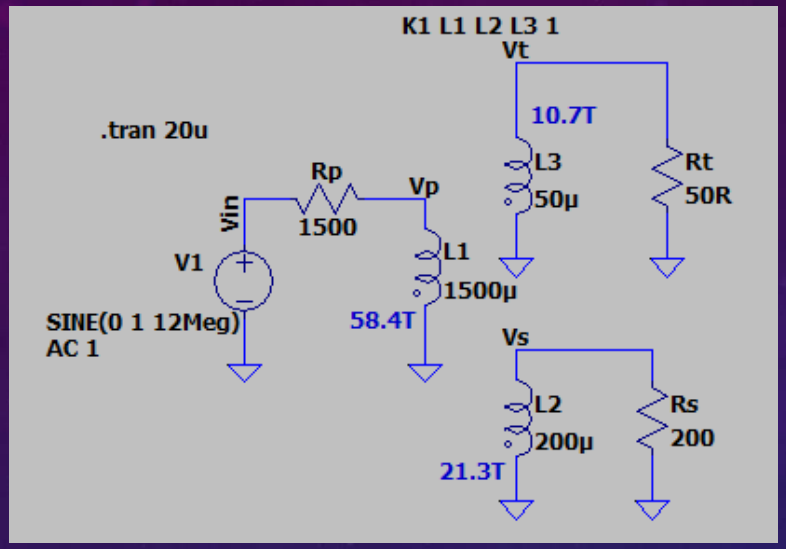


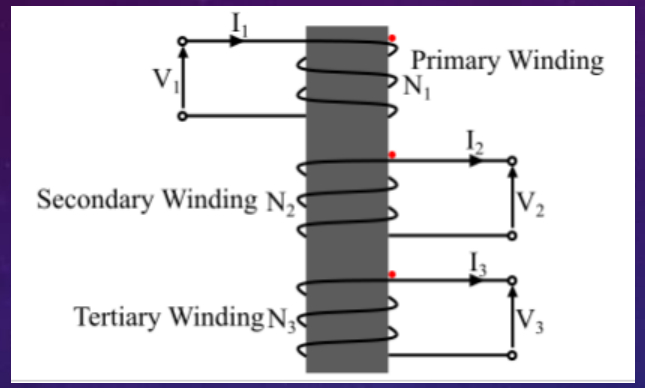


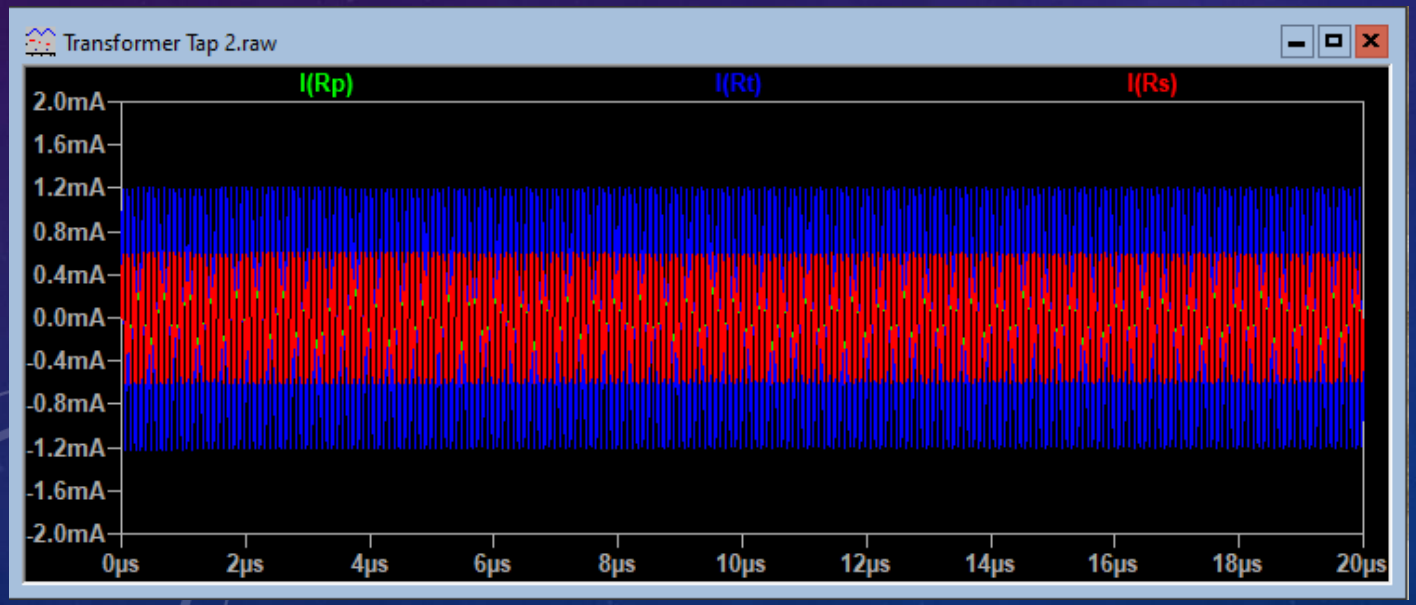
35.5uW + 35.4uW = 70.9uW (71uW)

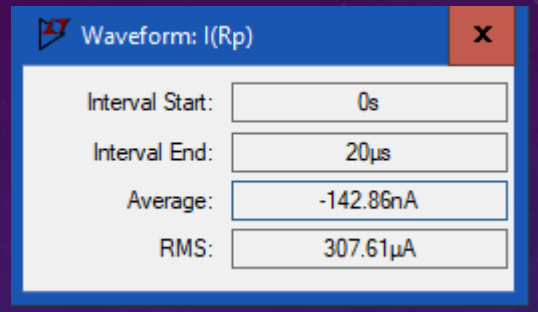
ADDING 50R TAP

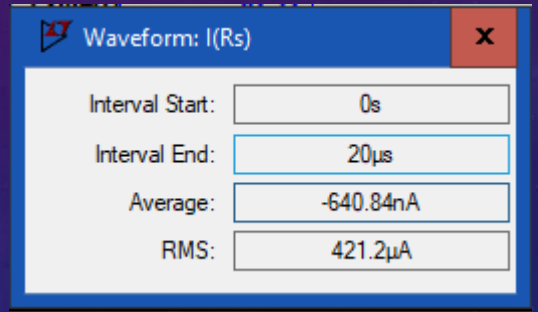
SIMPLE/COMPLEX Physics: Current Distribution

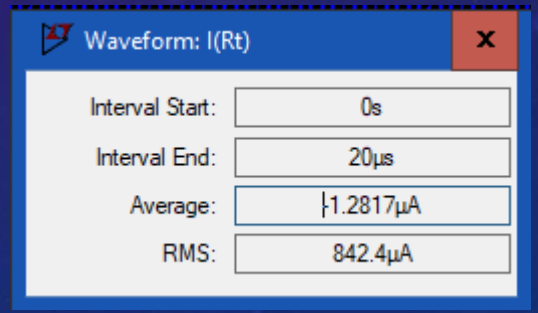












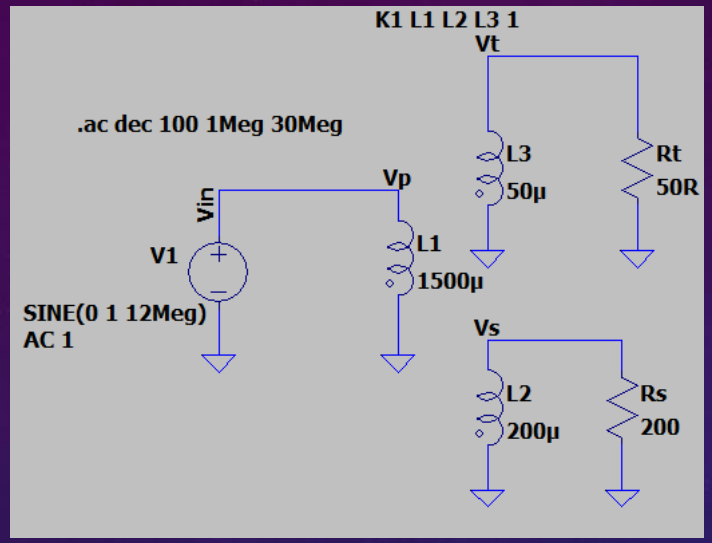
$$N_1 I_1 = N_2 I_2 + N_3 I_3$$

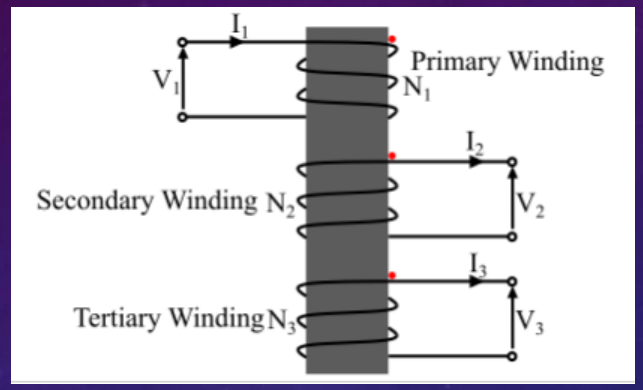
308x58.4 = 17963

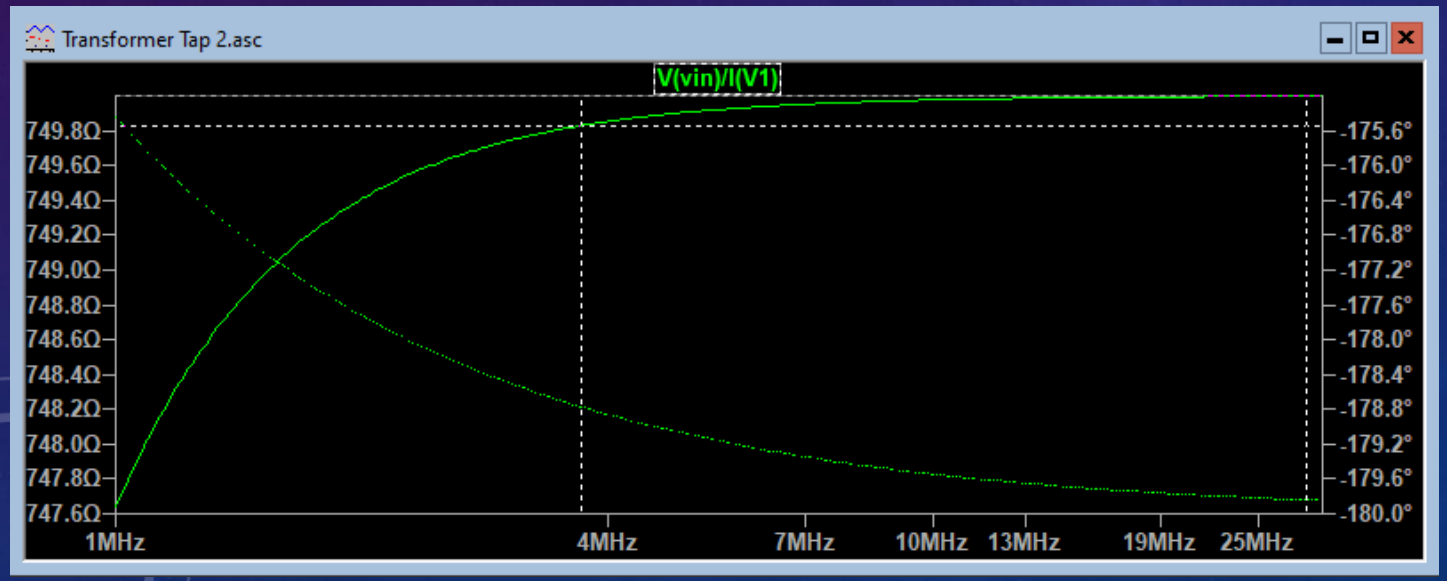
421x21.3 + 842x10.7 = 17985

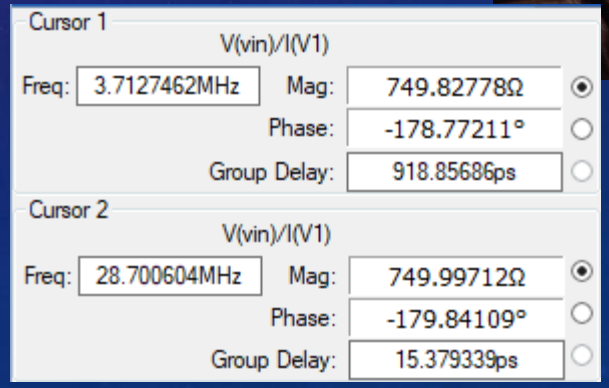
ADDING 50R TAP

COMPLEX Physics: Impedance Transformation



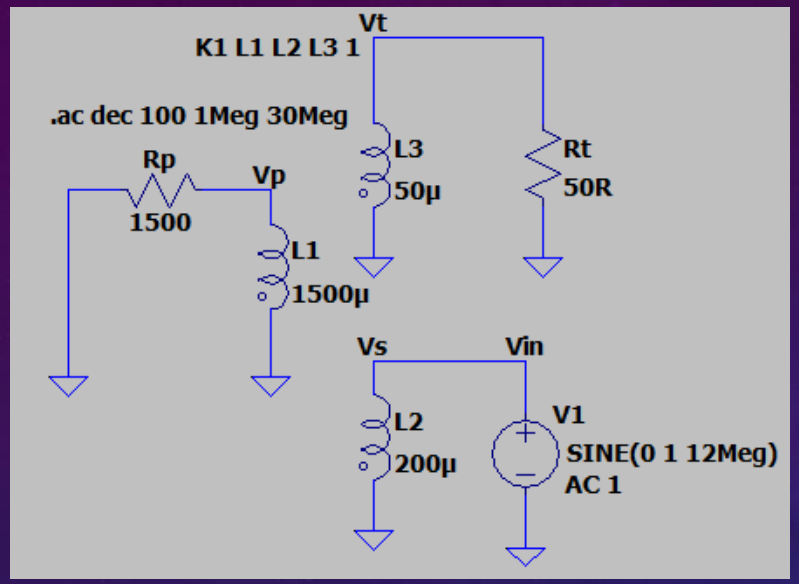


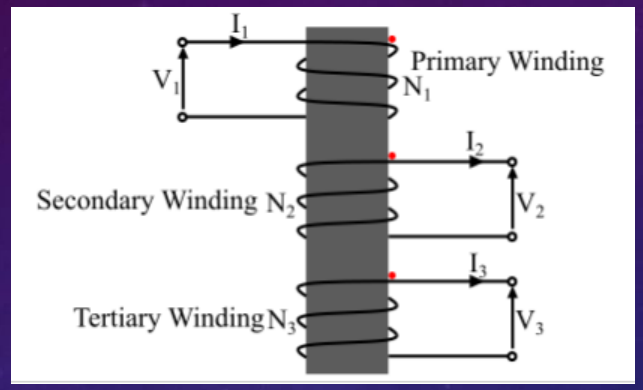


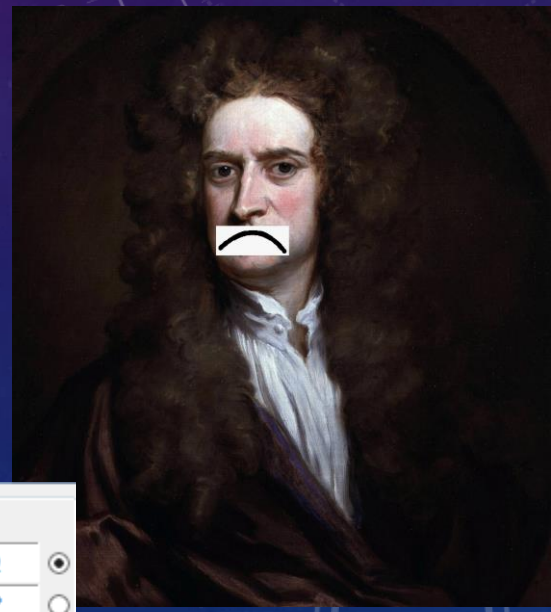


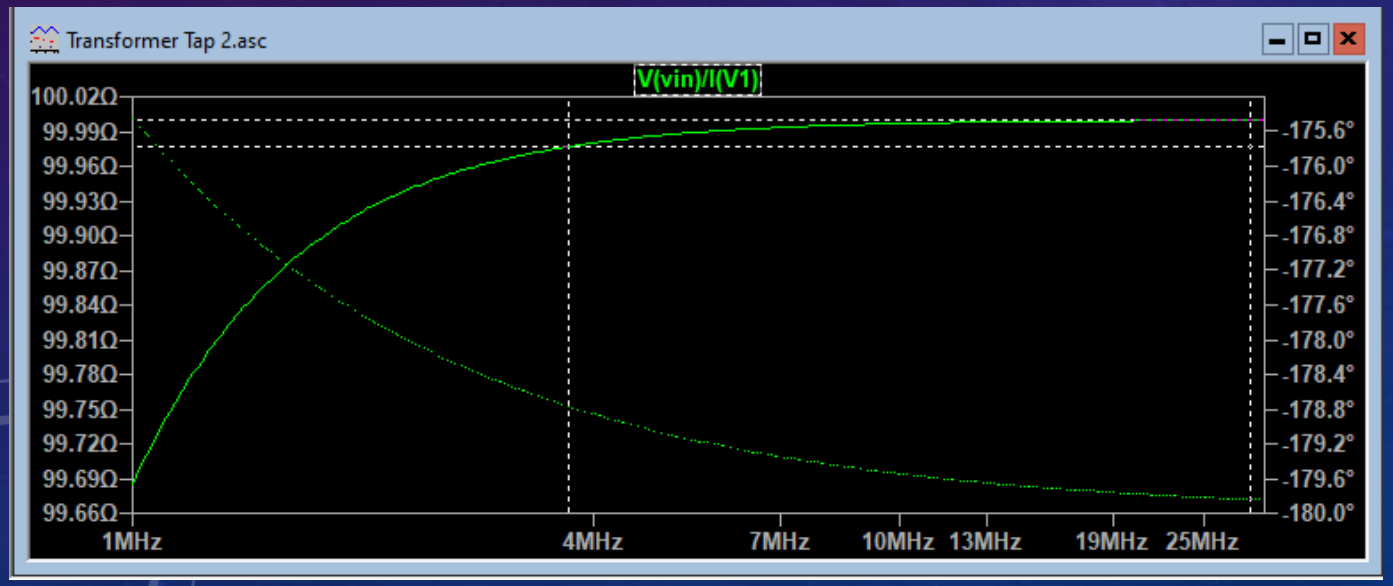
ADDING 50R TAP

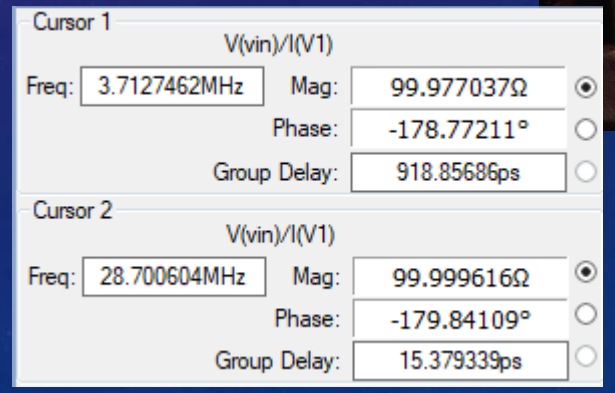
COMPLEX Physics: Impedance Transformation





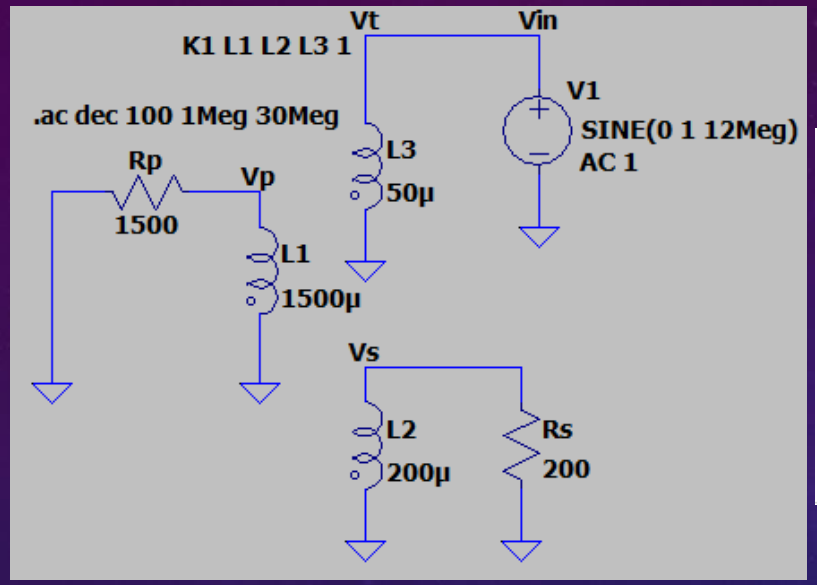


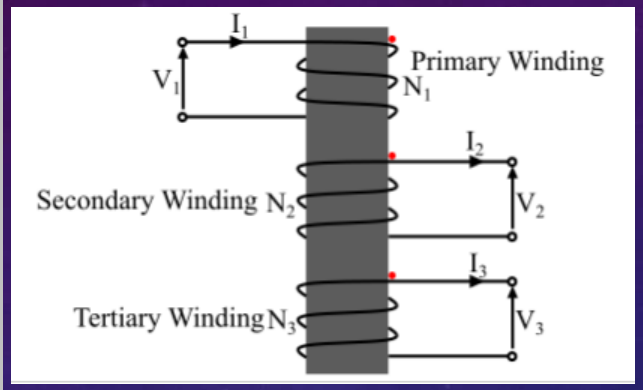


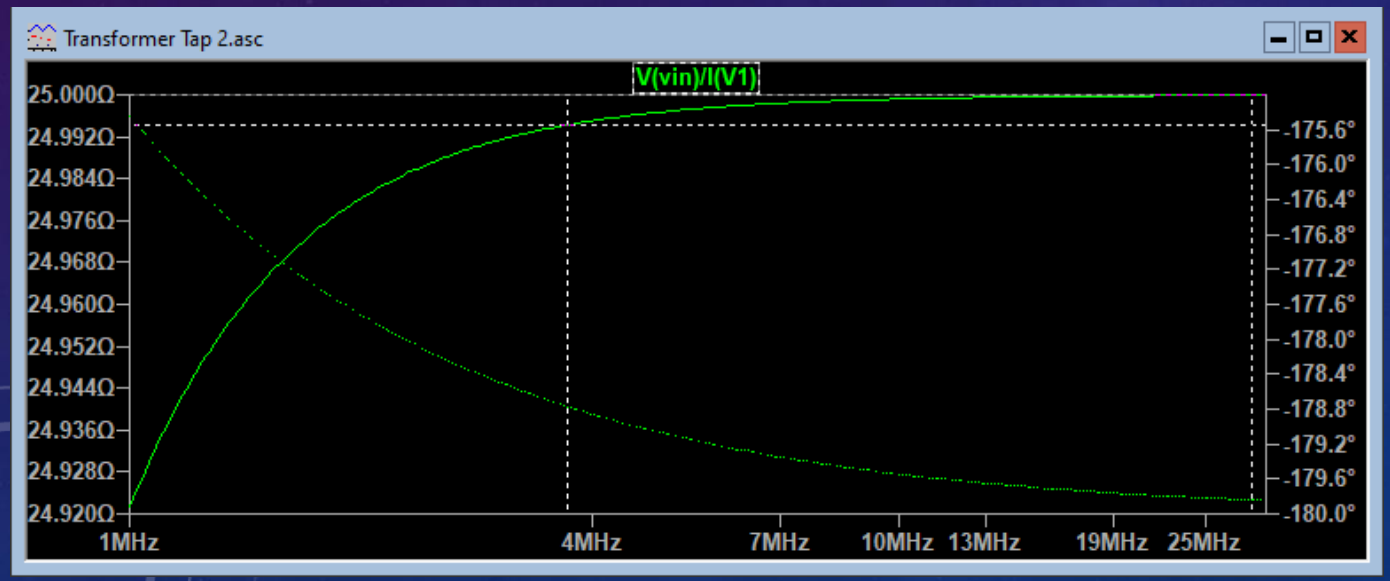


ADDING 50R TAP

COMPLEX Physics: Impedance Transformation



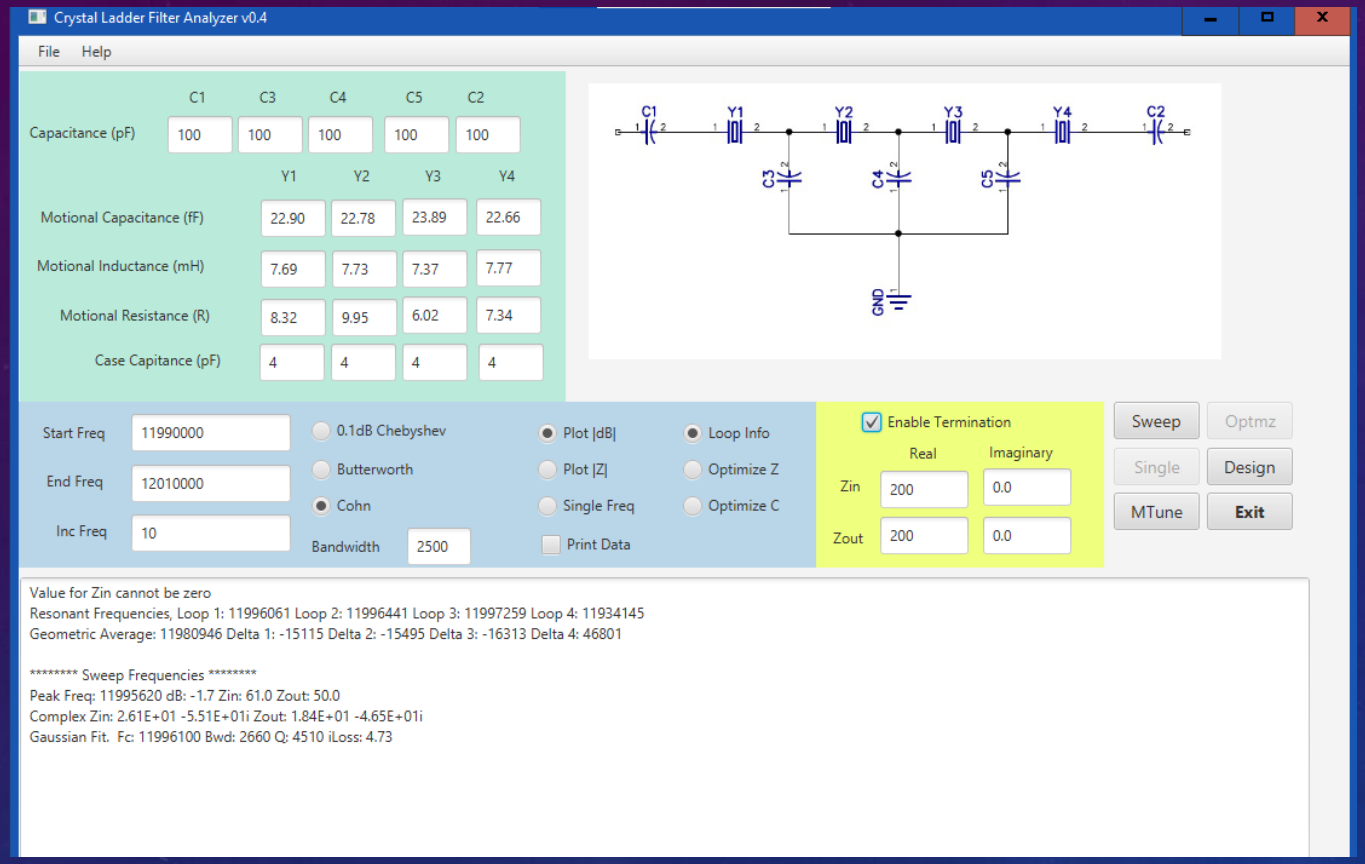




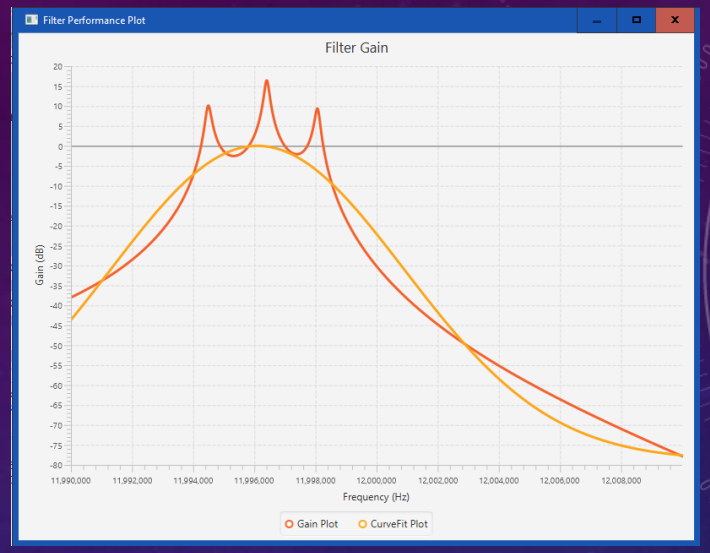
Cursor 1	V(vin)/I(V1)		
Freq:	3.7096448MHz	Mag:	24.994249Ω
		Phase:	-178.77106°
		Group Delay:	920.38721ps

Cursor 2	V(vin)/I(V1)		
Freq:	28.693325MHz	Mag:	24.999904Ω
		Phase:	-179.84105°
		Group Delay:	15.387025ps

CRYSTAL FILTER Q VS LOADING

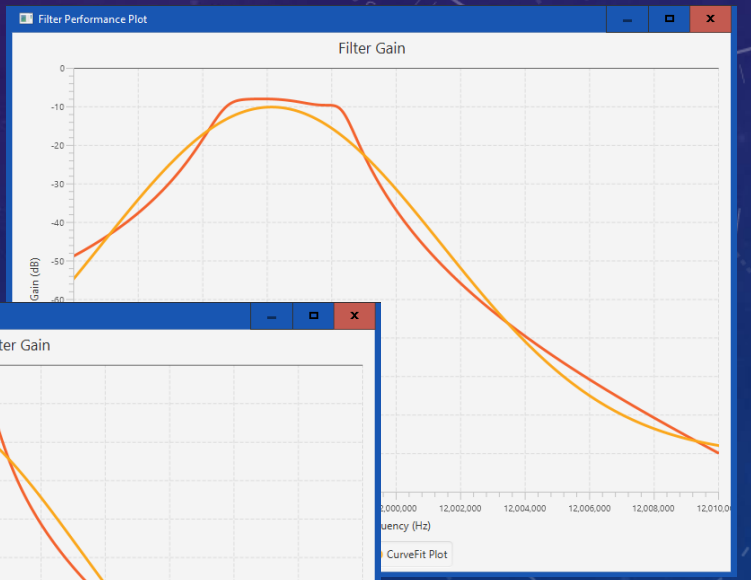


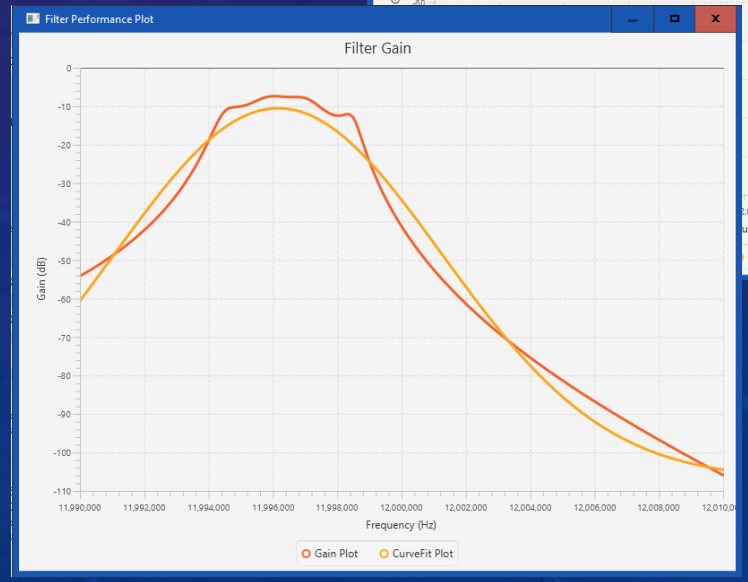
Filter Analysis Java Program written in circa 2018
Used to fine tune Crystal Filter used in D612 Transceiver



Unterminated

200R Terminated

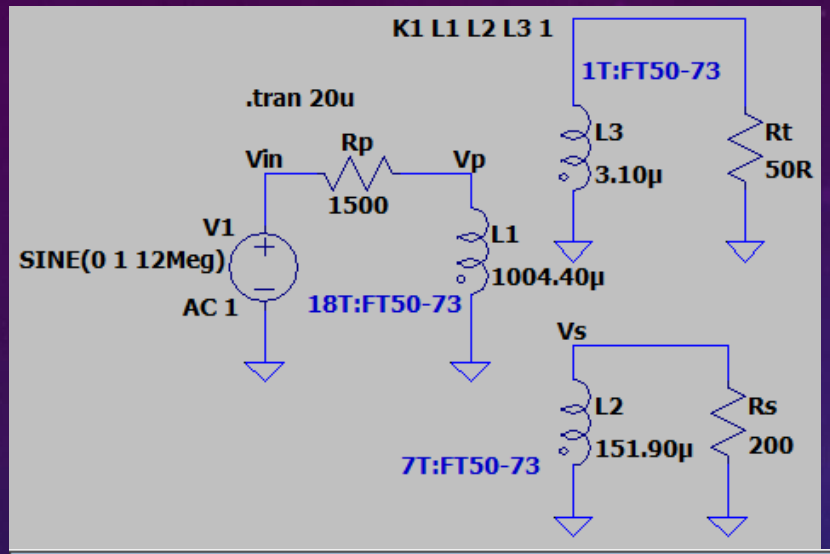


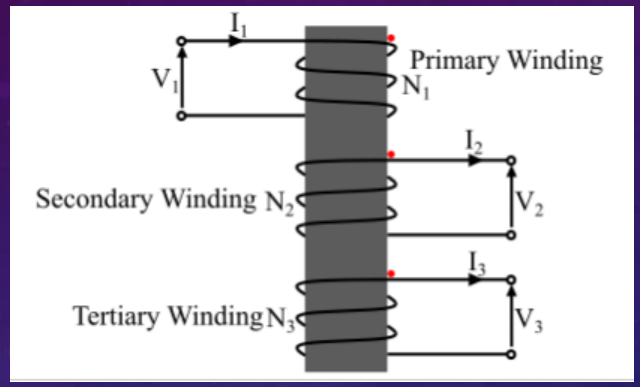


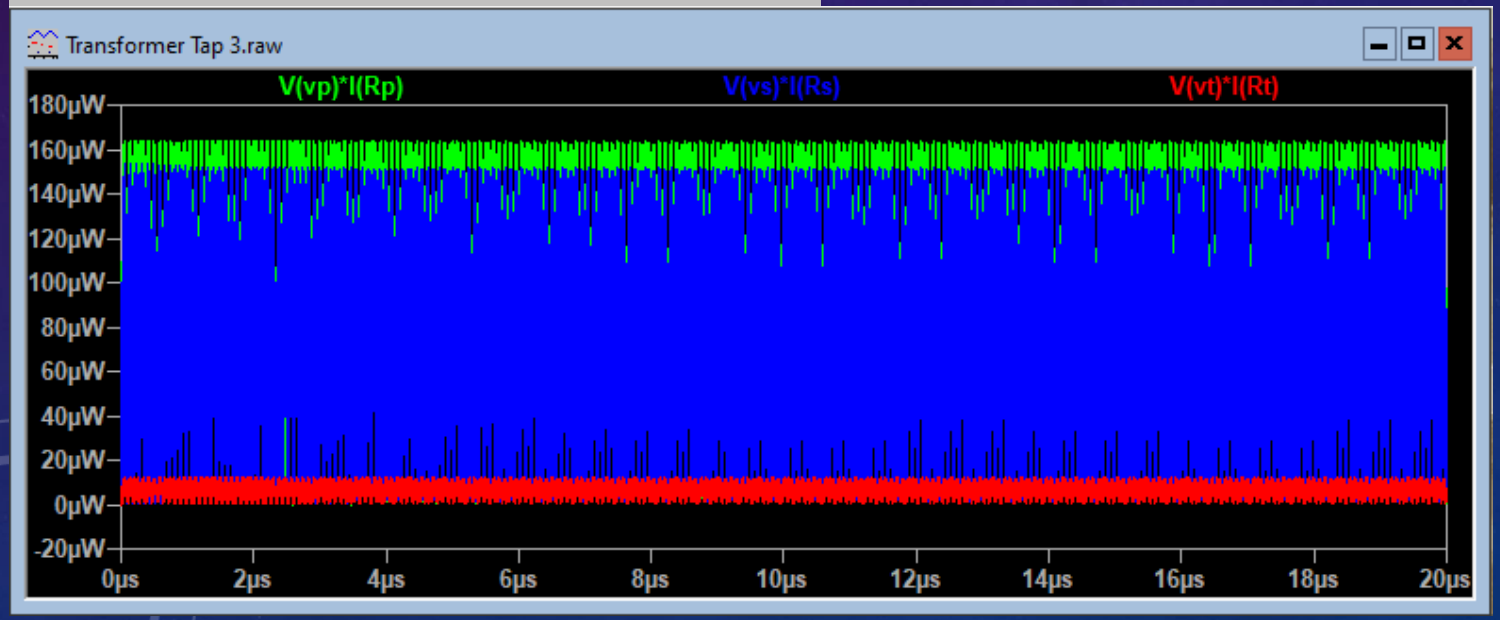
100R Terminated

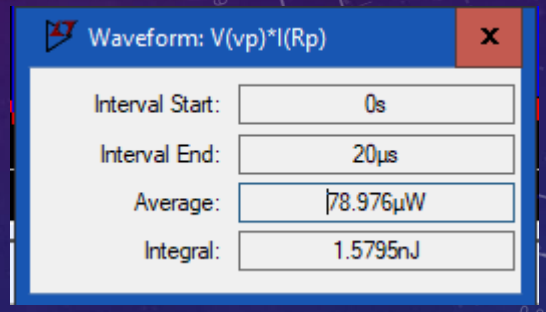
ADDING 1 TURN TAP

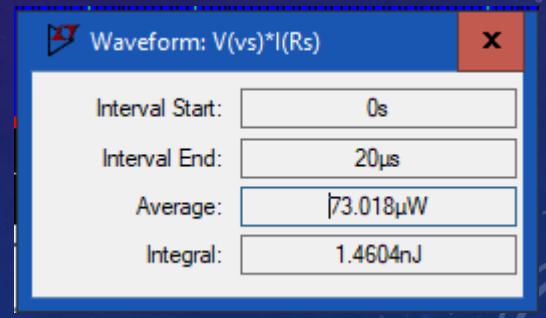
COMPLEX Physics: Power Transfer – 1st Law of Thermodynamics

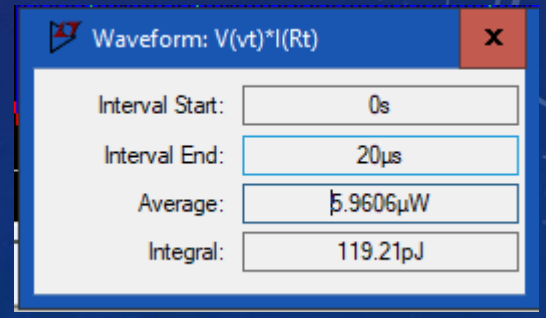






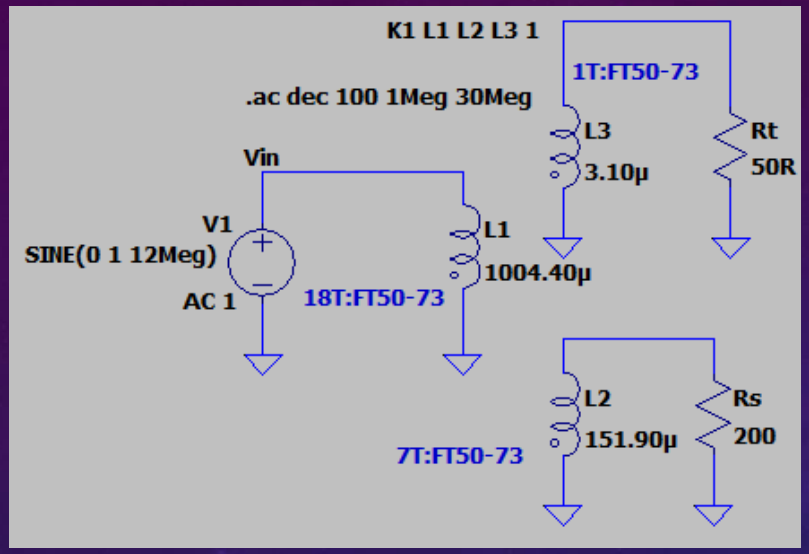


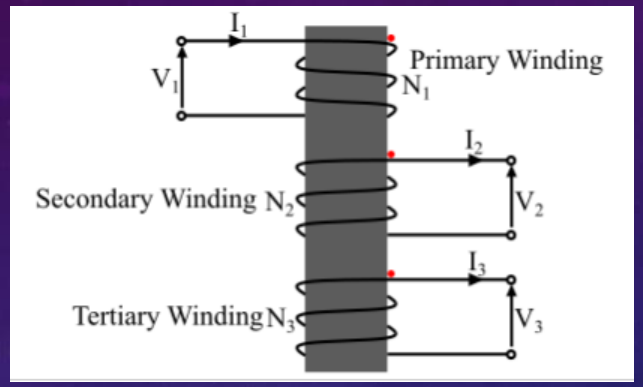


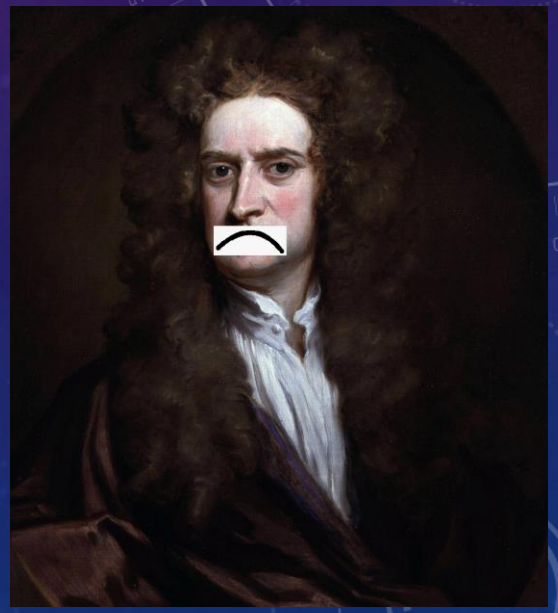


ADDING 1 TURN TAP

COMPLEX Physics: Impedance Transformation







Cursor 1 V(vin)/I(V1)		Cursor 2 V(vin)/I(V1)	
Freq: 3.7048419MHz	Mag: 1.220973KΩ	Freq: 28.702669MHz	Mag: 1.2226137KΩ
	Phase: -177.00639°		Phase: -179.61322°
	Group Delay: 2.2414249ns		Group Delay: 37.441139ps

Cursor 1 V(vin)/I(V1)		Cursor 2 V(vin)/I(V1)	
Freq: 3.7048419MHz	Mag: 207.27004Ω	Freq: 28.702669MHz	Mag: 207.62115Ω
	Phase: -176.63933°		Phase: -179.5657°
	Group Delay: 2.5150633ns		Group Delay: 42.041823ps

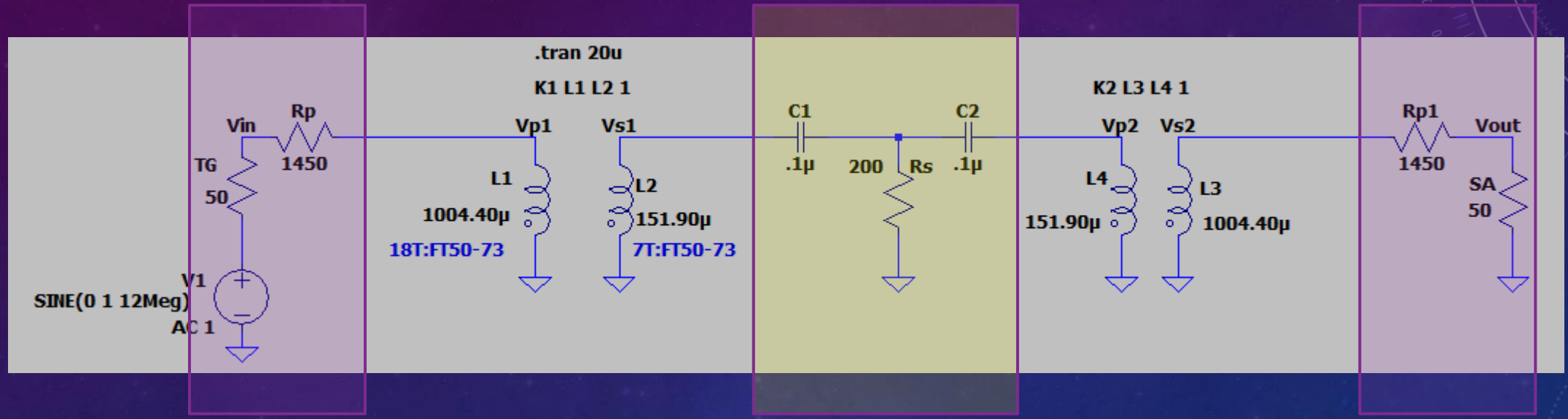
Cursor 1 V(vin)/I(V1)		Cursor 2 V(vin)/I(V1)	
Freq: 3.7048419MHz	Mag: 2.1682178Ω	Freq: 28.702669MHz	Mag: 2.1691811Ω
	Phase: -178.27811°		Phase: -179.77765°
	Group Delay: 1.2908131ns		Group Delay: 21.521953ps

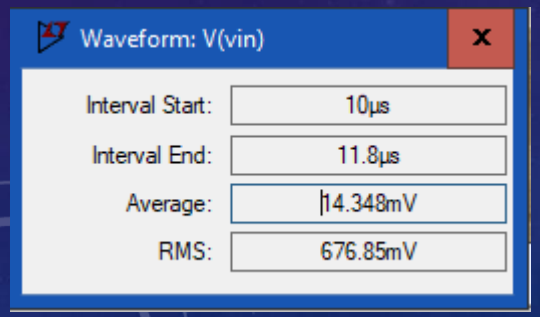
Small impact on Mixer and Crystal Filter

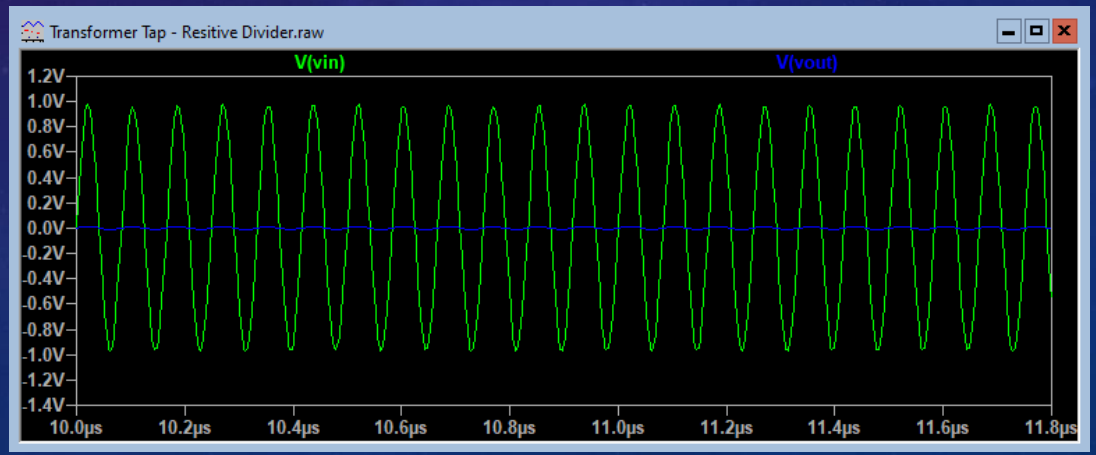
SA or TG seeing 2R (Short Circuit!)

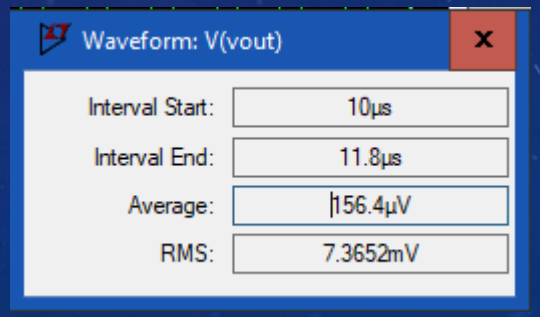
SUGGESTION

- ✓ Best Approach: Best to use a 50R:1500R transformer or a 50R:200R transformer
- ✓ Quick and Dirty Approach: Maybe use resistive voltage divider to your advantage. Frequency independent.









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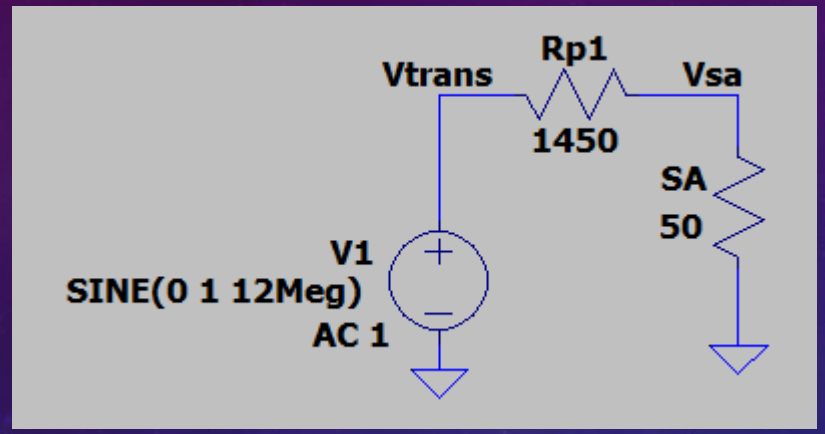

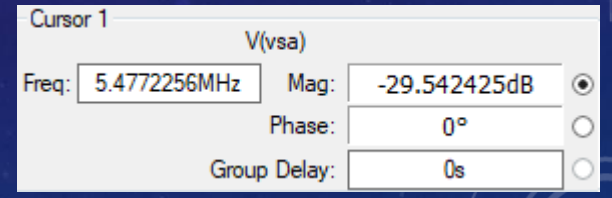

Act like a 29dB attenuator to SA


Fin