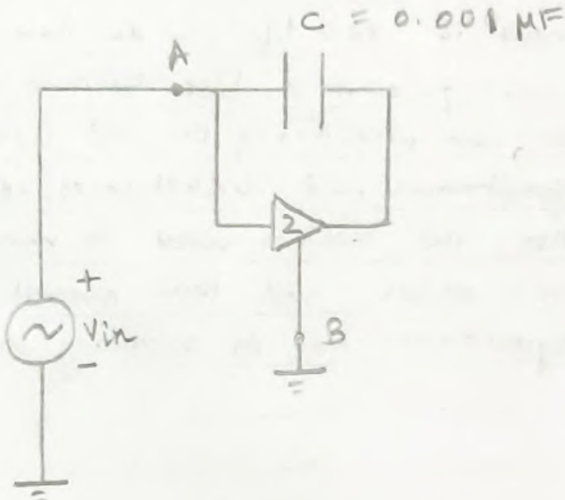
Kaushal Bauthia 19CS10039

Experiment 5

Negative Impedence Converter. (C to −C)



AB → Terminals of negative Impedence capacitor

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for capacitance $(C) = 0.001\ \mu F$,

Observation Table :

Frequency (f) (in Hz)	Applied Voltage Magnitude (in V) (Amplitude)	Current Magnitude (in A) (Amplitude)	Phase of current w.r.t voltage (in degree)	Calculated Complex Impedence in (Ω)
100	1	6.28×10^{-7}	90° Lagging	$1.592 \times 10^{6} \angle 90^\circ$
200	1	1.25×10^{-6}	90° Lagging	$8 \times 10^{5} \angle 90^\circ$
300	1	1.88×10^{-6}	90° Lagging	$5.319 \times 10^{5} \angle 90^\circ$
500	1	3.13×10^{-6}	90° Lagging	$3.195 \times 10^{5} \angle 90^\circ$
1000	1	6.19×10^{-6}	90° Lagging	$1.616 \times 10^{5} \angle 90^\circ$
2000	1	12.32×10^{-6}	90° Lagging	$8.117 \times 10^{4} \angle 90^\circ$
4000	1	25.05×10^{-6}	90° Lagging	$3.992 \times 10^{4} \angle 90^\circ$
5000	1	31.29×10^{-6}	90° Lagging	$3.196 \times 10^{4} \angle 90^\circ$
7000	1	43.96×10^{-6}	90° Lagging	$2.275 \times 10^{4} \angle 90^\circ$
9000	1	56.53×10^{-6}	90° Lagging	$1.769 \times 10^{4} \angle 90^\circ$
10000	1	62.82×10^{-6}	90° Lagging	$1.592 \times 10^{4} \angle 90^\circ$

When we use this negative impedence circuit, to convert a capacitor to its negative ~~f~~ part, we get the formula of $X_C = \frac{-1}{j\omega C} = \frac{j}{\omega C}$.

Now for inductors, $X_L = jL\omega$.

When we equating X_L and X_C, we get $jL\omega = \frac{j}{\omega C} \Rightarrow \omega = \frac{1}{\sqrt{LC}}$

Thus, even though, their phases are same, a negative cannot mimic an inductor for all the values of the frequencies. It can act as an inductor for only $\omega = \frac{1}{\sqrt{LC}}$. Thus, we cannot create an inductor using a capacitor (or vice-versa) using this negative impedence converter. For that, we need to use a gyrator

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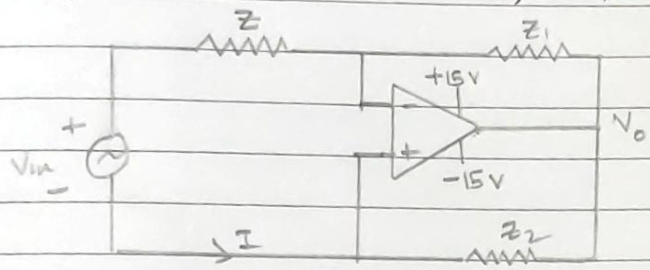
But, if we use the ~~new~~ circuit, as shown in the manual, ie,



Then $V_o = V_{in}\left(1+\frac{Z_1}{Z_2}\right) \Rightarrow V_{in} - V_o = -V_{in}\left(\frac{Z_1}{Z_2}\right)$ — ①

Also, $\Rightarrow V_{in} - V_o = I Z$ — ② (Since Op Amps takes 0 input current)
(So voltage drop across Z_1 is 0)

Now $Z_{input} = \frac{V_{in}}{I}$ — ③

Dividing ① and ②

$\Rightarrow 1 = \frac{-V_{in}\left(\frac{Z_1}{Z_2}\right)}{I Z}$

$\Rightarrow \frac{V_{in}}{I} = \frac{-Z}{\left(\frac{Z_1}{Z_2}\right)}$

From ③ $\Rightarrow Z_{input} = -Z\left(\frac{Z_2}{Z_1}\right)$

Now we usually take $Z_1 = Z_2$ to get negative impedence $(-Z)$
But now we can make Z and Z_2 as resistors and Z_1 as our capacitor. $\Rightarrow Z_{input} = \frac{-R \cdot R}{\left(\frac{1}{j\omega C}\right)} = -R^2 j\omega C = +\frac{R^2 \omega C}{j}$

Now, we feed this Z_{input} to a normal negative impedence converter and get $Z_{final} = -Z_{input} = -\frac{R^2 \omega C}{j} = j(R^2 \omega C)$

If we take $R^2 C = L$, then we get, $Z_{final} = j(L\omega)$
which is the expression for an inductor.

So its possible to convert a capacitor to an inductor.

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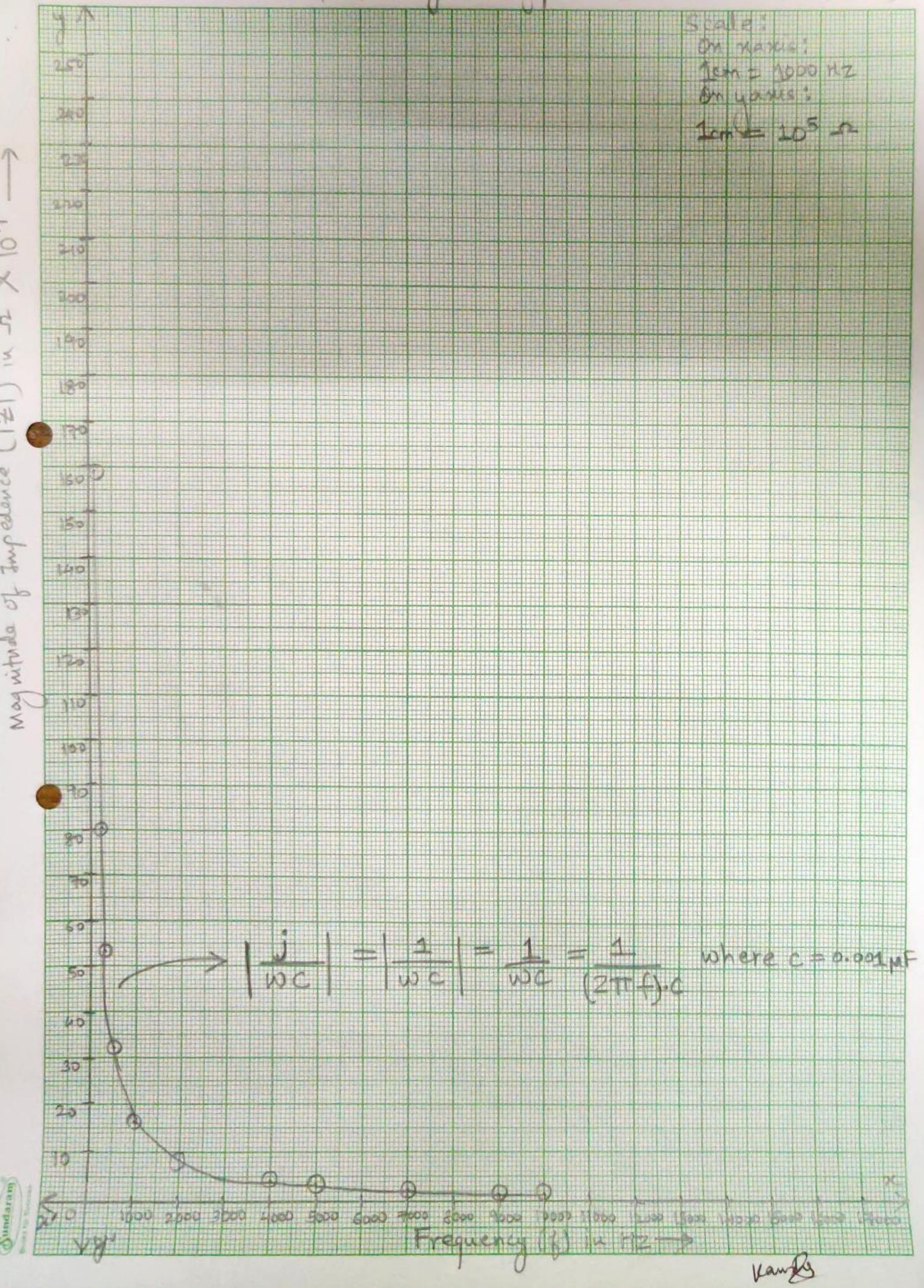
|Z| vs f for Negative Impedence Converter (c to −c)



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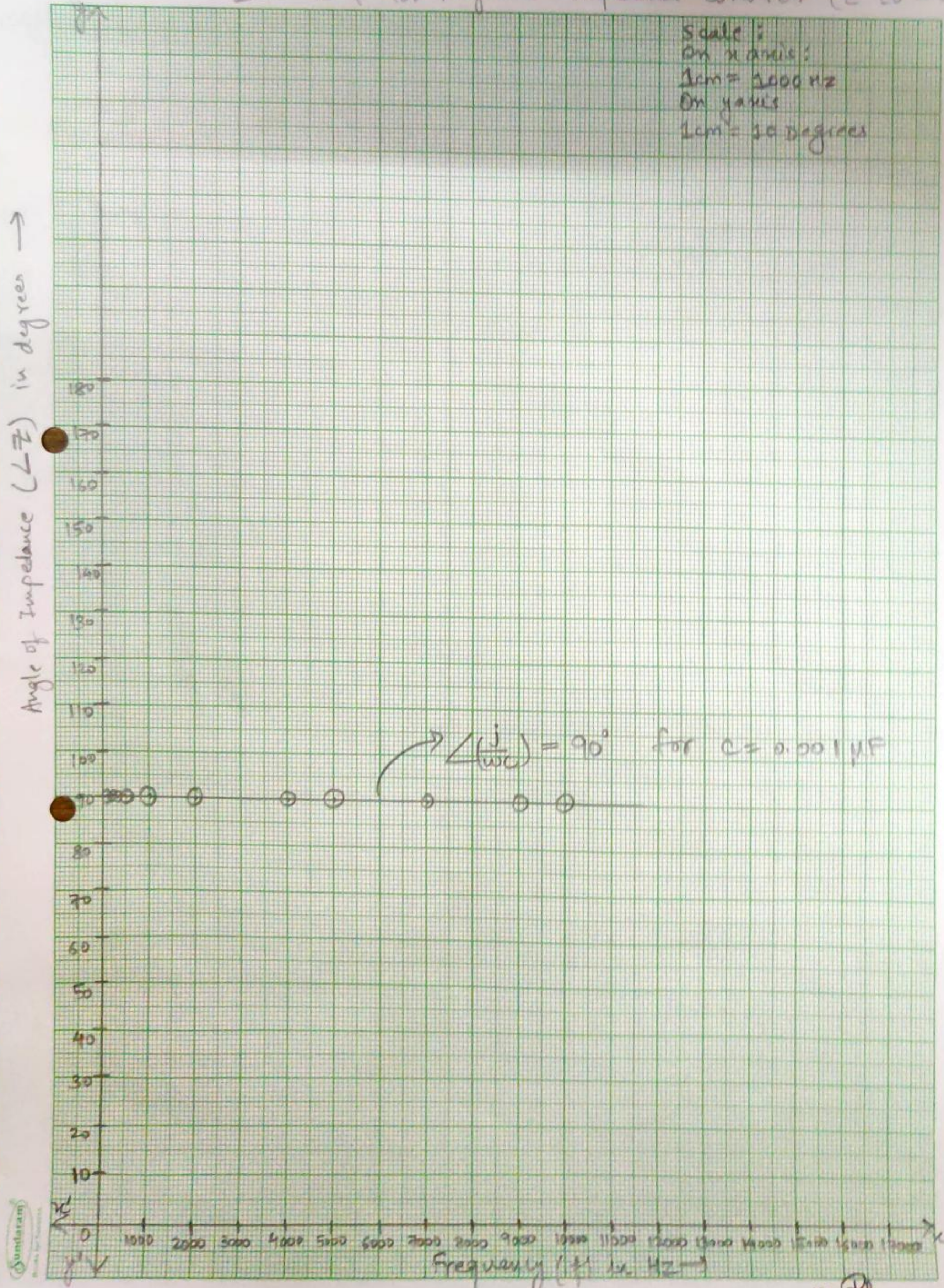
∠Z vs f for Negative Impedence Converter (C to −C)



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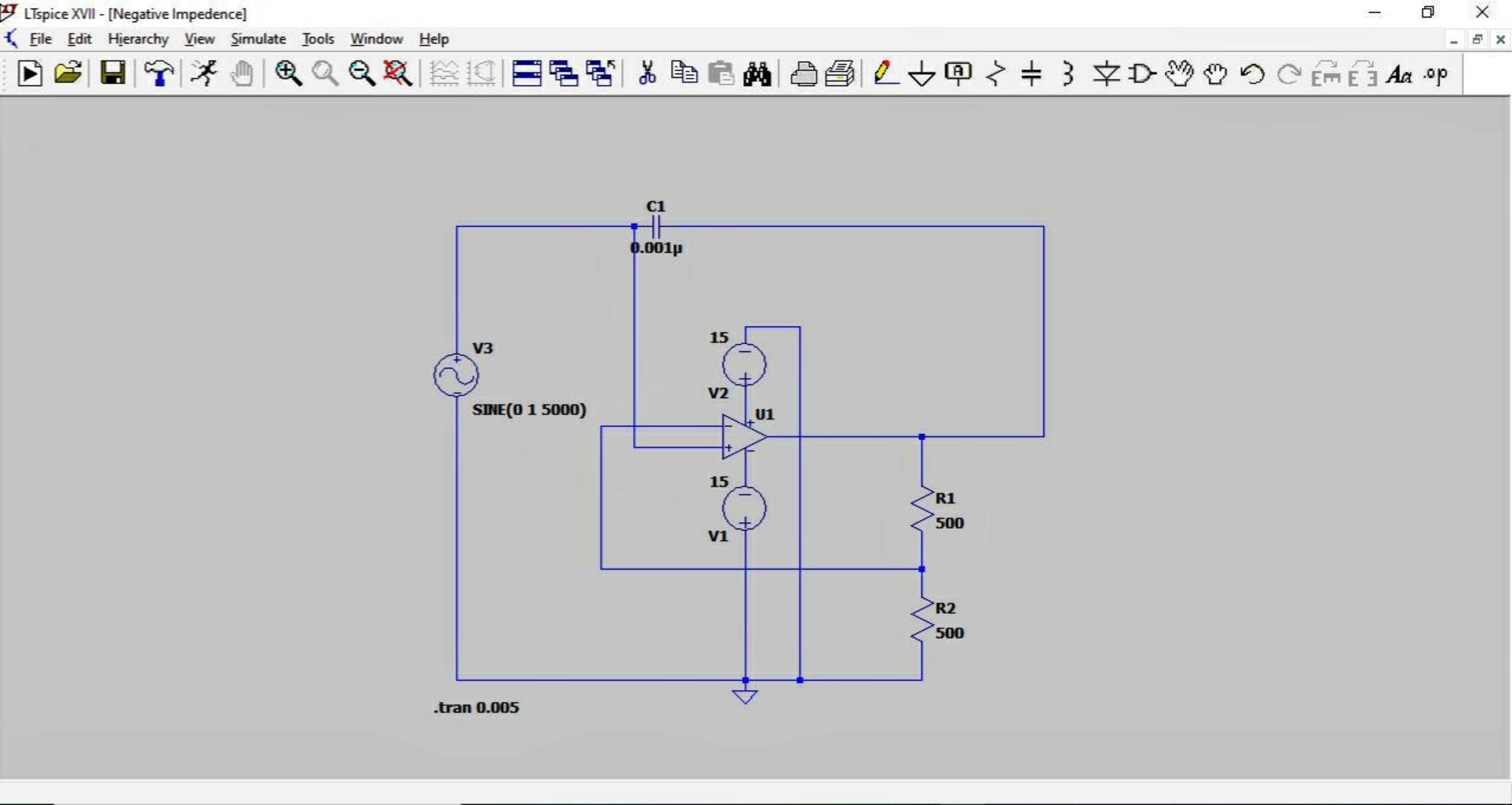
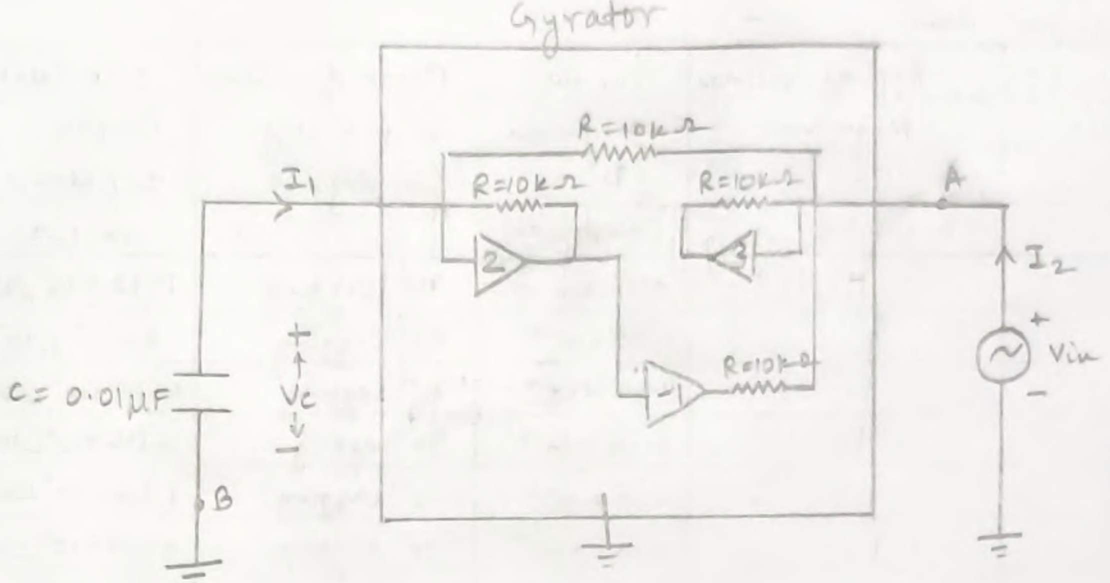

LTspice XVII - [Negative Impedence]
File Edit Hierarchy View Simulate Tools Window Help
C1
0.001µ
V3
SINE(0 1 5000)
15
V2
U1
15
V1
R1
500
R2
500
.tran 0.005

Gyrator, (Capacitance to Inductance)



AB → Terminals of the constructed Inductor.

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From the two-port network representation of the gyrator, we have the following equations,

$V_C = -R I_2$ —① and $V_{in} = R I_1$ —② (where R is value of the resistances used in the gyrator)
(NOTE: R is not the value of the resistances used in the Op-Amps)

Now, in Laplace Domain, we replace c by $1/(cs)$ and consider it as an impedence.

$\therefore V_c = (-I_1)\left(\frac{1}{cs}\right)$ —③

Now, we calculate the Impedence for the "Gyrator + Capacitor" part.

$\Rightarrow Z = \frac{V_{in}}{I_2}$

$Z = \frac{R I_1}{I_2}$ (from ②)

$Z = \frac{R I_1}{\left(-\frac{V_c}{R}\right)}$ (from ①)

$Z = \frac{-R^2 I_1}{V_c}$

$Z = -\frac{R^2 I_1}{(-I_1)\left(\frac{1}{cs}\right)}$ (from ③)

$Z = R^2 cs$

If we substitute R^2c by L, then we have
$Z = Ls$ (where $L = R^2c$) (This is the Laplace domain impedence of an inductor)

Thus, we get an effective inductor, with Inductance $(L) = R^2c$, by connecting a capacitor to a gyrator.

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For capacitance (C) = 0.01 μF and $R = 10 k\Omega$ ($\therefore L = 1 H$)

Observation Table: ($\because L = R^2 C$)

Frequency (f) (in Hz)	Applied Voltage Magnitude (in V) (Amplitude)	Current Magnitude (in A) (Amplitude)	Phase of current w.r.t. voltage (in degree)	Calculated complex Impedence (in Ω)
300	1	522.86×10^{-6}	90° Lagging	$1912.56 \angle 90°$
500	1	312.93×10^{-6}	90° Lagging	$3195.60 \angle 90°$
1000	1	158.76×10^{-6}	90° Lagging	$6298.82 \angle 90°$
2000	1	79.40×10^{-6}	90° Lagging	$12594.46 \angle 90°$
4000	1	39.57×10^{-6}	90° Lagging	$25271.67 \angle 90°$
5000	1	31.57×10^{-6}	90° Lagging	$31675.64 \angle 90°$
7000	1	22.39×10^{-6}	90° Lagging	$44662.80 \angle 90°$
9000	1	17.22×10^{-6}	90° Lagging	$58072.01 \angle 90°$
10000	1	15.43×10^{-6}	90° Lagging	$64808.81 \angle 90°$

NOTE: Here, the amplitude = $\frac{(I_{max} - I_{min})}{2}$. Also, the frequency is taken from 300 Hz, instead of 100 Hz, since from 100 Hz to around 250 Hz, the Output current is not sinusoidal.

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|Z| vs f for Gyrator (capacitor to inductor)

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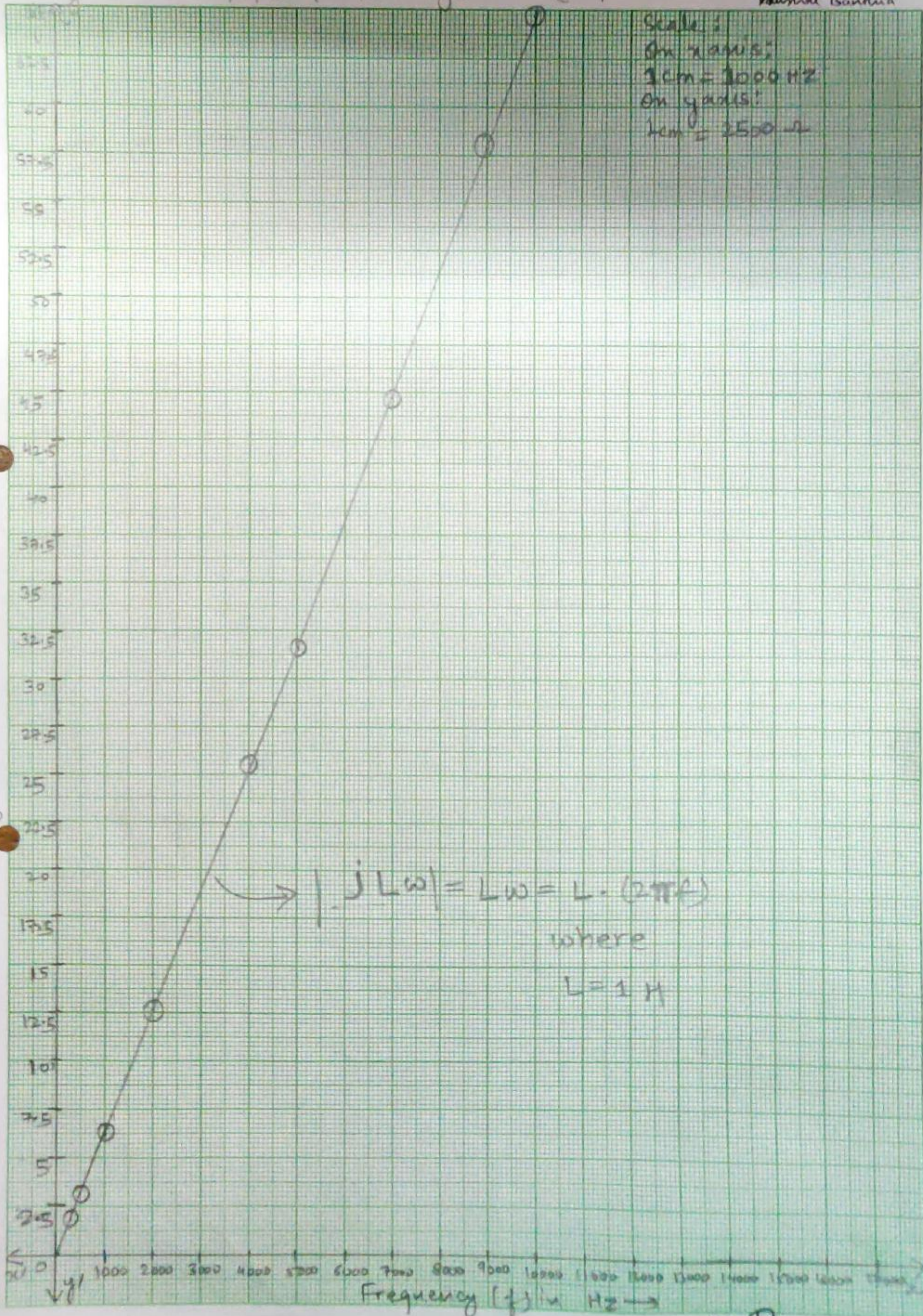

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∠Z vs f for Gyrator (capacitor to inductor)

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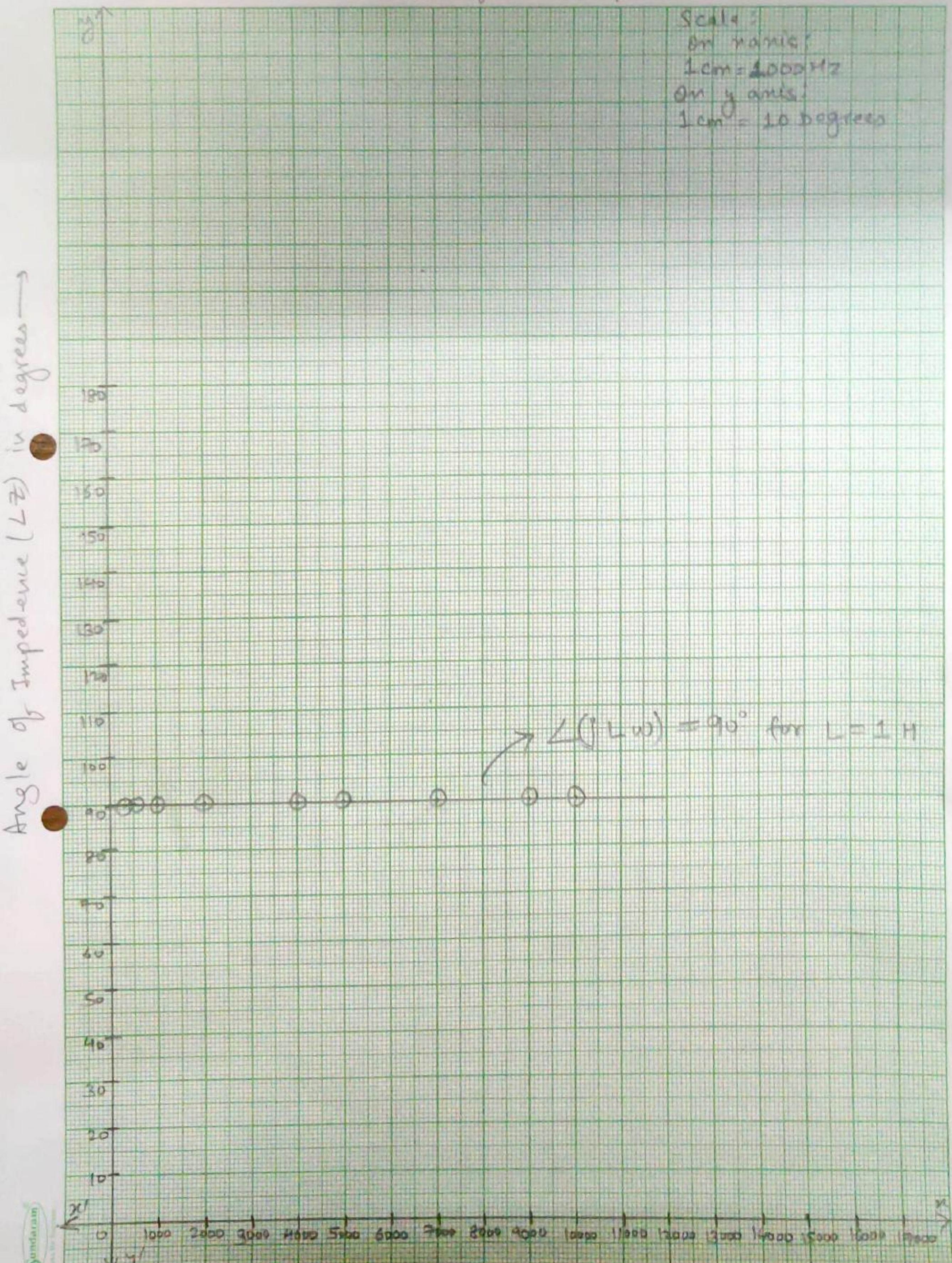

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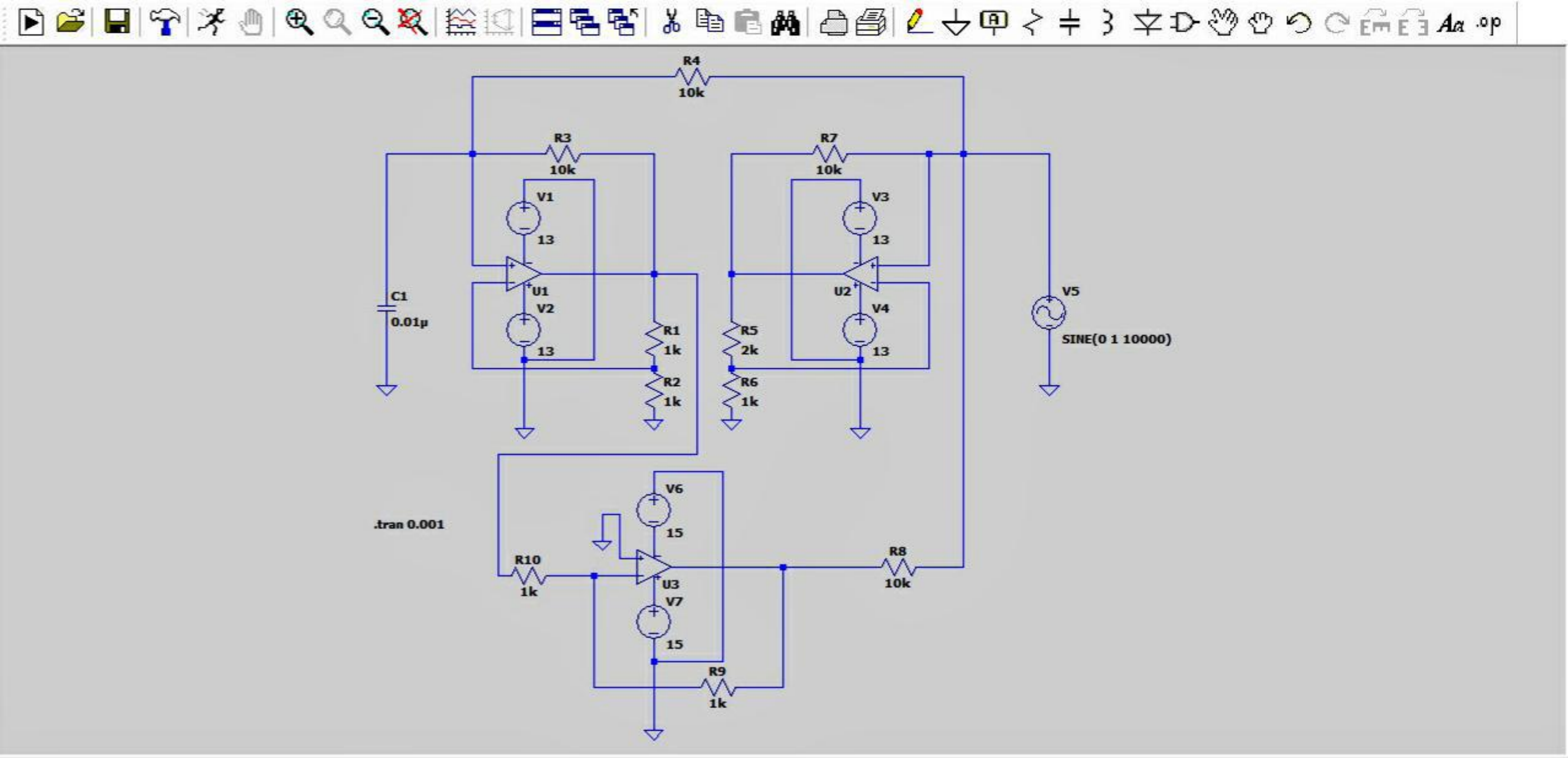
R4
10k
R3
10k
R7
10k
V1
13
V3
13
U1
U2
C1
0.01µ
V2
13
V4
13
V5
SINE(0 1 10000)
R1
1k
R5
2k
R2
1k
R6
1k
V6
15
.tran 0.001
R10
1k
U3
V7
15
R8
10k
R9
1k