ELECTRONIC WORKSHOP 2

AUDIO AMPLIFIER

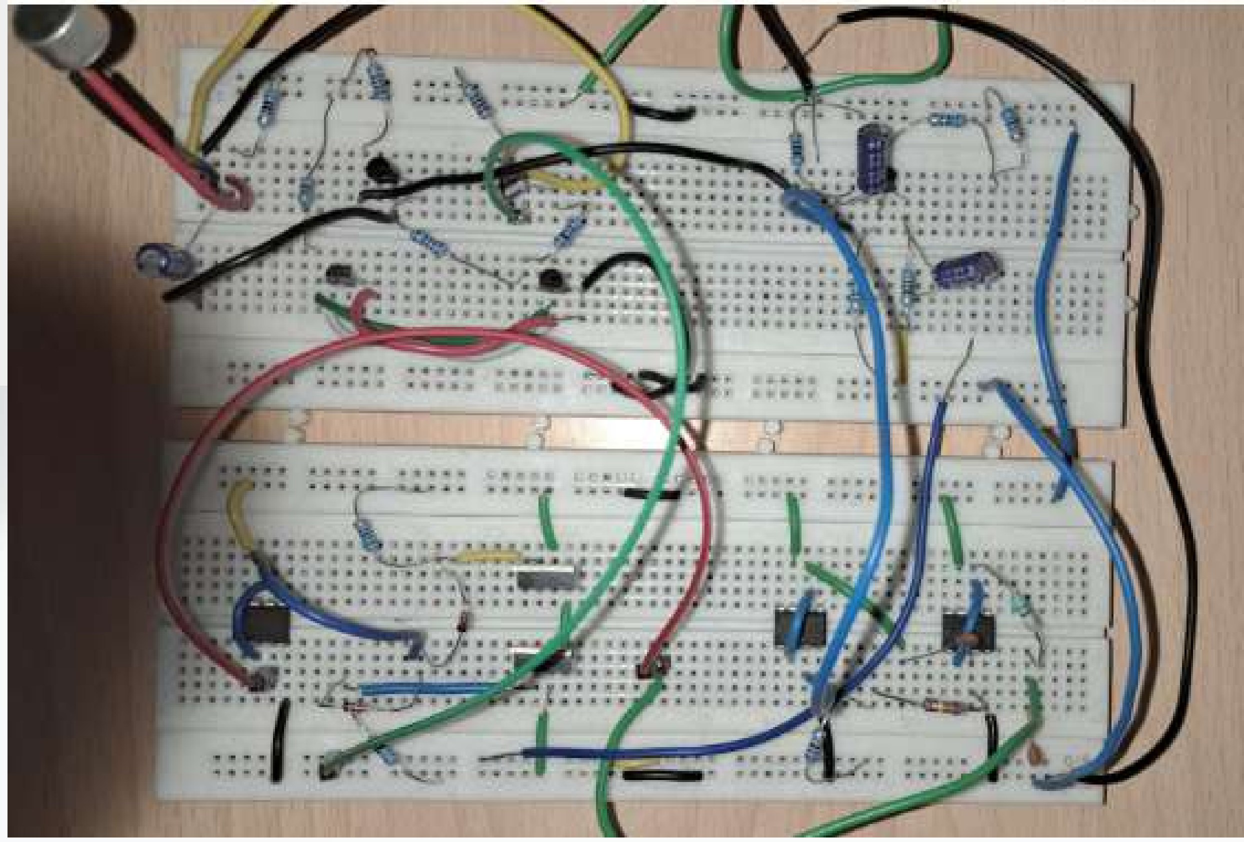
PRIYA MANDOT(2022102053), SAMKIT JAIN(2022102062)

CONTENT

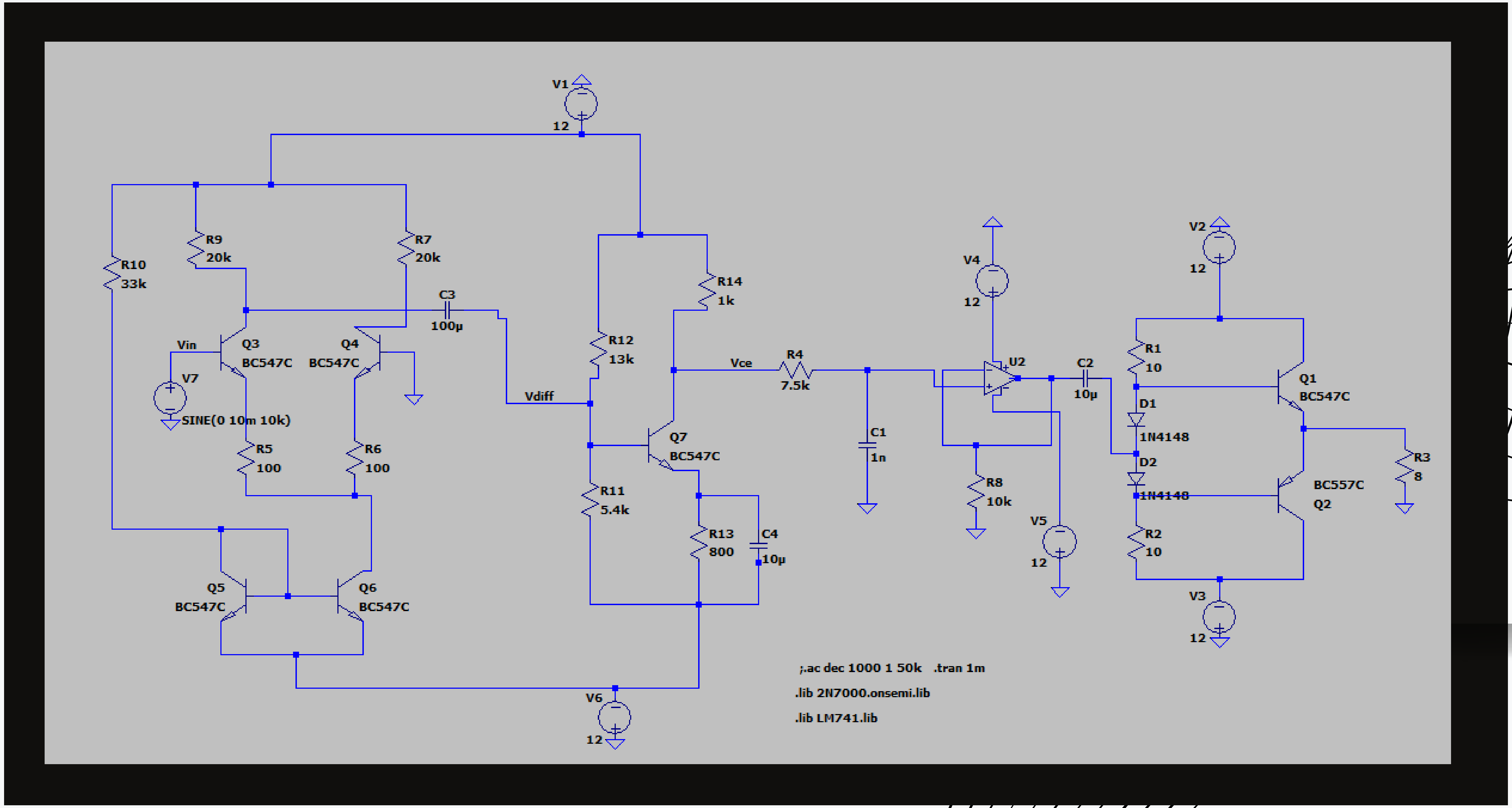
INTRODUCTION

An essential component in audio systems, the Audio Amplifier serves as an analog circuit primarily tasked with amplifying audio signals. Its primary function is to boost the power of an audio signal, typically sourced from a microphone, to a level suitable for playback through a speaker.

Breadboard



FULL CIRCUIT SIMULATION



STAGES

1) Pre Amplifier

Focuses on amplifying the amplitude (voltage) of the input from the mic. It involves cascading multiple voltage amplifiers to achieve the necessary gain.

2) Filter

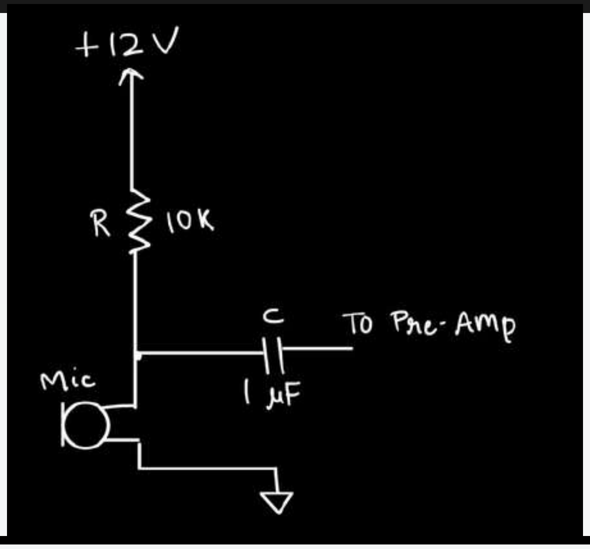
Plays a crucial role in removing frequencies outside the desired range (20 Hz- 20000 Hz).

3) Power Amplifier

Increasing the current directed to the output load, ensuring that the appropriate power is delivered to the speaker.

MICROPHONE

Circuit



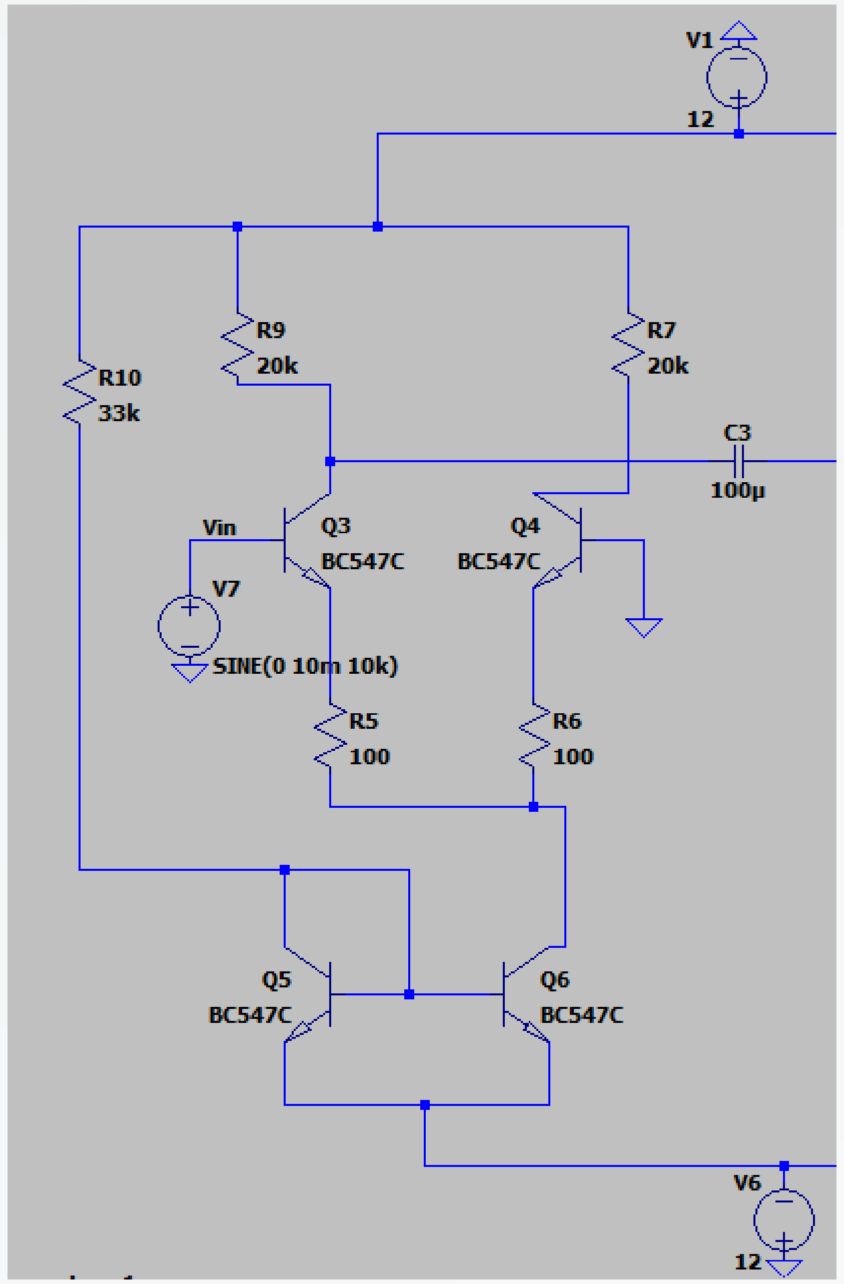
- A microphone is an essential input device used to convert sound waves into electric signals for various applications, such as inputting audio into computers. It captures sound by transforming sound waves into electrical signals, which can be either digital or analog.

- Here the resistor is used to limit current and the capacitor is responsible for amplifier gain which you can connect with this circuit to amplify the signals. The capacitor also blocks any DC signal, allowing a small AC input to flow to the circuit.

Breadboard

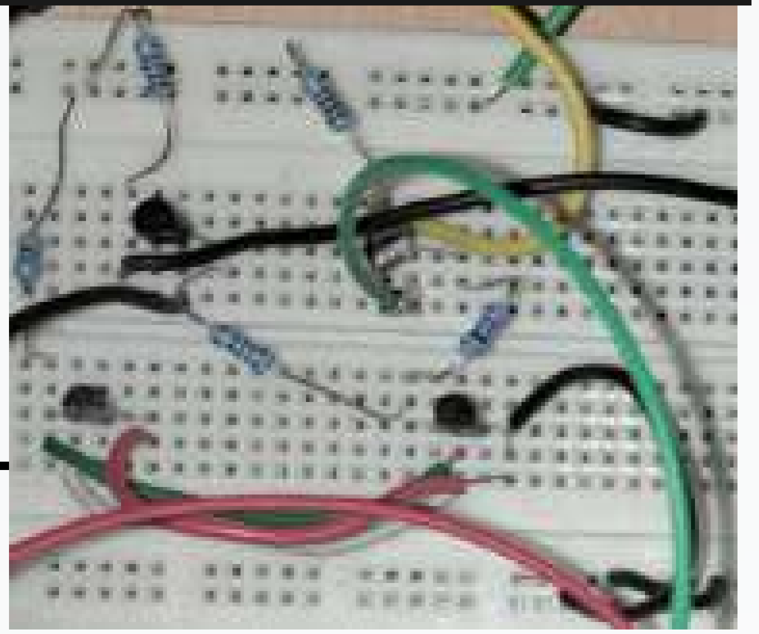
PRE AMP 1: DIFFERENTIAL AMPIFIER

Circuit



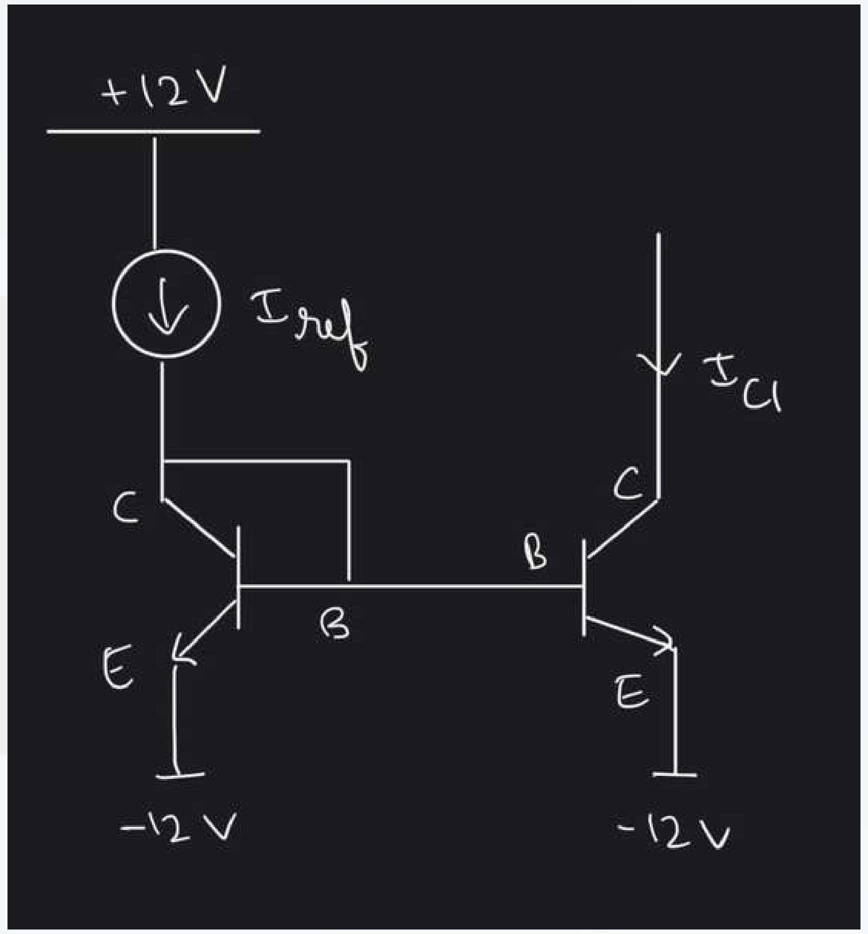
- Differential amplifier consists of two transistors with same emitter and collector currents.
- Designed to cancel out common-mode voltage, providing difference as output.
- Grounding one transistor's base/gate while applying input to the other removes common noise, amplifying input signal.
- Emitter/source ideally connected to constant current source for pull-down load.
- Current mirror used to create adjustable current source for pull-down load.
- Capacitor at output reduces DC offset.
- Resistors are added at the emitter of the Diff amp to increase the range of differential input.

Breadboard



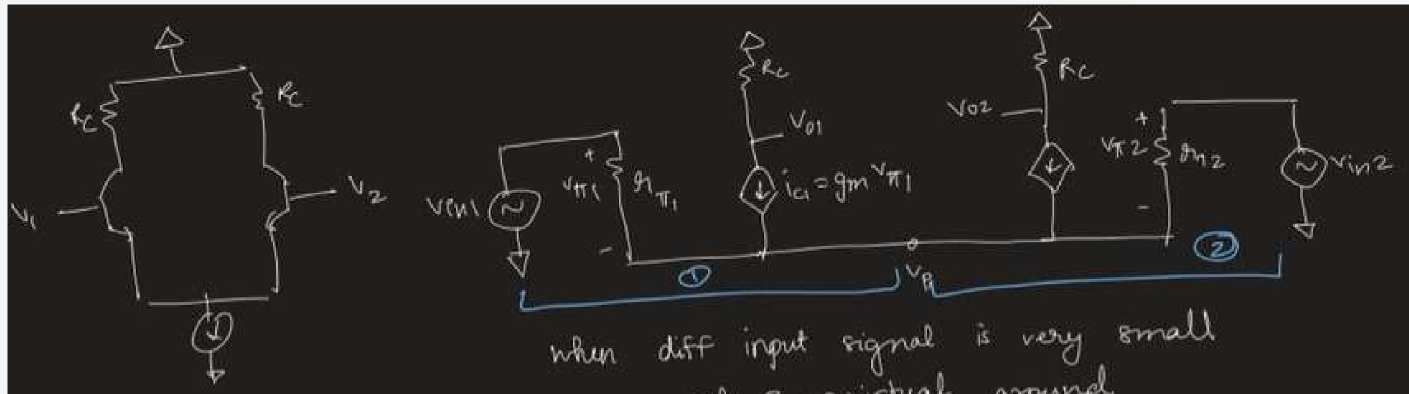
CURRENT MIRROR

Used to provide bias currents and active loads to circuits. It is used to model a more realistic current source (since ideal current sources do not exist) to provide a constant current at the emitters (Ie) of the BJT. As a result, Ie becomes independent of the base resistor and the current gain of the BJT.



Assuming negligible Ib: we get Ic approximately equal to Iref and thus Iref/2 applied at the emitters of the Diff amp

ANALYSIS- SMALL SIGNAL



when diff input signal is very small
node P → virtual ground

Proof

KVL 1

$v_{in1} - v_{\pi1} = V_P$

KVL 2

$v_{in2} - v_{\pi2} = V_P$

$V_{id} = V_{in1} - V_{in2}$

$V_{id} = V_{\pi1} - V_{\pi2}$

Take $V_{in1} = \frac{V_{id}}{2}$

$V_{in2} = -\frac{V_{id}}{2}$

KCL P

$$g_{m1} v_{\pi1} + g_{m2} v_{\pi2} + \frac{v_{\pi1}}{r_{\pi1}} + \frac{v_{\pi2}}{r_{\pi2}} = 0$$

Assume transistors perfectly matched

$g_{m1} = g_{m2} = g_m$

$r_{\pi1} = r_{\pi2} = r_\pi$

$$(v_{\pi1} + v_{\pi2})\left(g_m + \frac{1}{r_\pi}\right) = 0$$

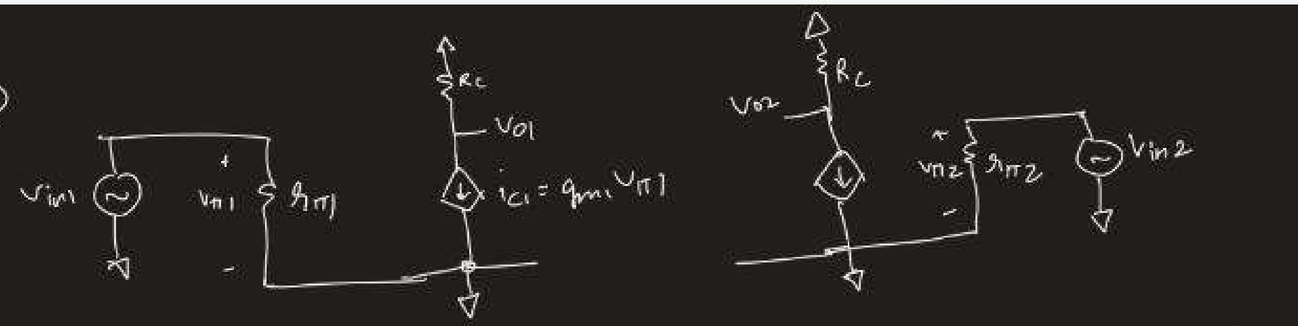
$v_{in1} = -v_{in2}$

$v_{\pi1} + v_{\pi2} = -2V_p$

$$(-2V_p)\left(g_m + \frac{1}{r_\pi}\right) = 0$$

$\Rightarrow V_p = 0$

$\Rightarrow$



Both circuits act as common emitter amplifiers

$V_{o1} = -g_m v_{\pi1} R_C$

$= -g_m \frac{V_{id}}{2} R_C$

$V_{in1} = V_{\pi1}$

$A_d = \frac{V_{o1}}{V_{i1}} = \frac{-g_m R_C}{2}$ (single ended output)

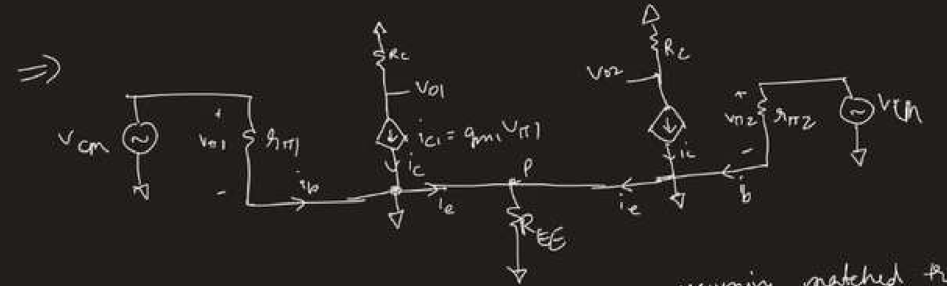
→ not utilising swing of other side

ANALYSIS- CMRR

Single ended output when there is a small change in V_{cm}

non-ideal current source $R_{EE} = R_{out}$

$\Rightarrow$



assuming matched transistors

$V_{cm} = V_{\pi 1} + V_p$

$i_e = i_b + i_c$

$= \frac{v_\pi}{r_\pi} + g_m v_\pi$

$V_p = 2 i_e R_{EE}$

$= 2R_{EE} v_\pi \left[g_m + \frac{1}{r_\pi}\right]$

$= 2R_{EE} v_\pi \left[g_m + \frac{g_m}{\beta}\right]$ $\beta >> g_m$

$V_p \approx 2R_{EE} v_\pi g_m$

$V_{cm} = v_\pi [2R_{EE} g_m + 1]$

$V_{o1} = -g_m v_\pi R_c$

$$\boxed{A_{cm} = \frac{V_{o1}}{V_{cm}} = \frac{-g_m R_c}{2R_{EE} g_m + 1} = \frac{-R_c}{\frac{1}{g_m} + R_{EE}}}$$

if $R_{EE} \to \infty$

$A_{cm} \to 0$

common mode gain

ΔV_{o1} & ΔV_{o2} change similarly (if matched transistors)

$$CMRR = \frac{A_d}{A_{cm}} = \frac{g_m R_c}{\frac{-R_c}{\cancel{\frac{1}{g_m}} + \cancel{R_{EE}}}} \to 0, \to \infty$$

$\Rightarrow CMRR \to \infty$

single ended output $A_d \to A_d/2$

CMRR ↓

↳ to inc an active load used with diff amp

↳ circuit made of active devices

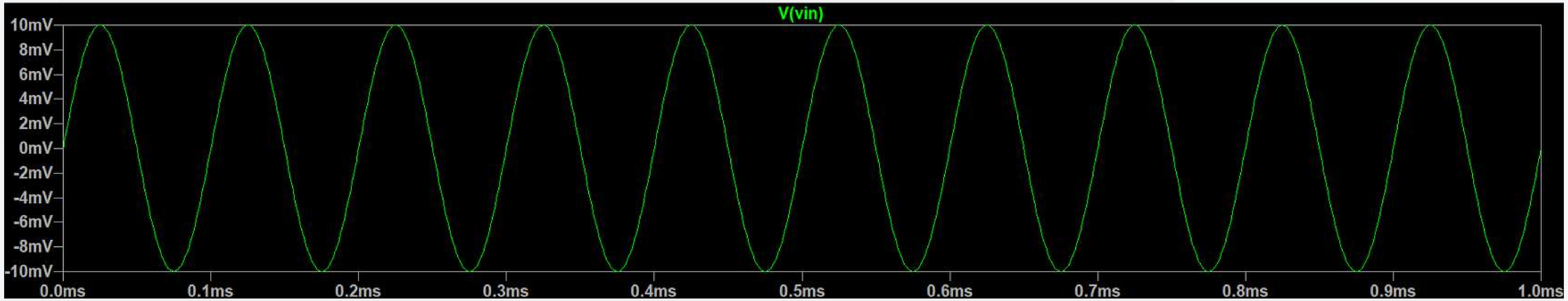
eg. transistors

(high small signal impedance not requiring large DC vdrop)

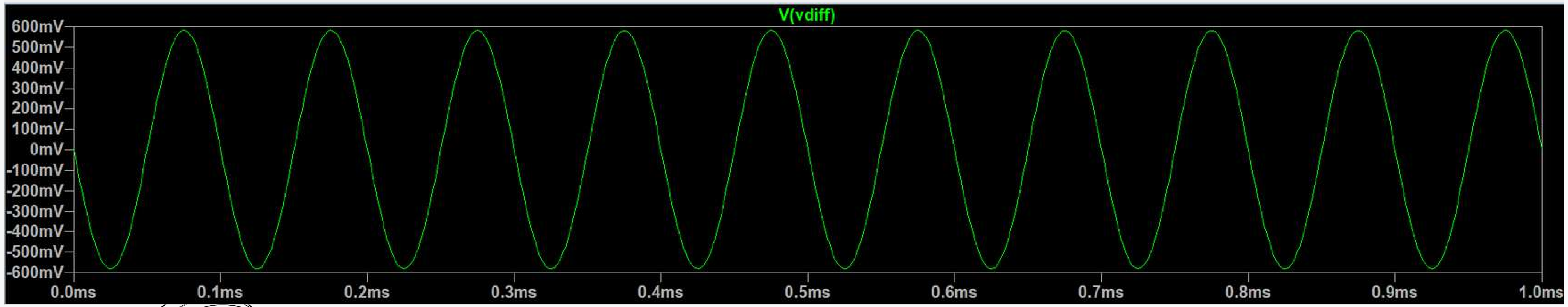
↳ high gain amplifiers

SIMULATIONS

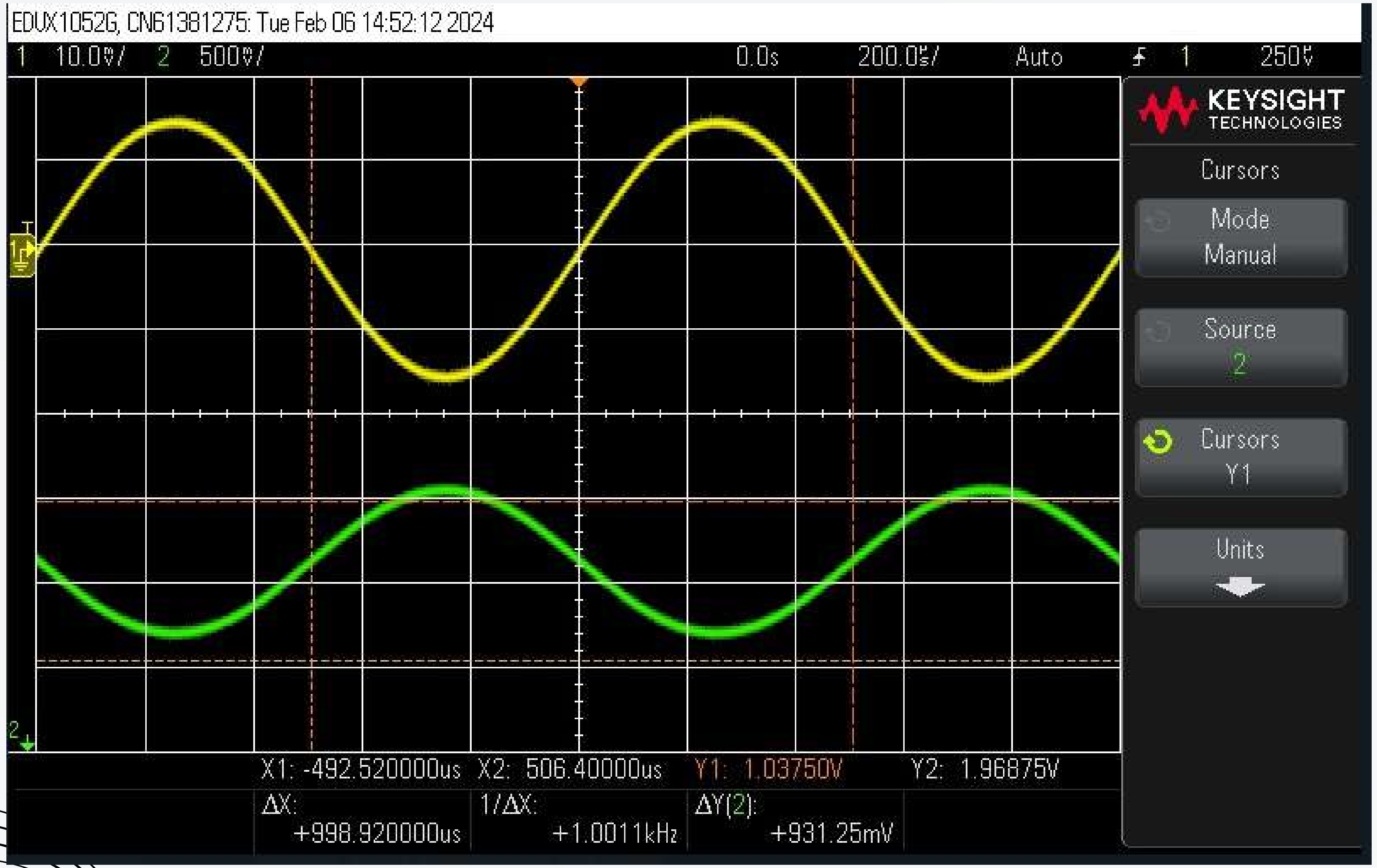
Input - a sine wave of amplitude 10 mV and frequency 10kHz



Output - Single ended different output. Phase shifted by 180 degrees and a gain of 600/10 = 60



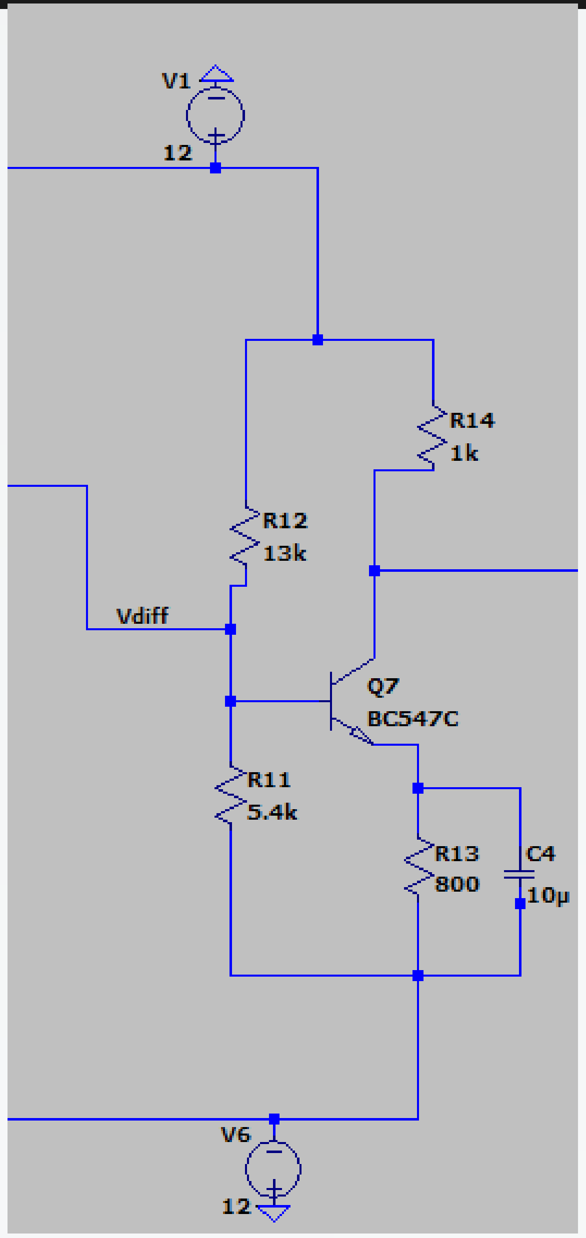
HARDWARE



For an input waveform of voltage 30mV we observe an output of 930mV which is a gain of approximately 31.

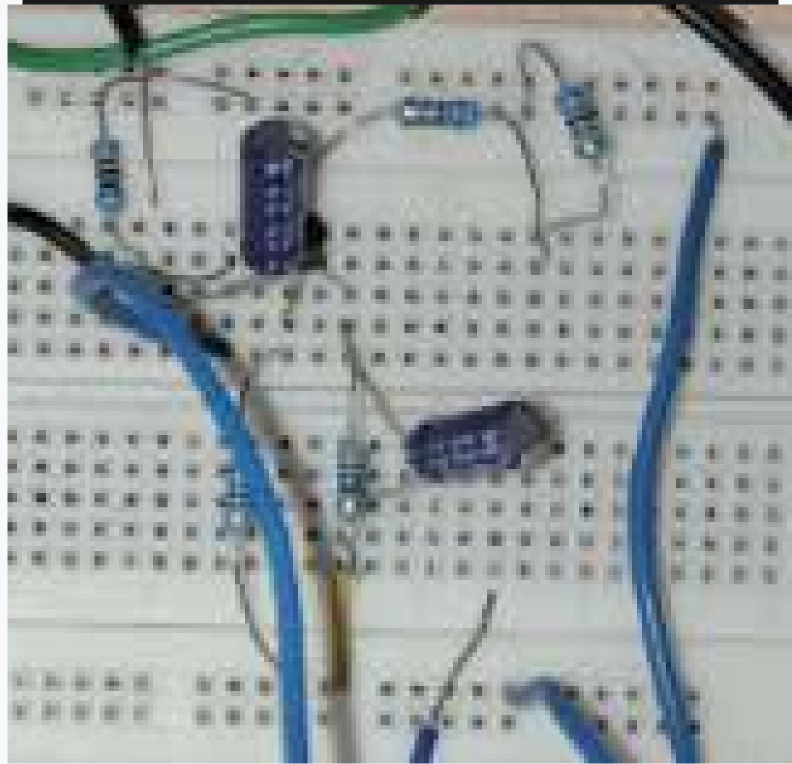
PRE AMP 2: CE AMPLIFIER

Circuit

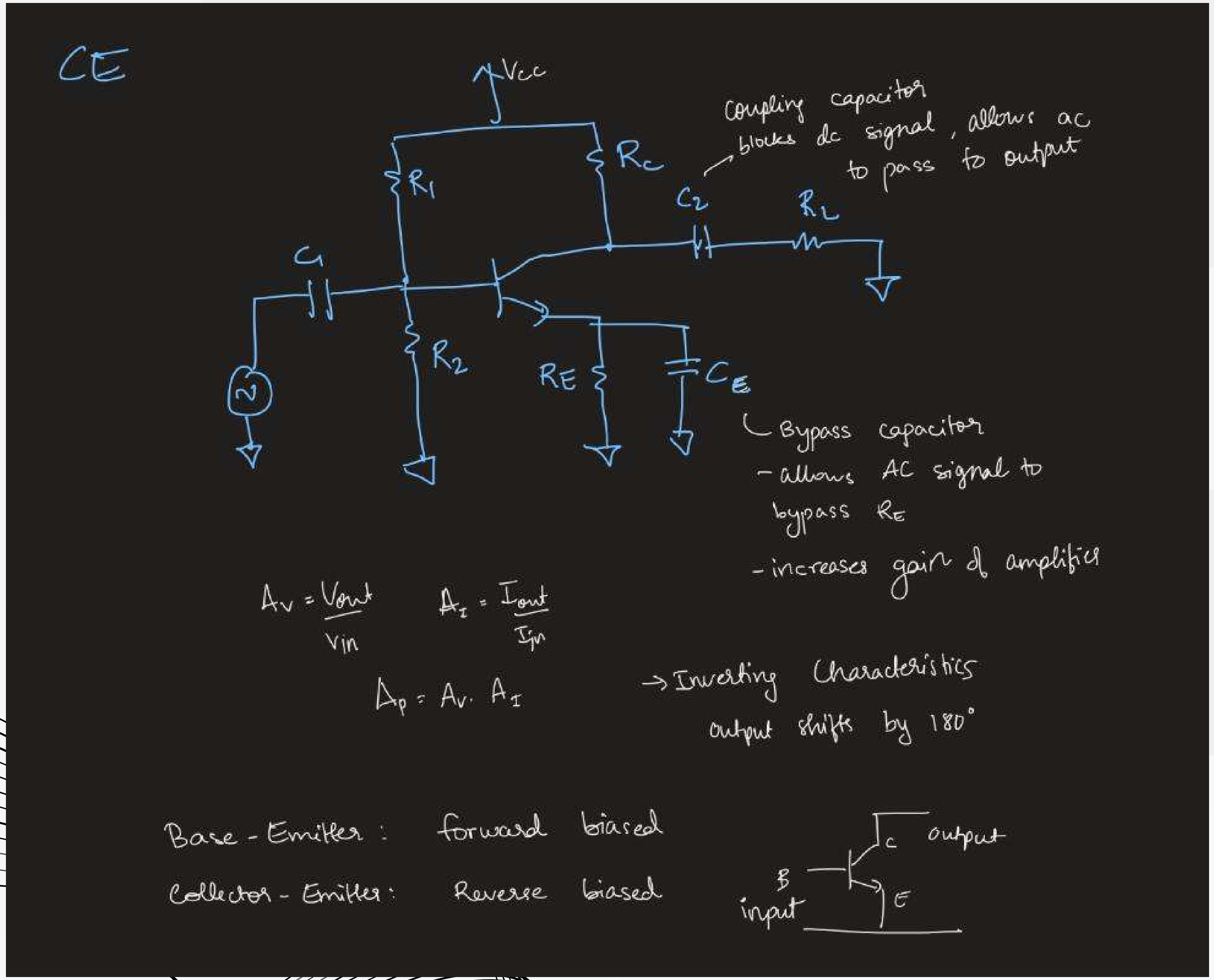


- The common emitter (CE) amplifier is utilized to further amplify the output of the differential amplifier by biasing it to the Linear region
- In this configuration, the emitter resistor (RE) is essential for stabilizing the transistor's operating point.
- Without RE, the emitter voltage directly reflects the negative supply voltage (VEE), leading to a high threshold for transistor activation.
- Including RE ensures a sufficient potential drop for the transistor to remain in its active region.
- It's important to note a 180-degree phase shift between input and output signals in the CE amplifier: an increase in input results in an increase in collector current (Ic) and a decrease in output voltage (Vout).

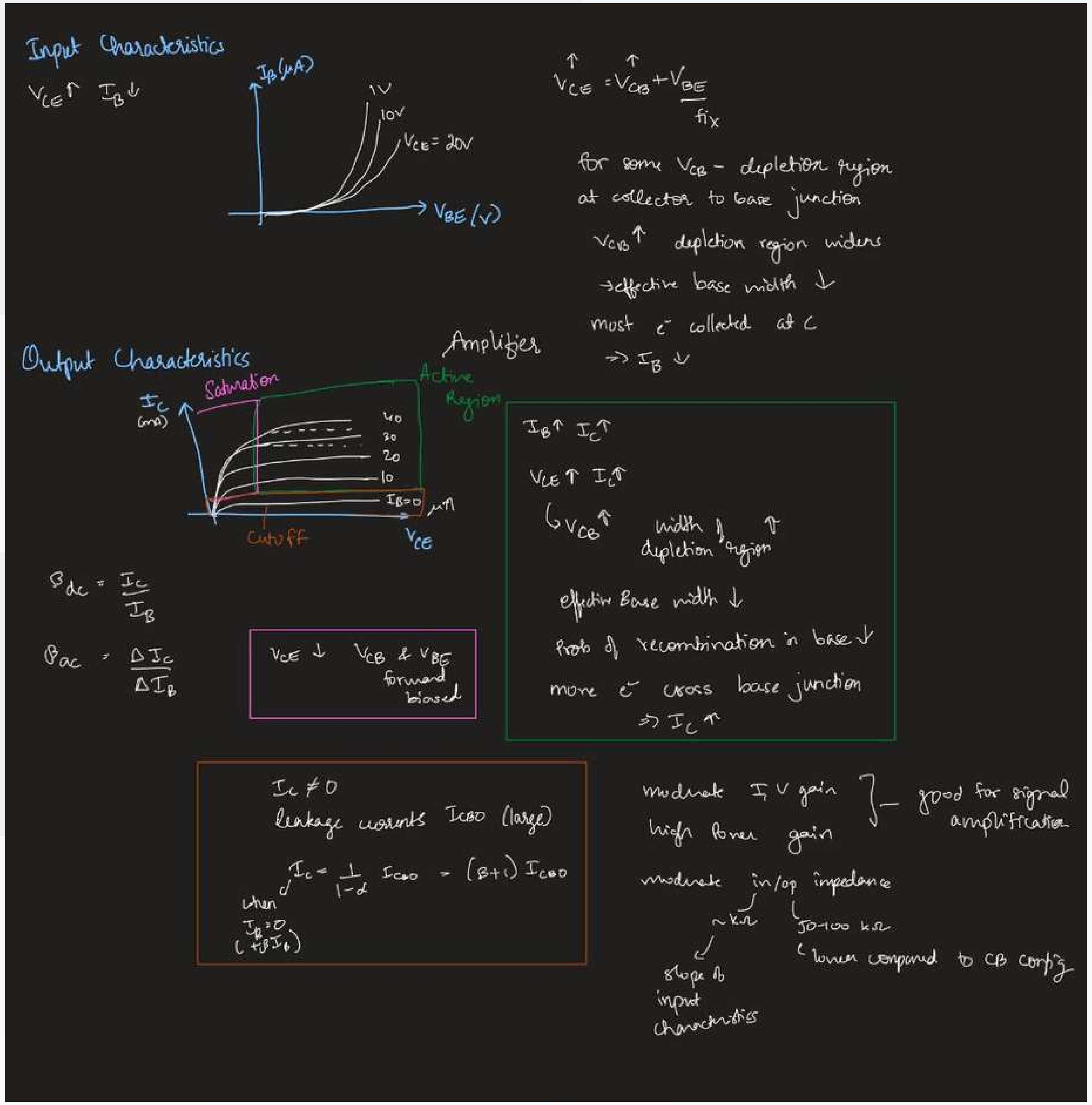
Breadboard



DESIGN



CE
Vcc
R1
Rc
C2
RL
C1
R2
RE
CE
Coupling capacitor
blocks dc signal, allows ac to pass to output
Bypass capacitor
- allows AC signal to bypass RE
- increases gain of amplifier
Av = Vout / Vin
AI = Iout / Iin
Ap = Av · AI
→ Inverting Characteristics
output shifts by 180°
Base - Emitter : forward biased
Collector - Emitter : Reverse biased
B
input
C
output
E



Input Characteristics
VCE ↑ IB ↓
IB (μA)
1V
10V
VCE = 20V
VBE (V)
VCE = VCB + VBE
fix
for some VCB - depletion region at collector to base junction
VCB ↑ depletion region widens
→ effective base width ↓
most e⁻ collected at C
→ IB ↓
Output Characteristics
Amplifier
Saturation
Active Region
IC (mA)
40
30
20
10
IB = 0 μA
Cutoff
VCE
IB ↑ IC ↑
VCE ↑ IC ↑
VCB ↑ width of depletion region ↑
effective Base width ↓
Prob of recombination in base ↓
more e⁻ cross base junction
→ IC ↑
βdc = IC / IB
βac = ΔIC / ΔIB
VCE ↓ VCB & VBE forward biased
IC ≠ 0
leakage currents ICEO (large)
when IB = 0
IC = 1/(1-α) ICBO = (β+1) ICBO
moderate I, V gain
high Power gain
good for signal amplification
moderate in/op impedance
~ kΩ
slope of input characteristics
50-100 kΩ
lower compared to CB config

ANALYSIS - SMALL SIGNAL

AC Analysis

→ short capacitors → ac current passes through

short dc sources - with their internal resistances

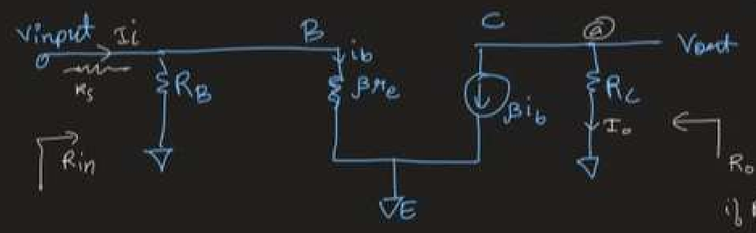
→ from DC analysis get $I_{B,Q}$ $V_{CE,Q}$

→ AC equivalent model

→ AC analysis

ohm's law
KCL
KVL
cv divider rule

$R_1 \parallel R_2 = R_B$ ↓ B4 input



$R_o = R_C$

if R_L present $R_o = R_C \parallel R_L$

1) $A_V = \frac{V_{out}}{V_{in}}$ (A_{V_S}, A_{V_L}) source resistance, load resistance

node ⓐ
KCL $\beta i_b + \frac{V_o}{R_C} = 0$

$V_o = -\beta i_b R_C$

i_b through βr_e

$\frac{V_i}{i_b} = \beta r_e$ $\quad i_b = \frac{V_i}{\beta r_e}$

$\frac{V_o}{V_i} = -\frac{R_C}{r_e}$

$g_m = \frac{1}{r_e}$

$A_V = -g_m R_C$ (r_π model)

$\beta r_e = h_{ie}$
$\beta = h_{fe}$

$A_V = -R_C \cdot \frac{h_{FE}}{h_{ie}}$ (h-parameters)

2) A_I

$I_o = -\beta i_b$

$i_b = \frac{R_B}{R_B + \beta r_e} \times I_i$

$A_I = -\beta \left[\frac{R_B}{R_B + \beta r_e} \right]$

3) $R_{out} = \frac{V_o}{I_o}$

$= R_C$ (w/o R_L)

$= R_C \parallel R_L$ (w/ R_L)

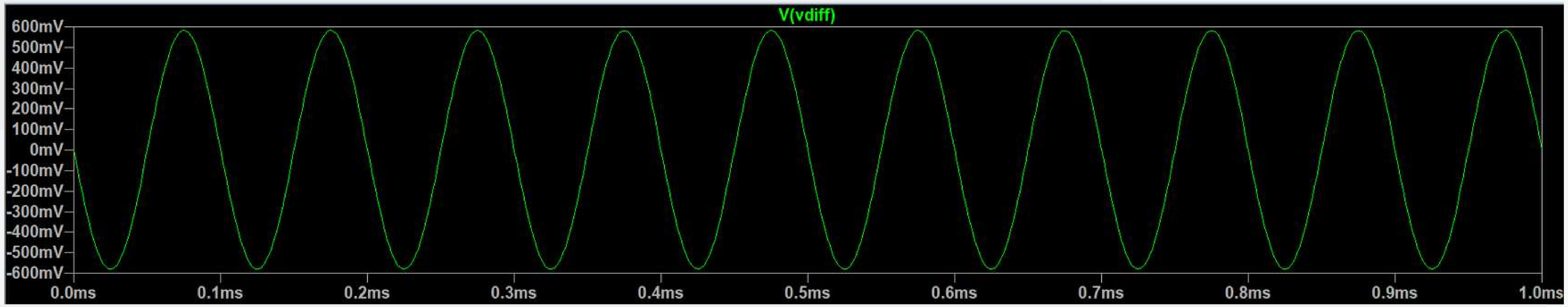
4) $R_{in} = \frac{V_{in}}{I_{in}}$

$= R_B \parallel \beta r_e$ (w/o R_S)

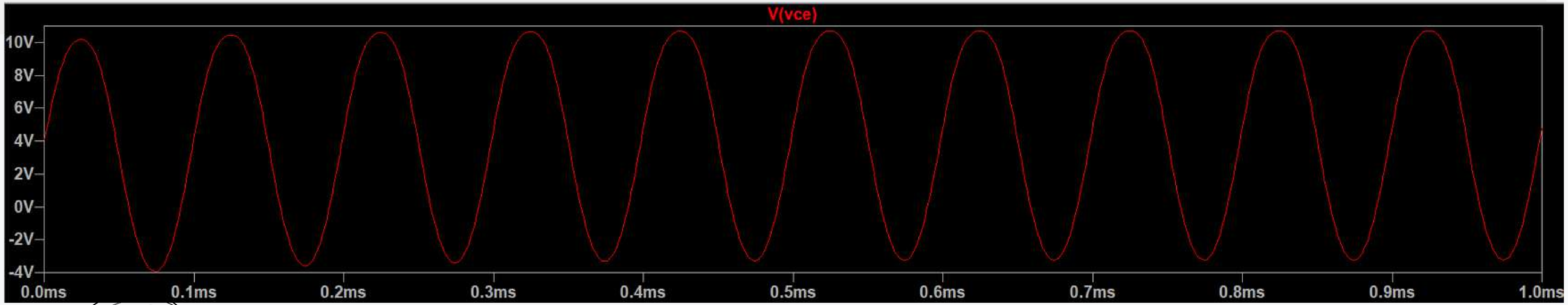
$= R_S + R_B \parallel \beta r_e$ (w R_S)

SIMULATIONS

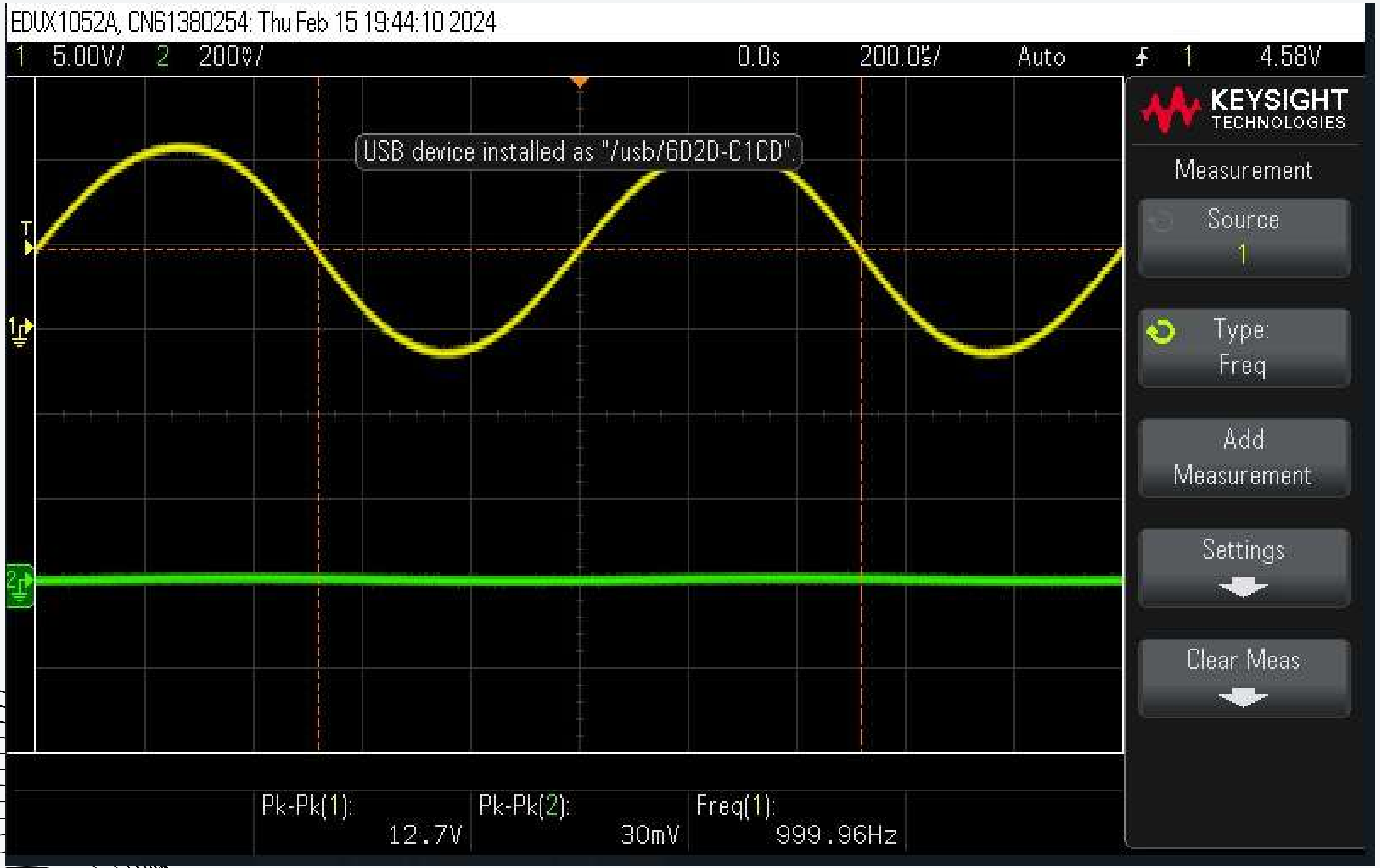
Input - Single ended differential output of 600 mV



Output - Phase shifted but now in phase with input. 6 V output implying CE gain of 10 and a total pre ampifier gain of 600



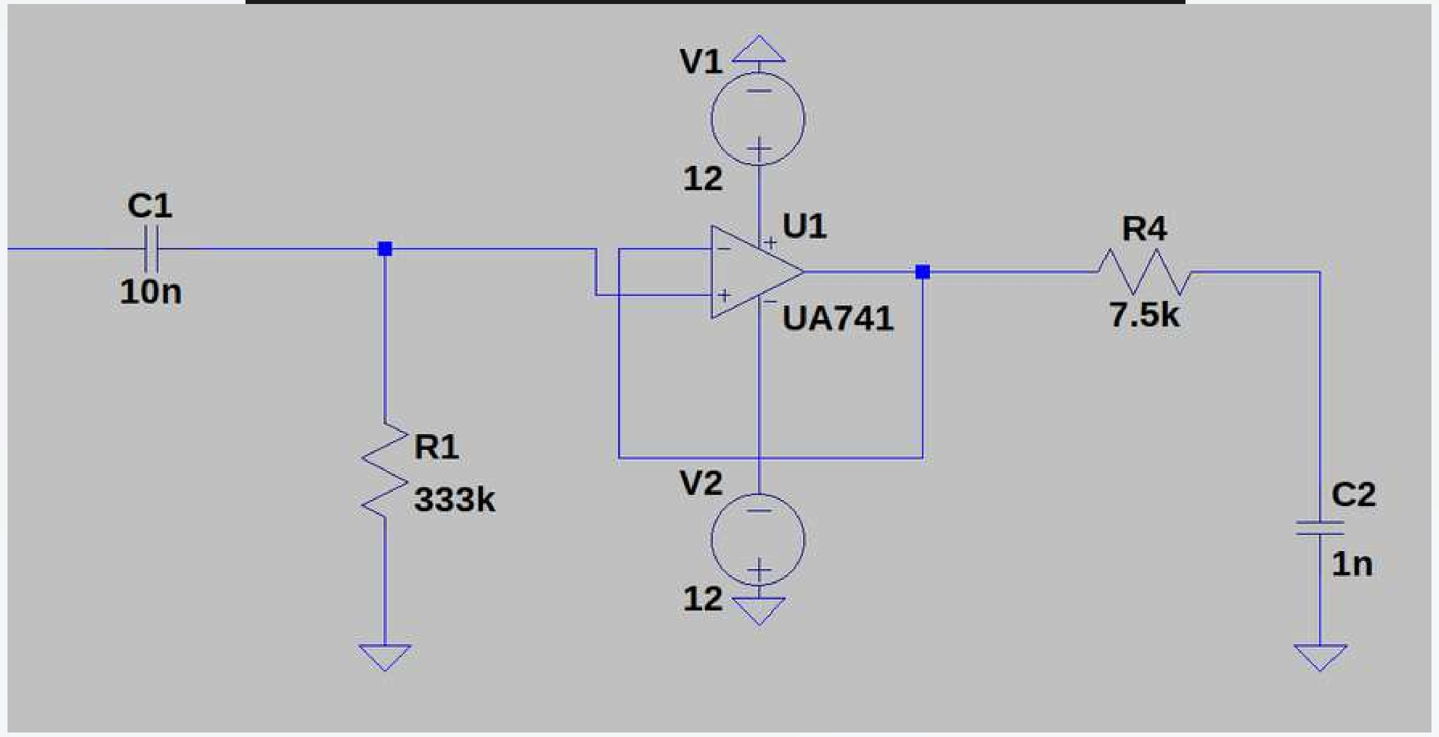
HARDWARE



For an input of 30mV into the Differential Amplifier an output of 12.7V is observed at the CE amplifier (Pre-Amp 2). This is an approximate gain of 423.

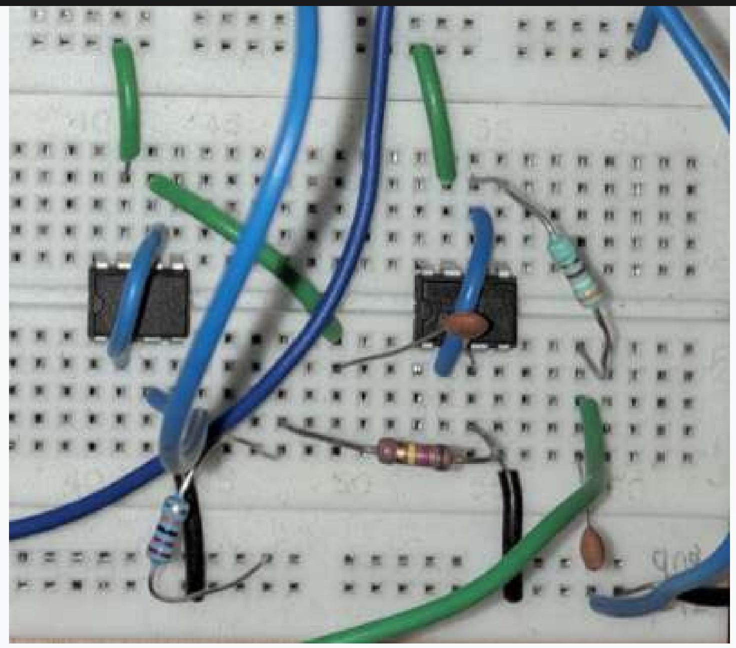
PASSIVE BANDPASS FILTER

LTspice



A filter is used to cut-out the frequencies outside the hearing range of a human, i.e. , the frequencies between 20Hz and 20kHz. This is done using passive R and C components.

Breadboard



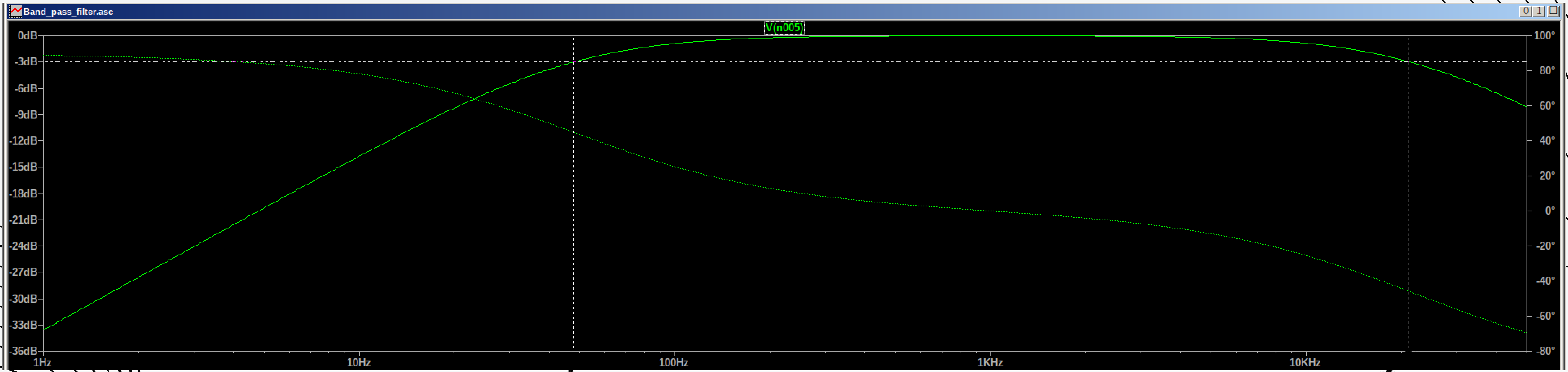
CALCULATIONS

For a passive RC filter, the cut-off frequency is calculated using the expression:

$$fc=1/2\pi RC$$

An op-amp buffer is added between the HPF and the LPF to prevent any issues related loading effects

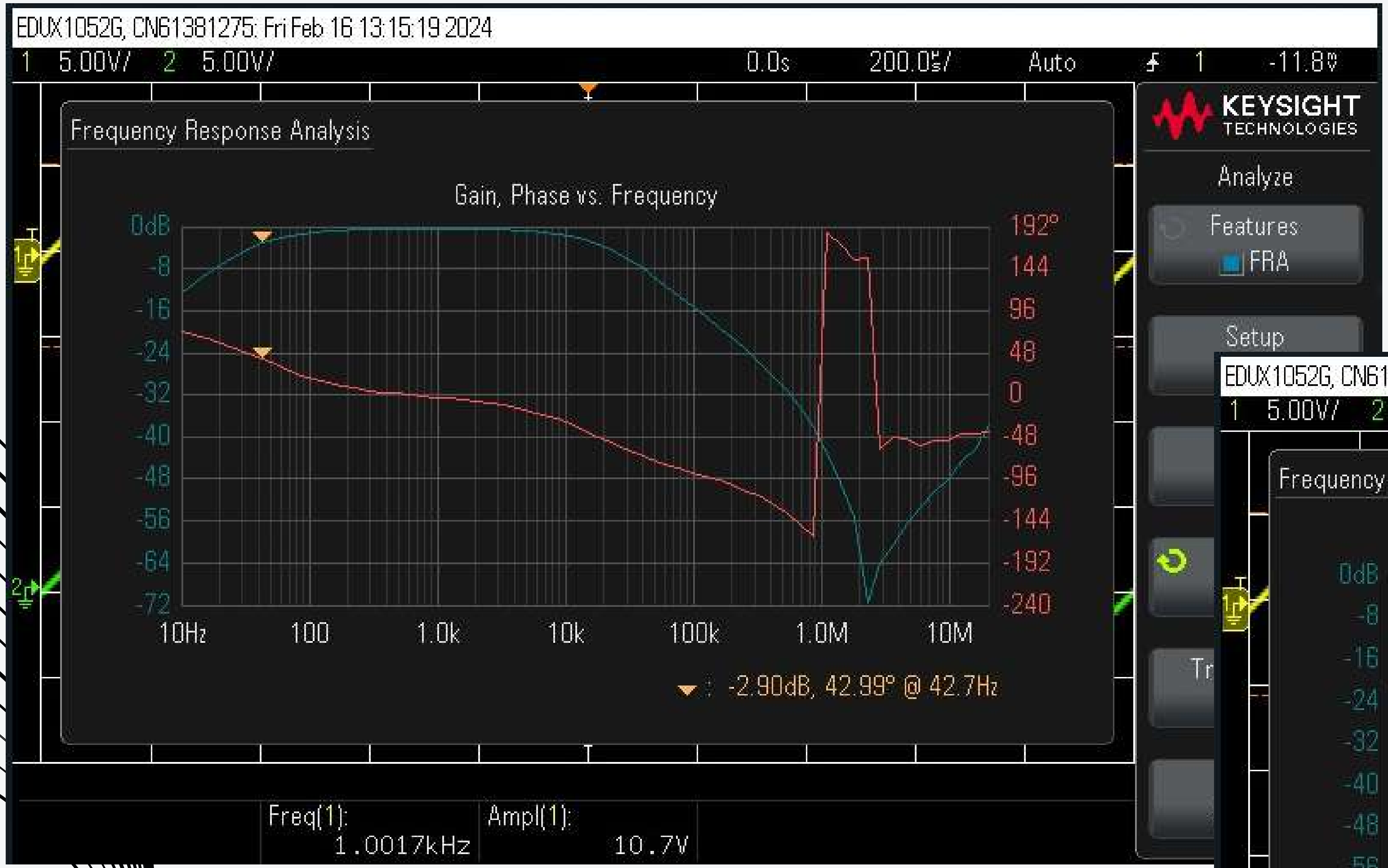
AC ANALYSIS

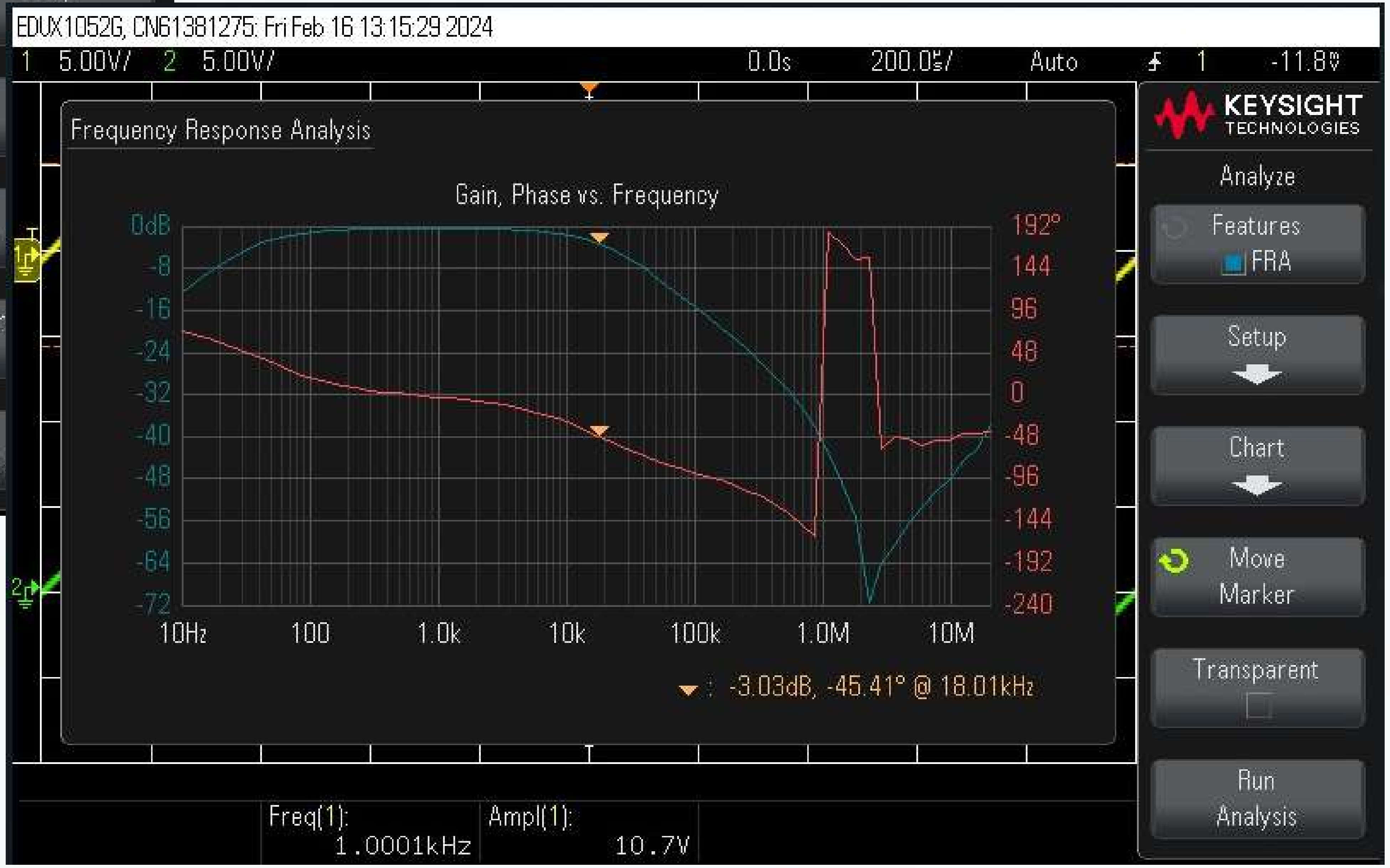


47Hz lower cut-off frequency

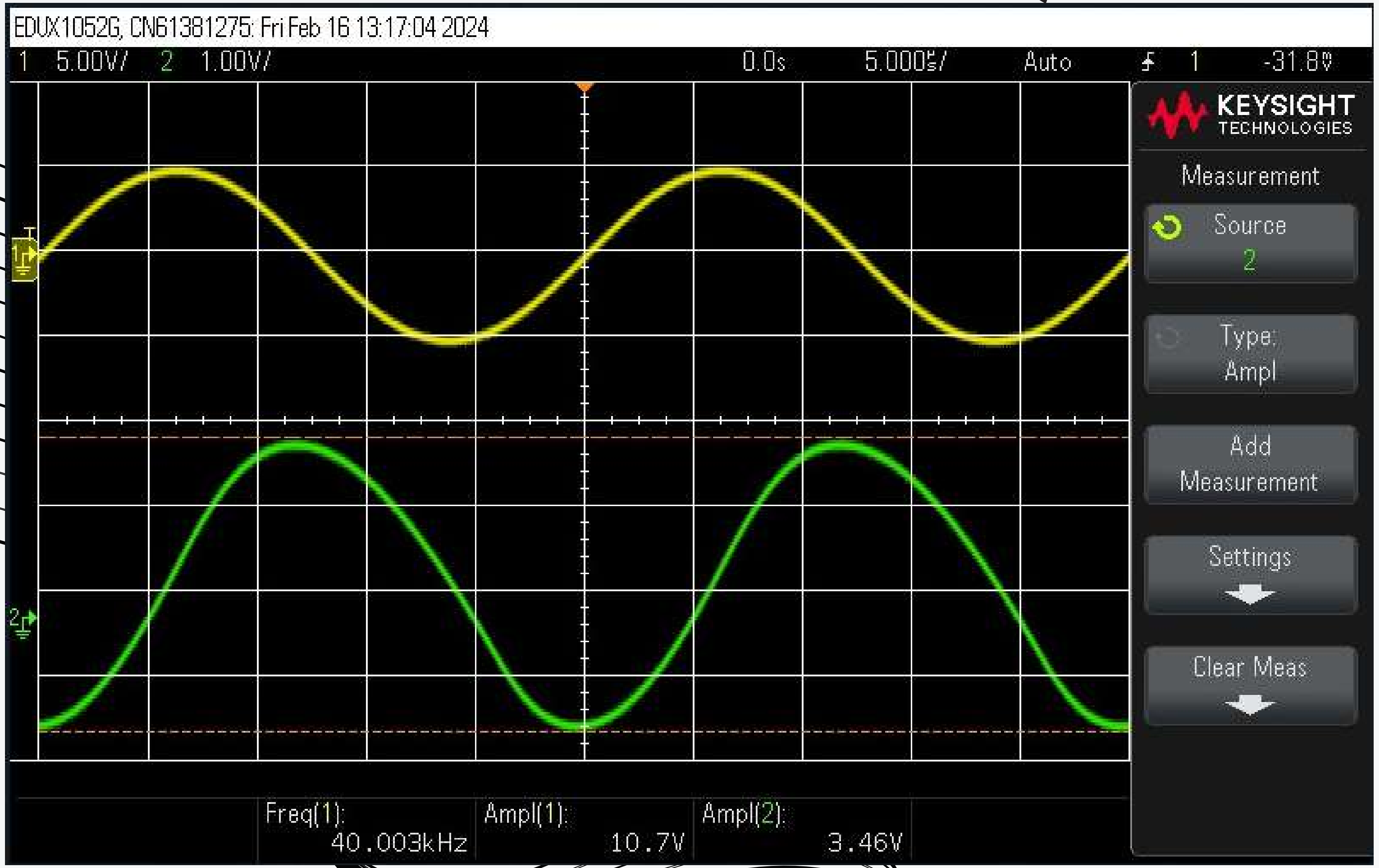
21kHz upper cut-off frequency

HARDWARE READINGS





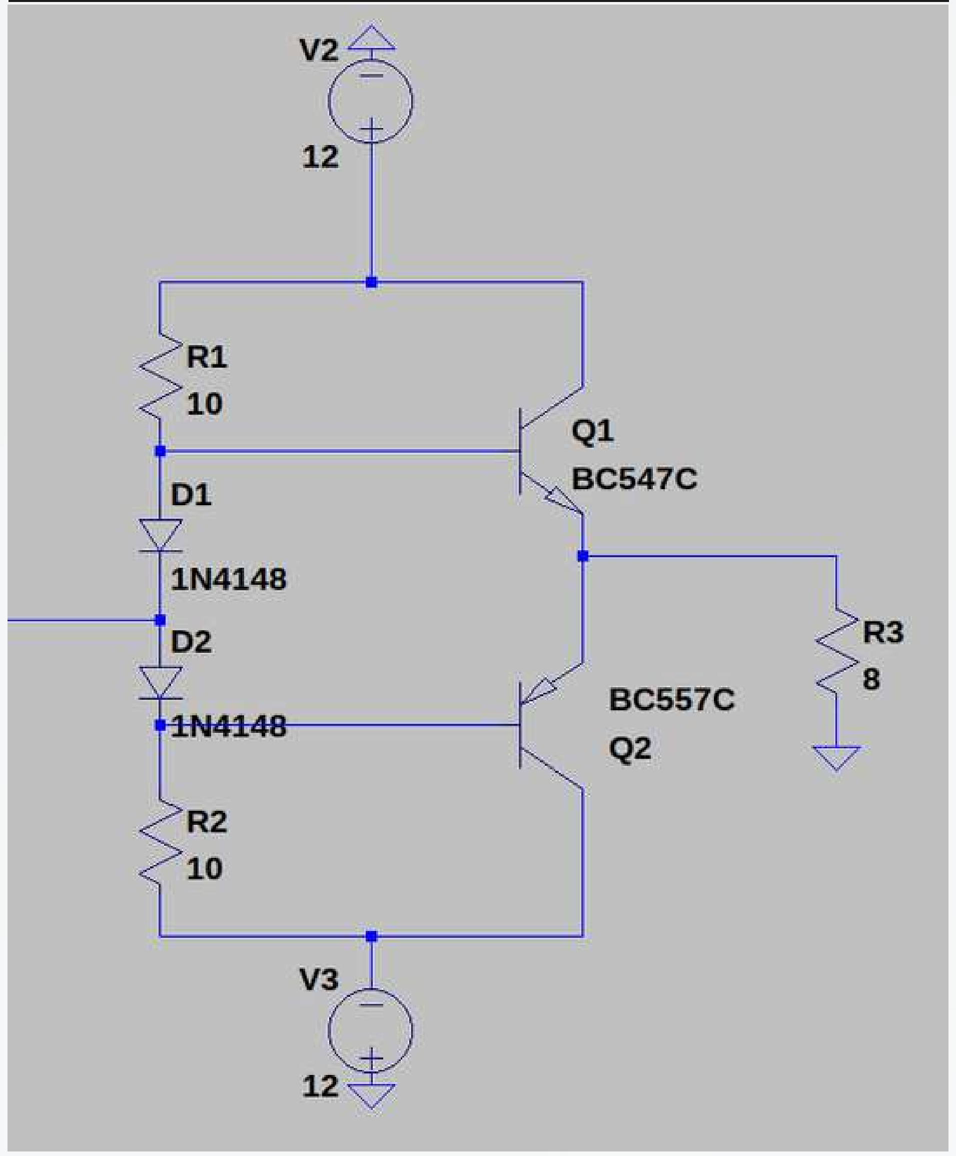
ATTENUATION OF FREQUENCIES



Since the signal frequency is beyond the cut-off frequency of the filter, we observe that there is major attenuation from 10.7V to 3.46V for the signal of frequency 40kHz

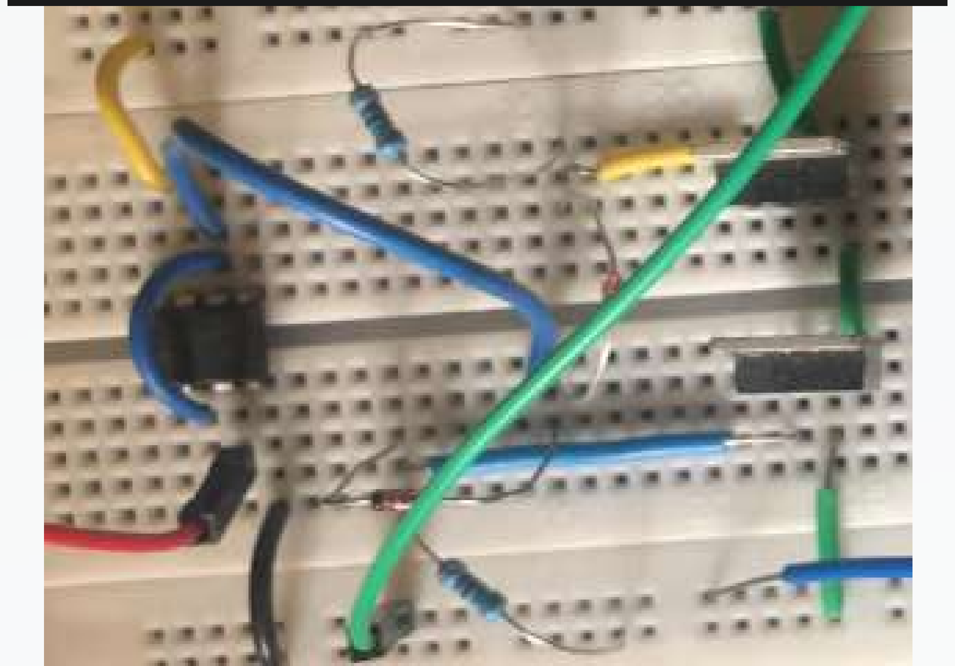
POWER-AMP

Simulation



A power amplifier is used to increase the power output of the amplifier, so as to run the speaker.
The power amplifier increases the current for the same voltage waveform.
This results in an increased power output at the load.

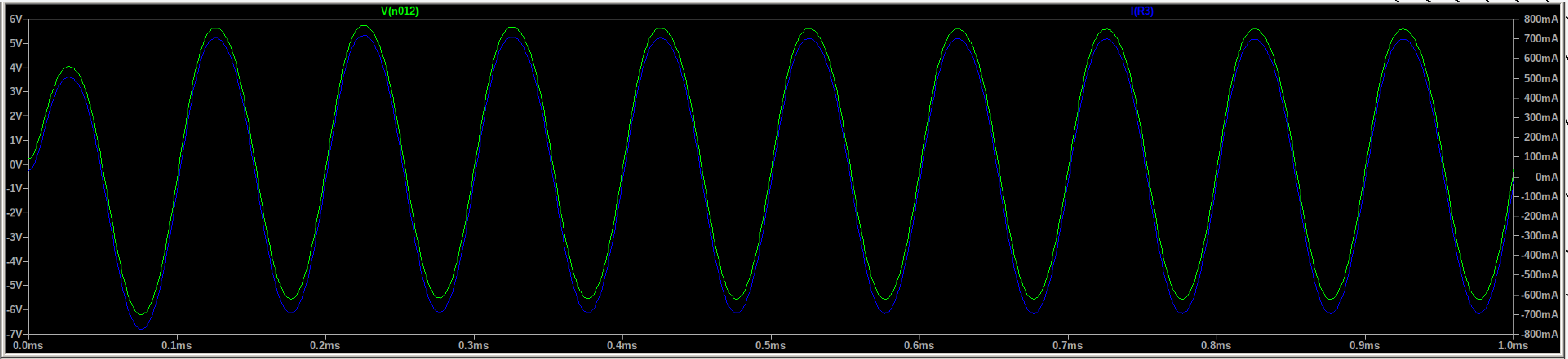
Breadboard



WORKING

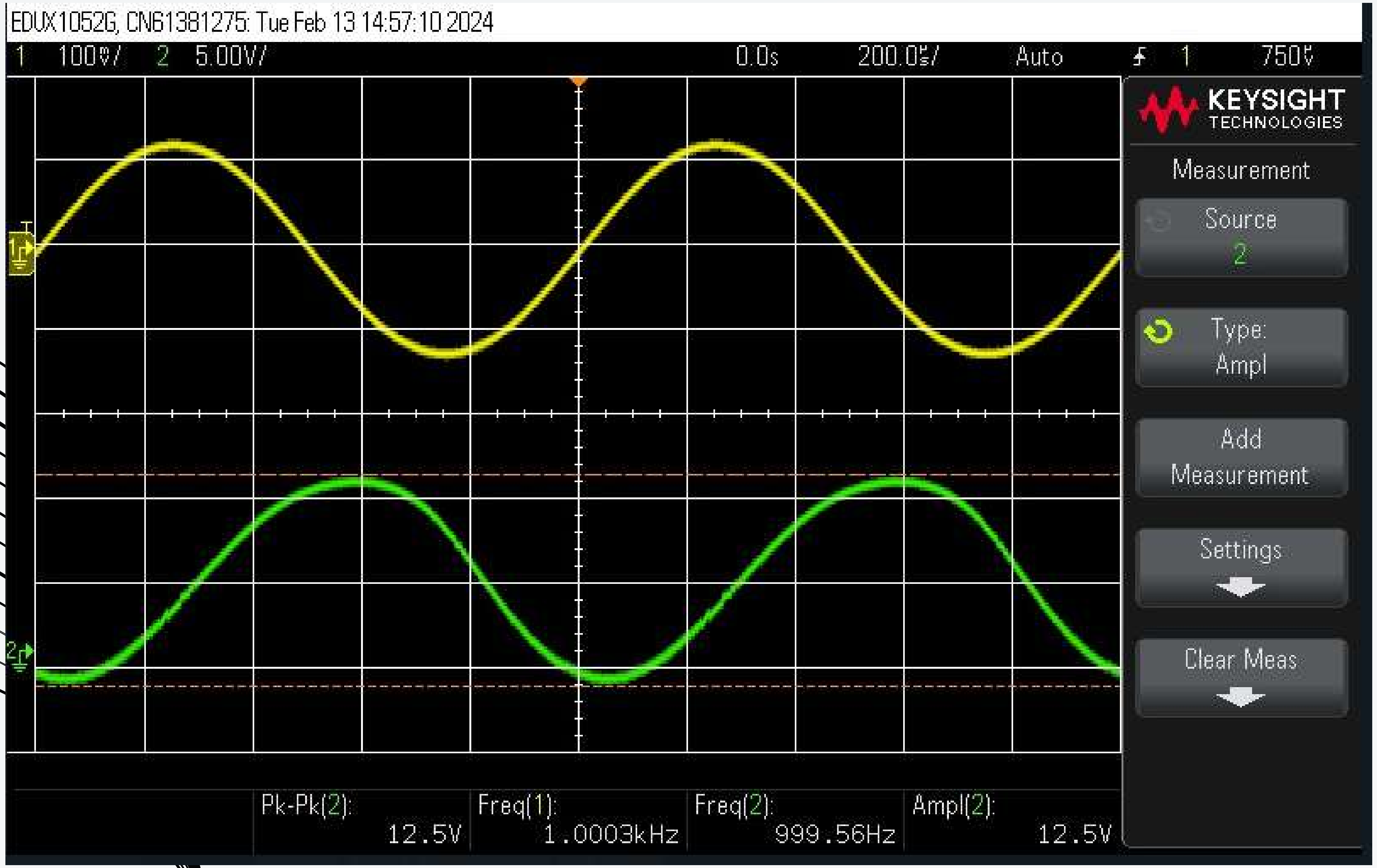
When the input signal is in its positive half cycle, the npn transistor is on and the pnp is turned on during the negative half cycle. The small resistors in series allow for a low impedence path thus increasing the current in the power amplifier. This results in a higher power output since P=I*I*RL . Since I is larger we get a larger power output.

SIMULATION



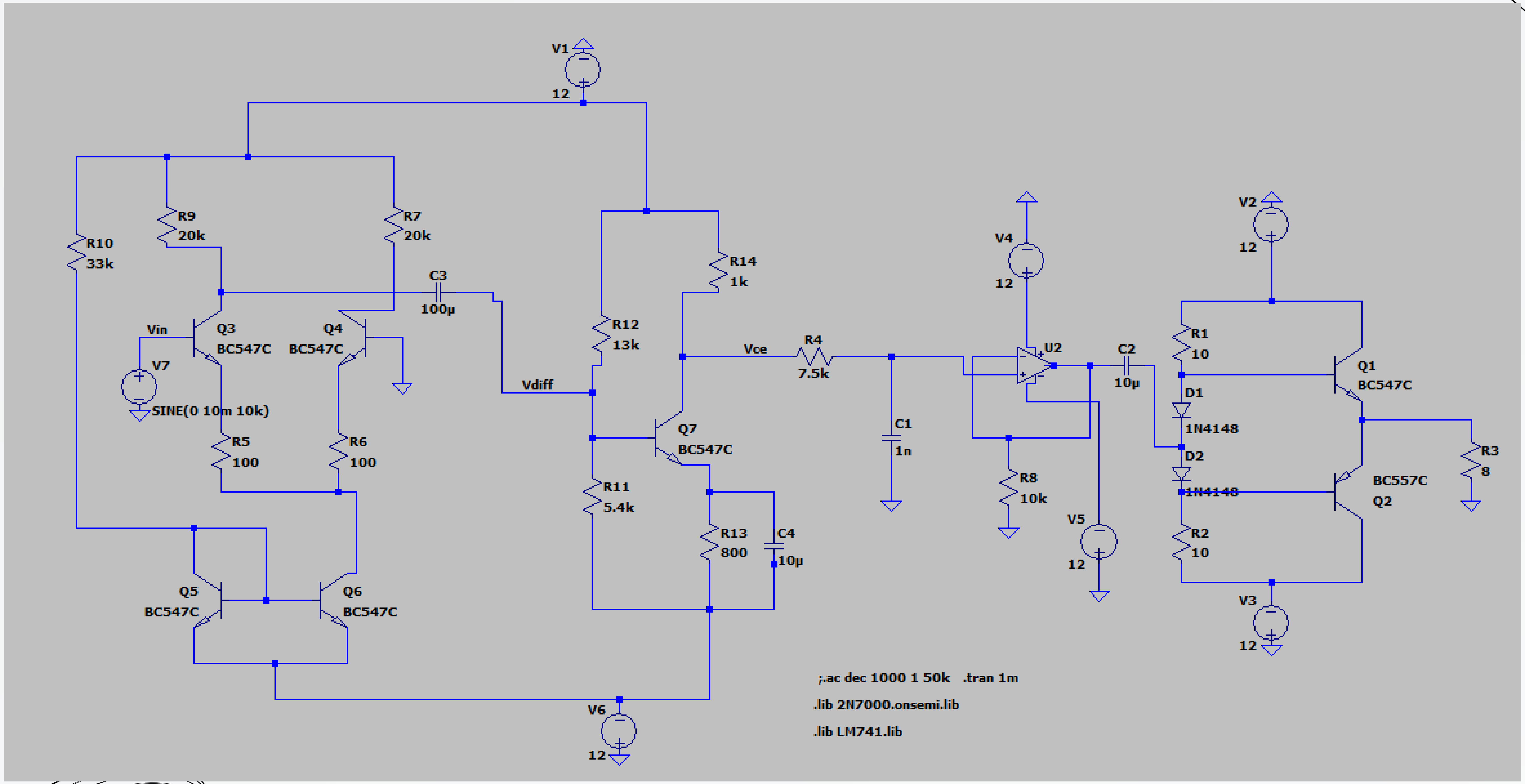
We observe that the current output has increased and the output power is more than the minimum power requirements for the speaker to run

HARDWARE OUTPUT



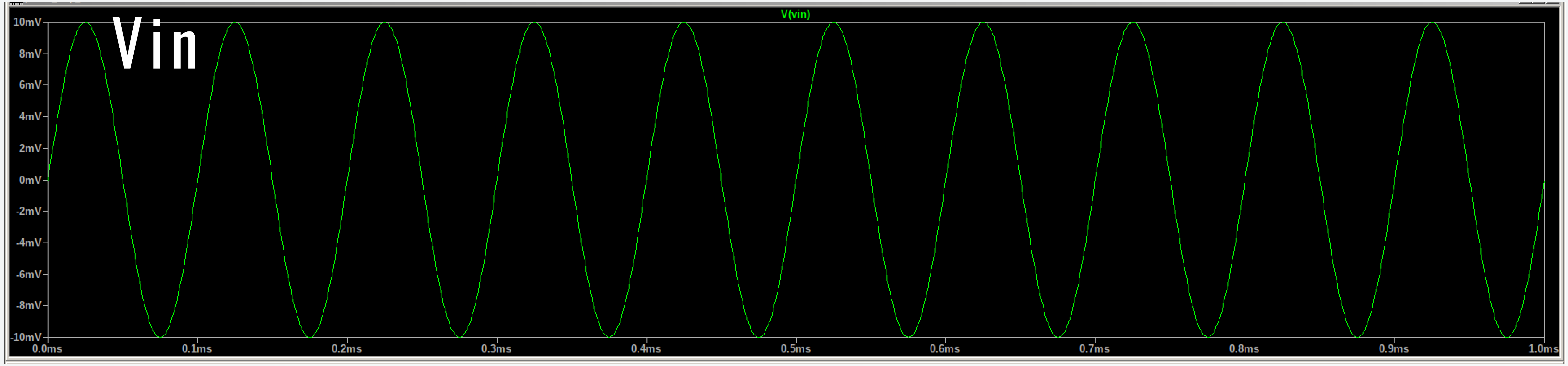
The voltage is observed to remain the same but the power output drastically increases

FINAL SIMULATIONS

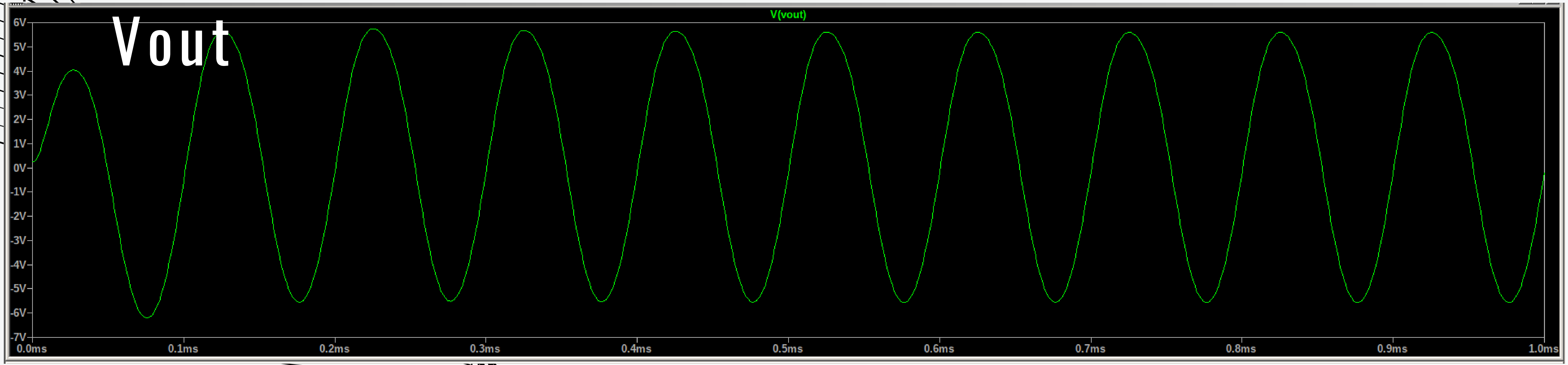


FINAL SIMULATION

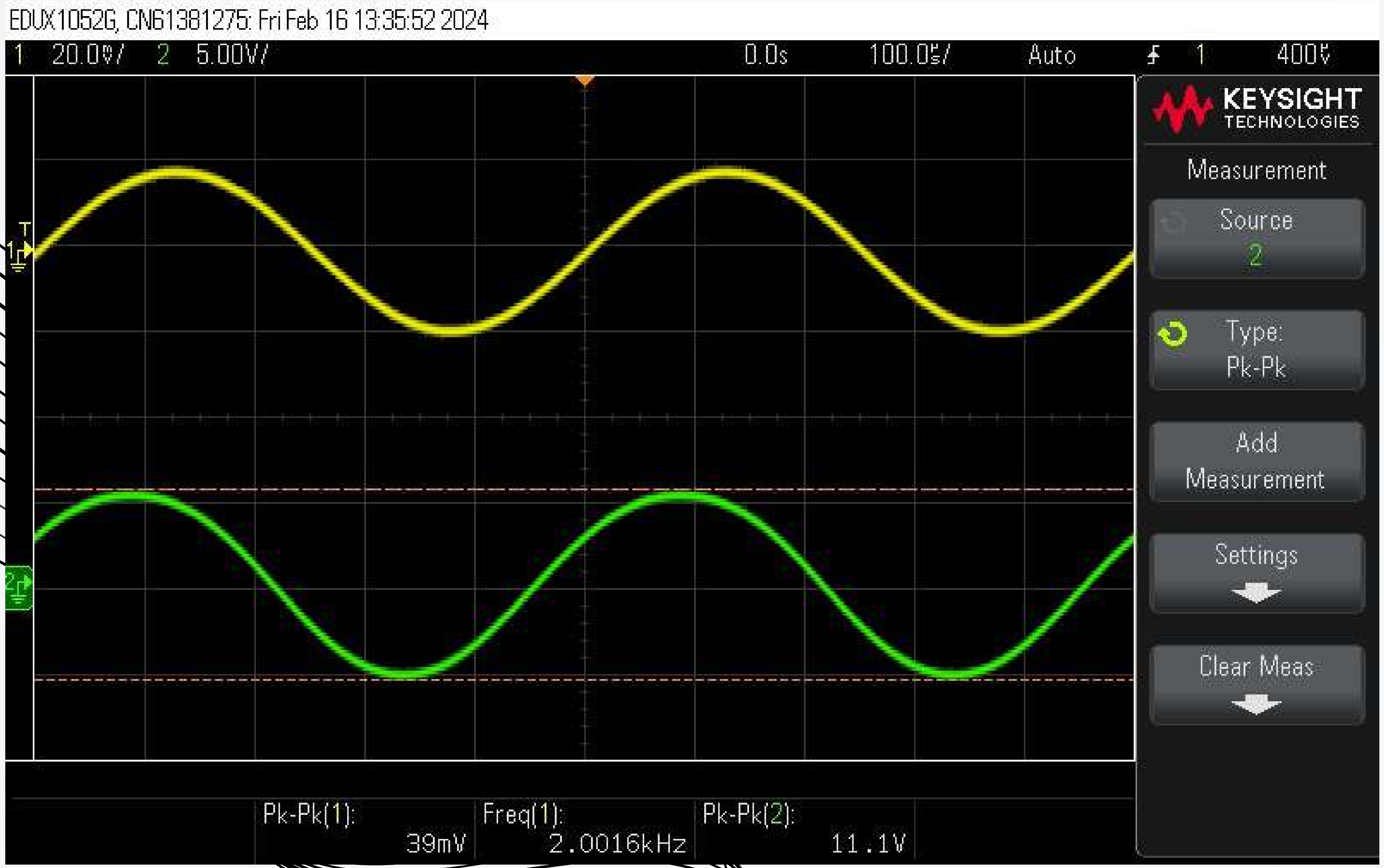
Input - a sine wave of amplitude 10 mV and frequency 10kHz



Output- an amplified wave at 5.8 V and 10kHz with sufficient power to operate a speaker



HARDWARE OUTPUT



Results for 2kHz sine wave at 20 mV amplitude when it is provided as input for the designed audio amplifier. The output is an amplified wave at 11.1 V at the end of the power amplifier stage with minimal noise or distortions. Therefore, the goal of the project was achieved.

THE END