Muğla Sıtkı Koçman University

EEE-2006 – Electronics II

DESIGN PROJECT

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JFET Amplified

2-Channel Active Signal Mixer

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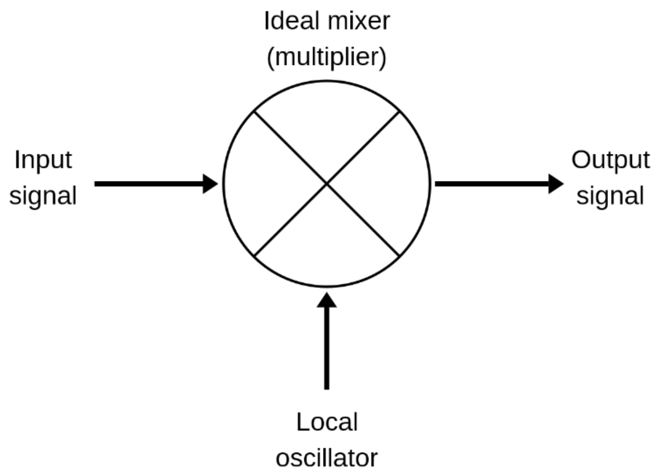
Introduction

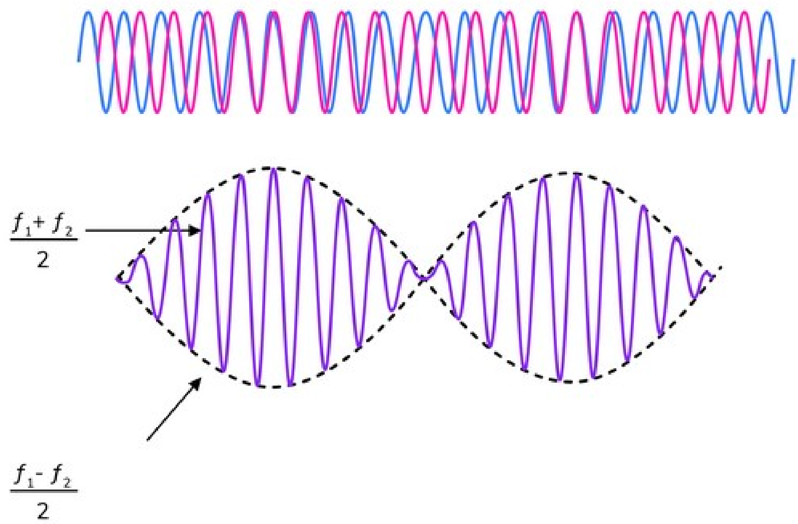
A signal or frequency mixer is an electrical circuit that creates new signals of different frequencies from the signals applied to it.

Mixers can either be passive or active. Passive mixers use passive elements in the form of diodes, and no amplification process is undertaken. While in active mixers, active components such as BJTs FETs are used which provide some level of gain to the resulting output signal.

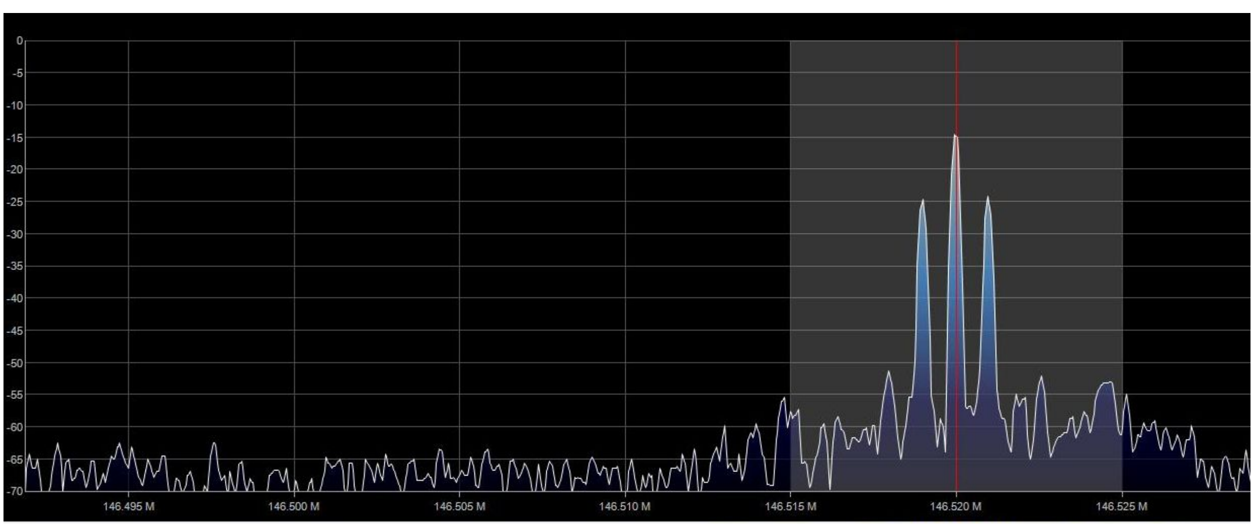


Mixers are prevalent electronic components. Finding abundant use in telecommunications and radio technology. It gives control over signal modification, enabling signals to be changed from one frequency range to any other desirable one, this process being called heterodyning. Either for it to later be processed, or transmitted.

Mixers are largely used in audio processing as well. Whereby multiple input audio waveforms are fed into a mixer and are adjusted in multiple ways to obtain a desired audio at the receiving end, whether it be one that has reduced noise from a certain frequency range, or one where all receiving audio signals are normalized to same level, or is one that produces pleasant beats. Effect pedals for guitars and other instruments consist of mixers in addition to other audio processing components.



Ideally, when two signals of differing frequencies, say f_1 and f_2, are received by a mixer, new output signals are produced at the sum and difference of the original frequencies. i.e. at $f_1 + f_2$ and $f_1 - f_2$. But in regards to the signal amplitude, at any point on the output signal, the instantaneous amplitude is the result of the product of the instantaneous amplitudes of the incoming signals at that point. It is for this reason that mixers are also called multipliers.



Design

Design Aim and Implementation

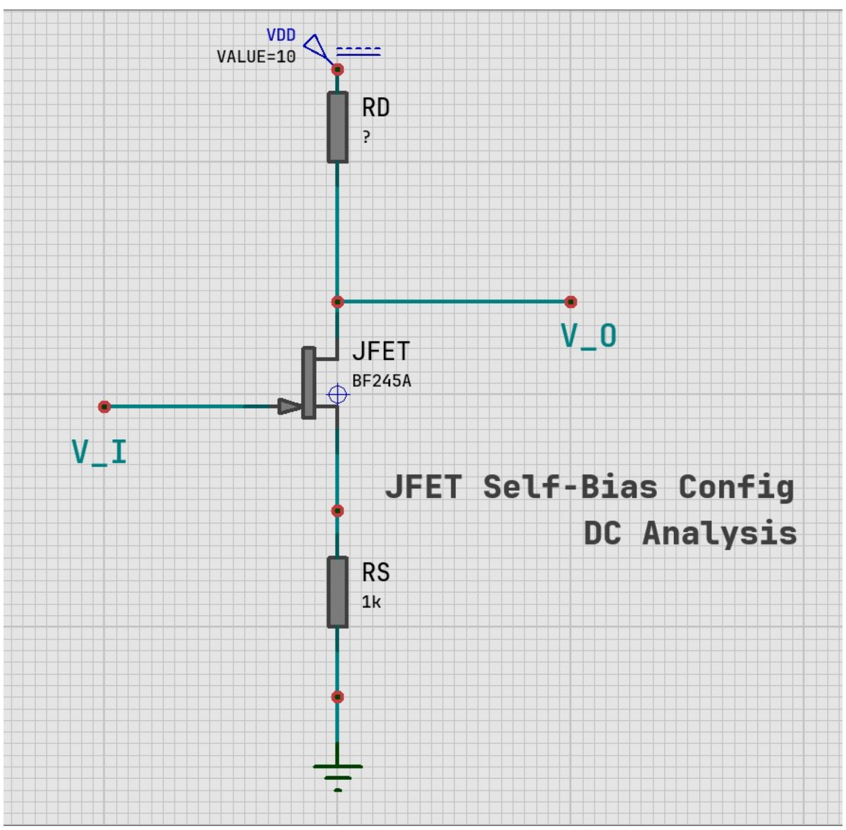
Suppose we are to design a mixer that takes in two signals, mixes them and gives out an amplified resultant signal of a certain gain. Let it be approximately 6 times the signal fed.

Let there also be some kind of mechanism to adjust the effect of the input signals.

Now, of course in order to achieve gain, an active mixer is to be implemented. We will use a JFET, in particular BF245A for this purpose. Let us also implement it with a self-bias configuration to reduce the number of dc biases required to maintain. As we are aware of the self-bias amplifier configuration, the resulting gain will be noninverting, but the input impedance will be high enough not to disturb the circuit when any sort of signal is introduced. This is of utmost importance.

DC Analysis

If we assume a source resistor of $R_S = 1k\Omega$, and a drain bias voltage of $V_{DD} = 10V$, then we only have to determine the drain resistor R_D. But first of all we will need to find the operating point with the assumed source resistor via load line analysis.



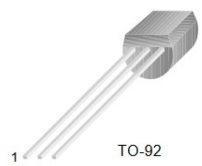
A look at the datasheet for the JFET at hand, BF245A, reveals that the pinch off potential $V_P = V_{GS(off)}$ ranges from $-0.5V$ to $-8V$, while saturation current I_{DSS} ranges from $2 - 6.5\ mA$.

FAIRCHILD
SEMICONDUCTOR®

BF245A/BF245B/BF245C

N-Channel Amplifiers

- This device is designed for VHF/UHF amplifiers.
- Sourced from process 50.



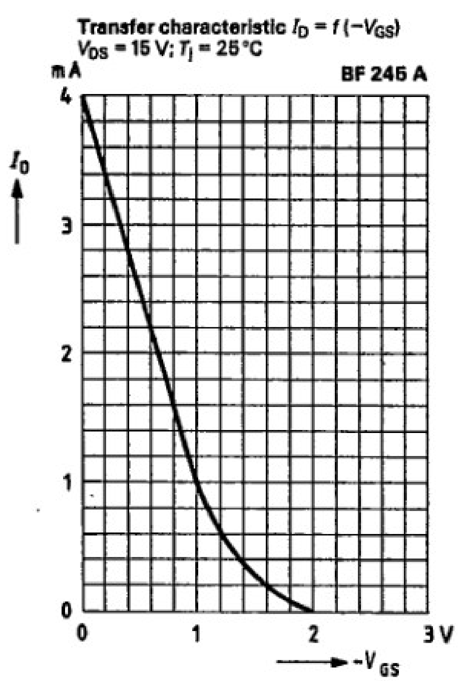
1. Gate 2. Source 3. Drain

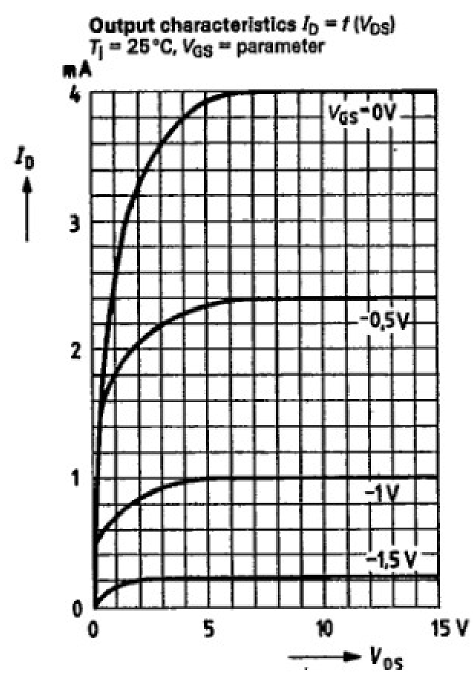
BF245A/BF245B/BF245C

Electrical Characteristics T_a=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Max.	Units
Off Characteristics					
$V_{(BR)GSS}$	Gate-Source Breakdown Voltage	V_{DS} = 0, I_G = 1μA	-30		V
V_{GS}	Gate-Source BF245A BF245B BF245C	V_{DS} = 15V, I_D = 200μA	-0.4 -1.6 -3.2	-2.2 -3.8 -7.5	V
V_{GS}(off)	Gate-Source Cut-off Voltage	V_{DS} = 15V, I_D = 10nA	-0.5	-8	V
I_{GSS}	Gate Reverse Current	V_{GS} = -20V, V_{GS} = 0		-5	nA
On Characteristics					
I_{DSS}	Zero-Gate Voltage Drain Current BF245A BF245B BF245C	V_{GS} = 15V, V_{GS} = 0	2 6 12	6.5 15 25	mA

The typical values, though presents average values of $V_P = -4V$ and $I_{DSS} = 4mA$.





An application of Kirchhoff's Voltage Law in the gate-source loop will give the load equation:

$$V_{GS} = -I_D R_S$$

$$I_D = -\frac{1}{1k\Omega} V_{GS} \ (mA)$$

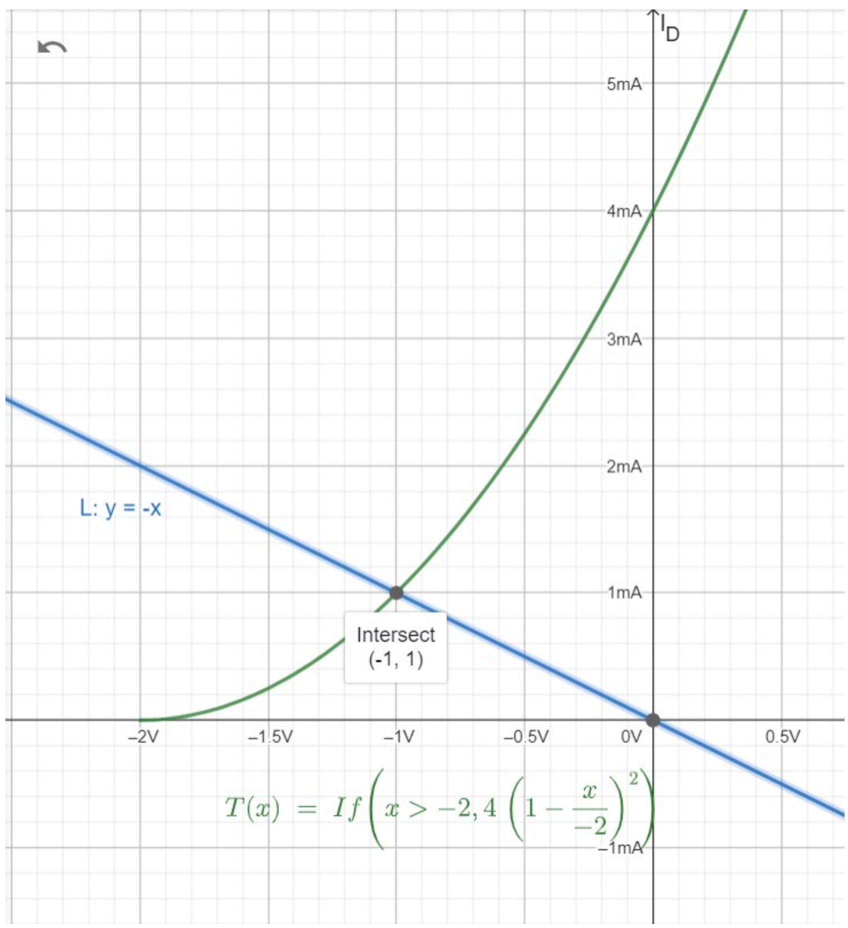
While Shockley's Equation says:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 4mA\left(1 - \frac{V_{GS}}{-2V}\right)^2$$

Solving these two equations simultaneously, we obtain the Q-point at:

$$V_{GS_Q} = -1V$$

$$I_{D_Q} = 1mA$$



We realize that the AC voltage gain of a self-biased JFET is:

$$A_V = -g_m(r_d || R_D) \cong -g_m R_D$$

Where the transconductance value will be:

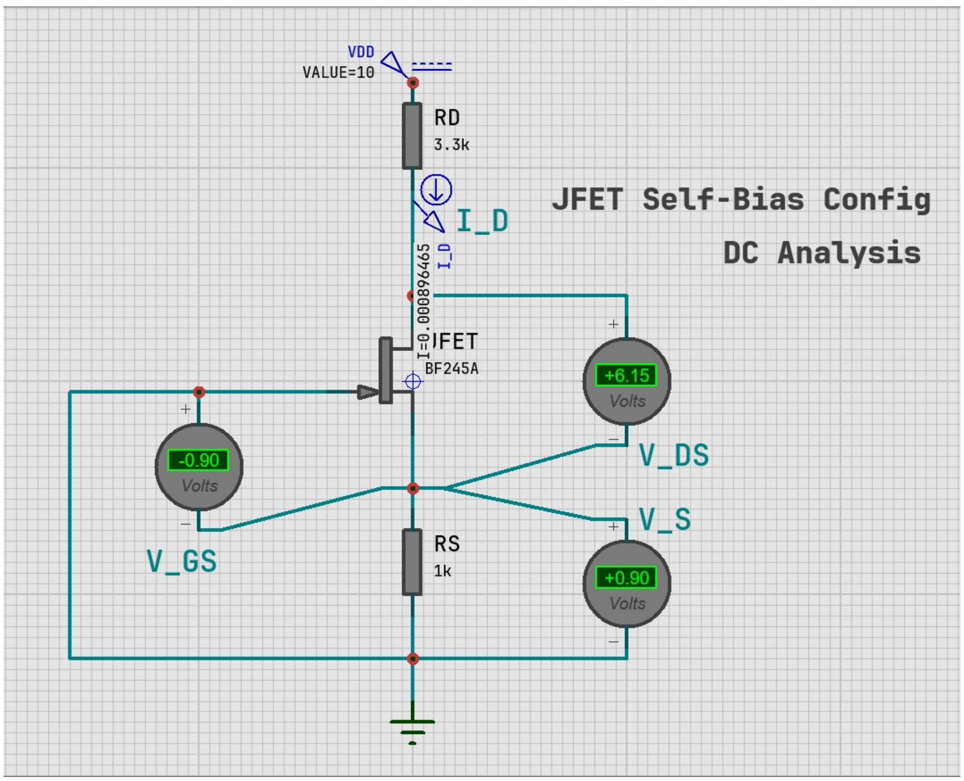
$$g_m = g_{mo}\left(1 - \frac{V_{GS}}{V_P}\right) = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right) = -2mS$$

Then in order to achieve the desired gain of $A_V = 6$:

$$R_D = \left|\frac{A_V}{g_m}\right| = 3k\Omega$$

Where the closest resistor commercial value is $3.3k\Omega$.

Hence with R_D decided, if we put the values to the test we observe:



With some little discrepancies, they confirm with the calculated values, where:

$$V_{GS_Q} = -1V$$

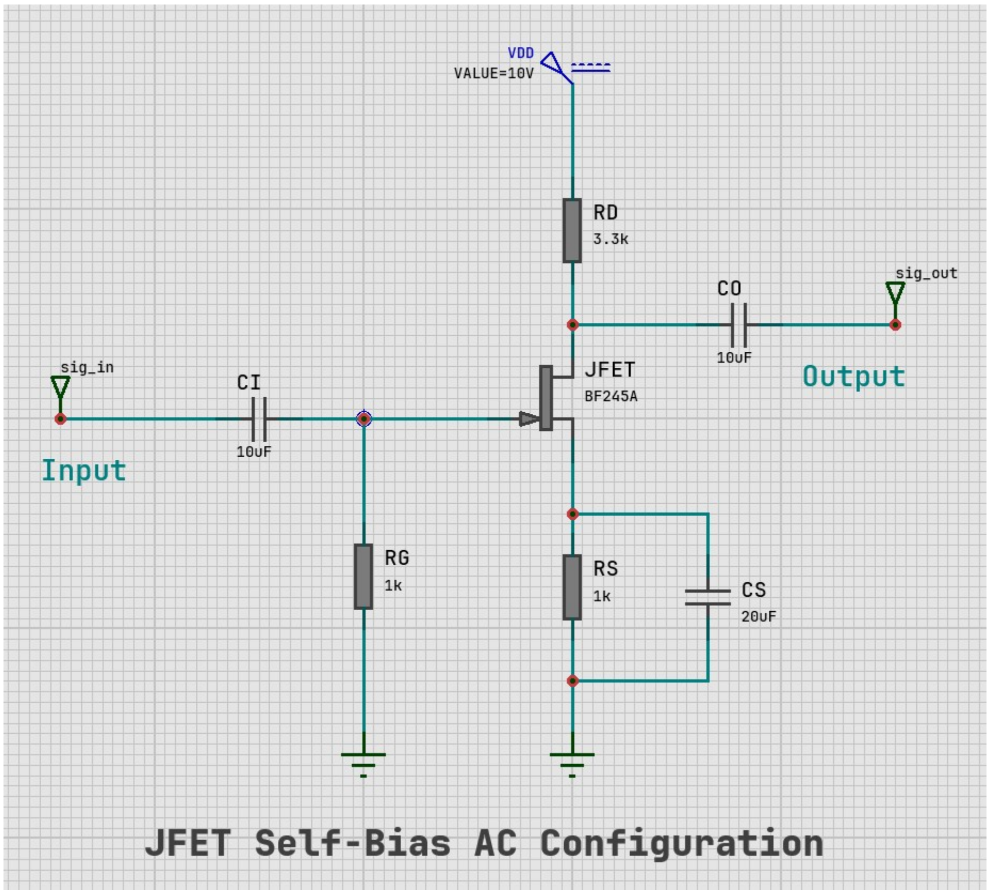
$$V_S = I_D R_S = 1V$$

$$V_{DS} = V_{DD} - I_D(R_S + R_D) = 5.7V$$

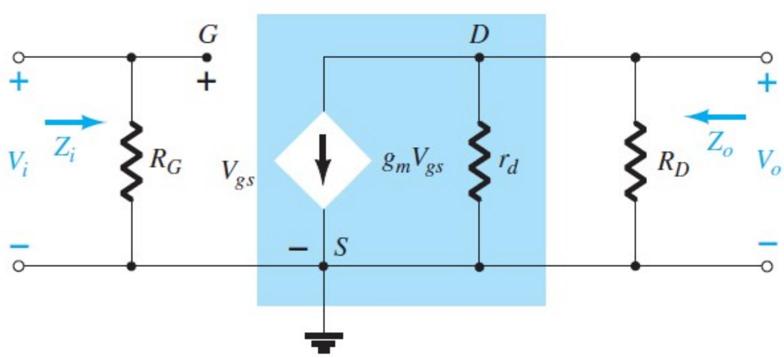
$$I_{D_Q} = 1mA$$

AC Analysis

For AC cases, the self-bias configuration would include some capacitors. And R_G that would serve as input impedance for the bypassed R_S case. Of course it would be replaced later by the input signals. Also observe C_S bypass capacitor to bypass R_S.



The small signal equivalent is:



Input and output impedances are:

$$Z_i = R_G$$

$$Z_o = r_d || R_D$$

And voltage gain is:

$$A_V = -g_m(r_d || R_D) \cong -g_m R_D$$

On the datasheet we observe $g_{os} = y_{os} = 40mmhos$, then

$$r_d = \frac{1}{y_{os}} = 25k\Omega$$

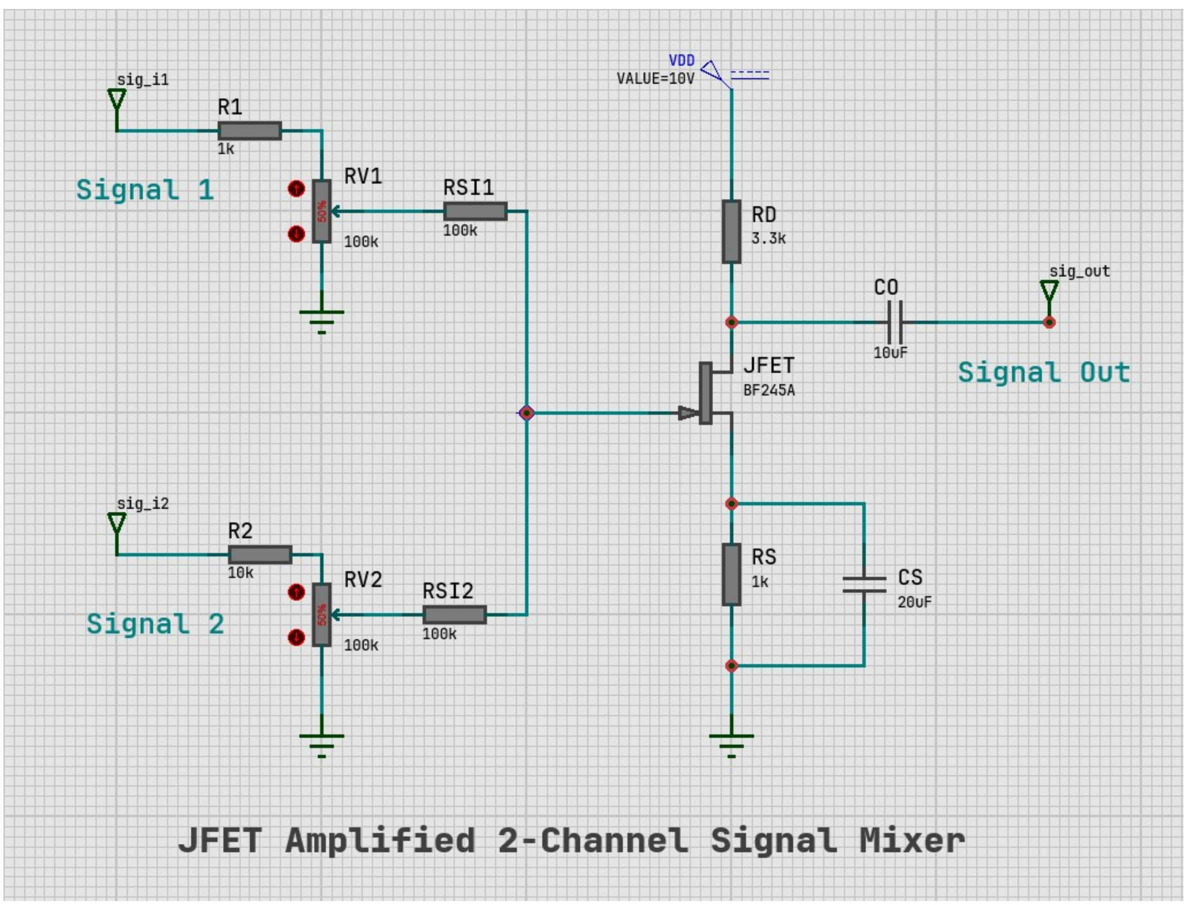
Since r_d is almost greater than $10R_D$, then we can approximate:

$$Z_o = R_D = 3.3k\Omega$$

$$A_V = -g_m R_D \cong -6$$

Signal Mixer

The two signals can be fed into the gate in two branches as shown below to result in the desired mixer:



Notice each signal receiver consists of a potentiometer labelled R_V and additional resistors labelled R_{SI}. The initial resistors R_1 and R_2 are meant to represent the internal resistances of the input signal devices.

The resistors R_{SI} are termed signal isolation resistors, and their purpose is to compensate for any difference in signal impedance to ensure that one does not load down the other and develop a mixed level of signals at the amplifier. If we try to measure the voltage at the gate using superposition theorem, we can clearly see the difference when they are included and when they are not:

$$v_G = \frac{1k\Omega}{10k\Omega + 1k\Omega} v_2 + \frac{10k\Omega}{10k\Omega + 1k\Omega} v_1$$

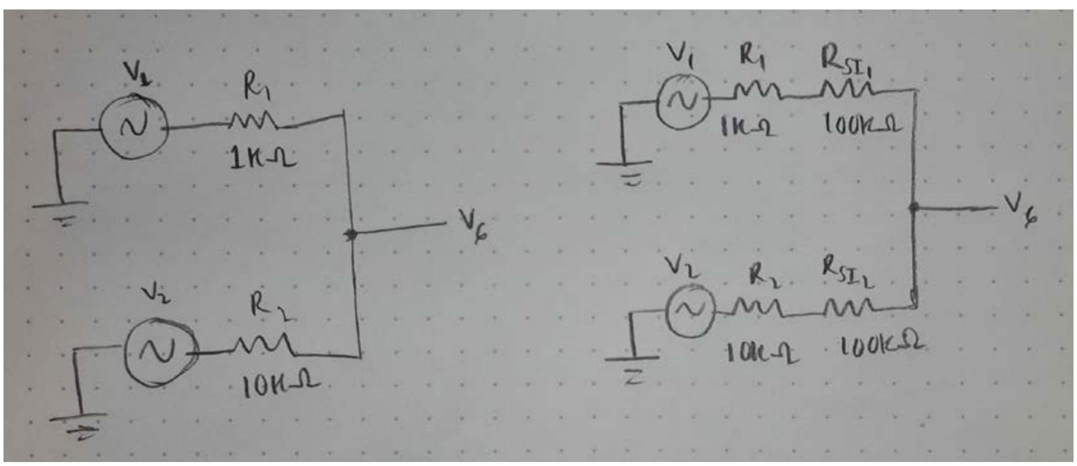
$$v_G = 0.09 v_2 + 0.9 v_1 \cong v_1$$

But with signal isolation resistors included:

$$v_G = \frac{100k\Omega + 1k\Omega}{100k\Omega + 10k\Omega + 1k\Omega} v_2 + \frac{100k\Omega + 10k\Omega}{100k\Omega + 10k\Omega + 1k\Omega} v_1$$

$$v_G = 0.909 v_2 + 0.990 v_1$$

Hence their contributions are normalized, no matter their internal resistances.



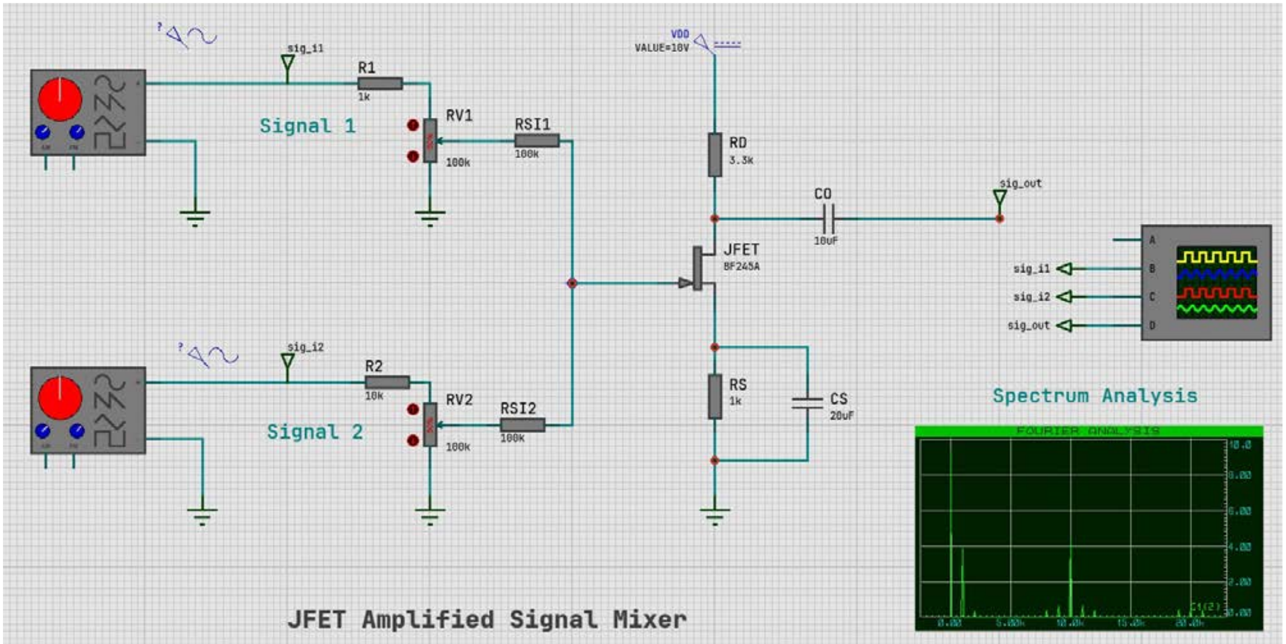
The potentiometers R_V act as volume controllers. By increasing or decreasing some more resistance, the effects of the signals at the gate is adjusted. Thereby providing a way to modify the incoming signals and adjust how they are to be combined.

It goes without saying that the higher the values of the R_V and R_{SI} the better, to be prepared for inputs of any impedance levels.

Simulation and PCB

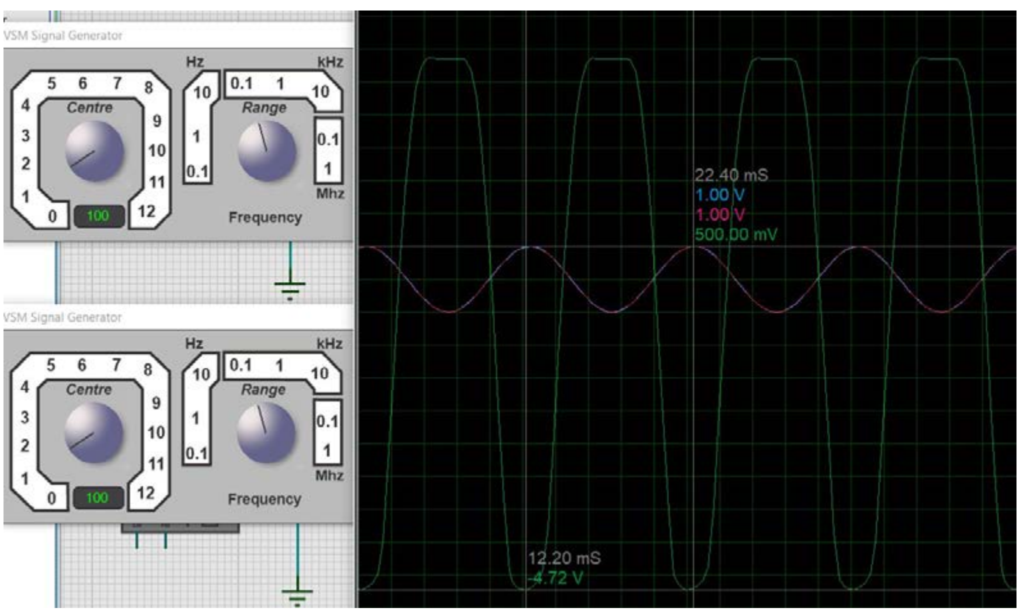
Simulation

Ready for simulation:

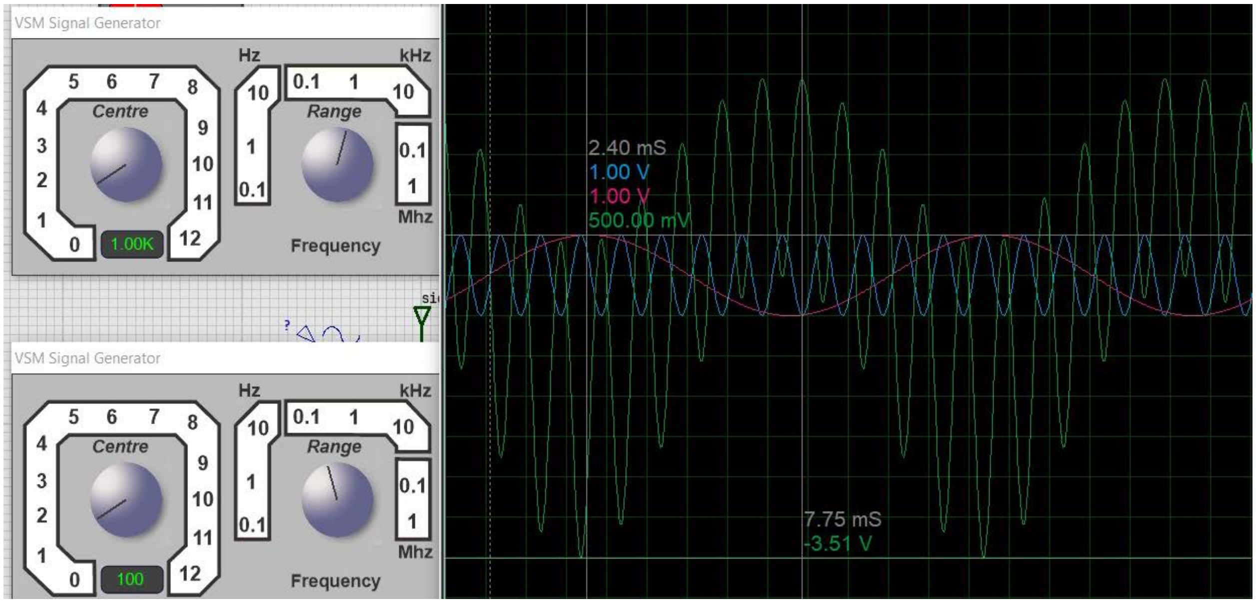


Results

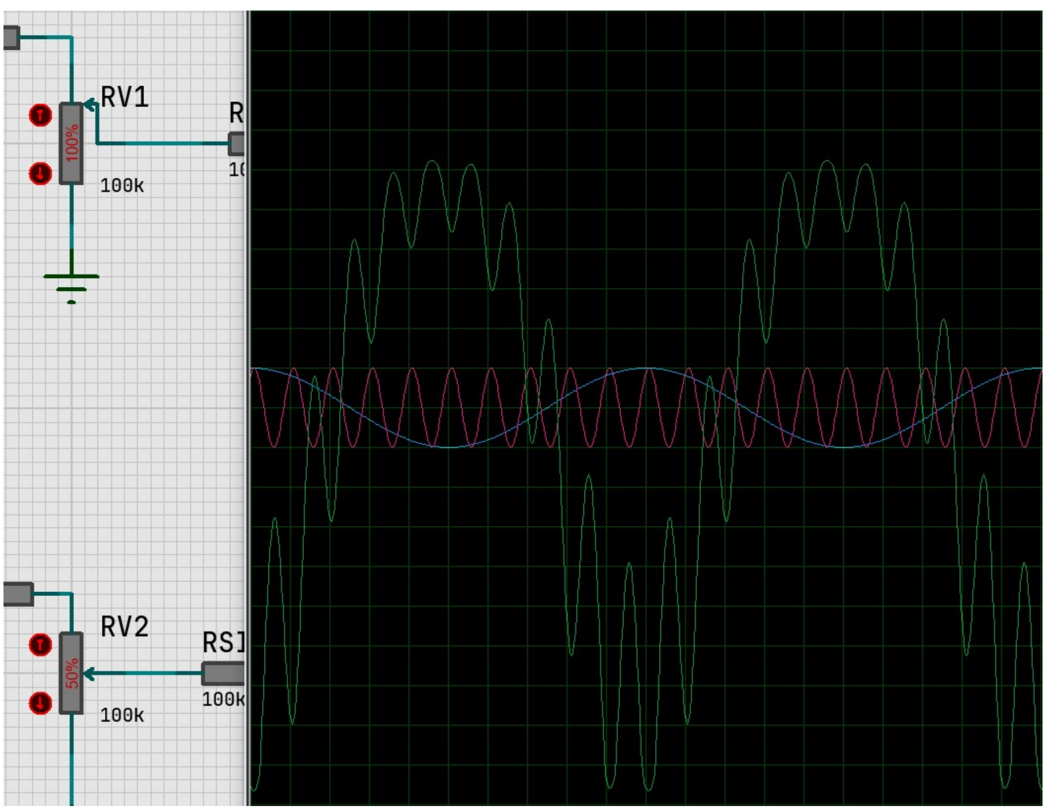
When both input signals are set at $V_{in} = 2V_{PP}$ and suppose they both have same frequency then it works as a regular inverting amplifier. Where $A_V = -4.7$ is close to the theoretical value.

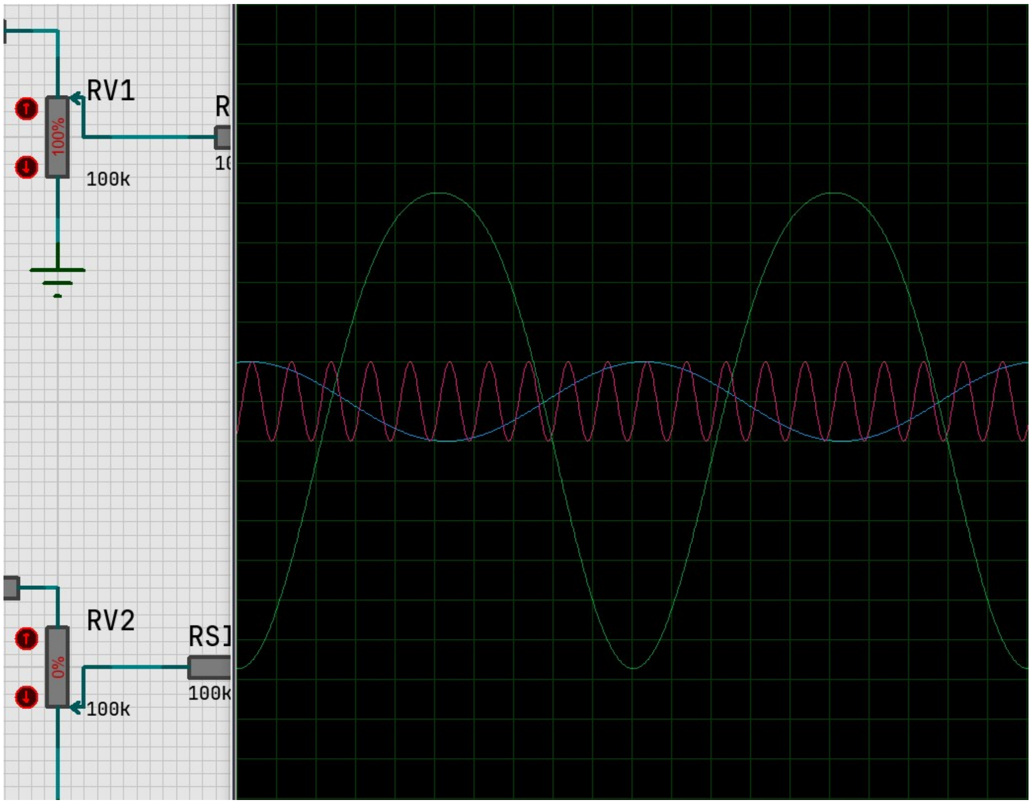


But if the signal frequencies differ, e.g say $\boldsymbol{f_1 = 1kHz}$ and $\boldsymbol{f_2 = 100Hz}$, then they mix to form the output signal with frequencies, $\boldsymbol{f_1 \pm f_2}$.

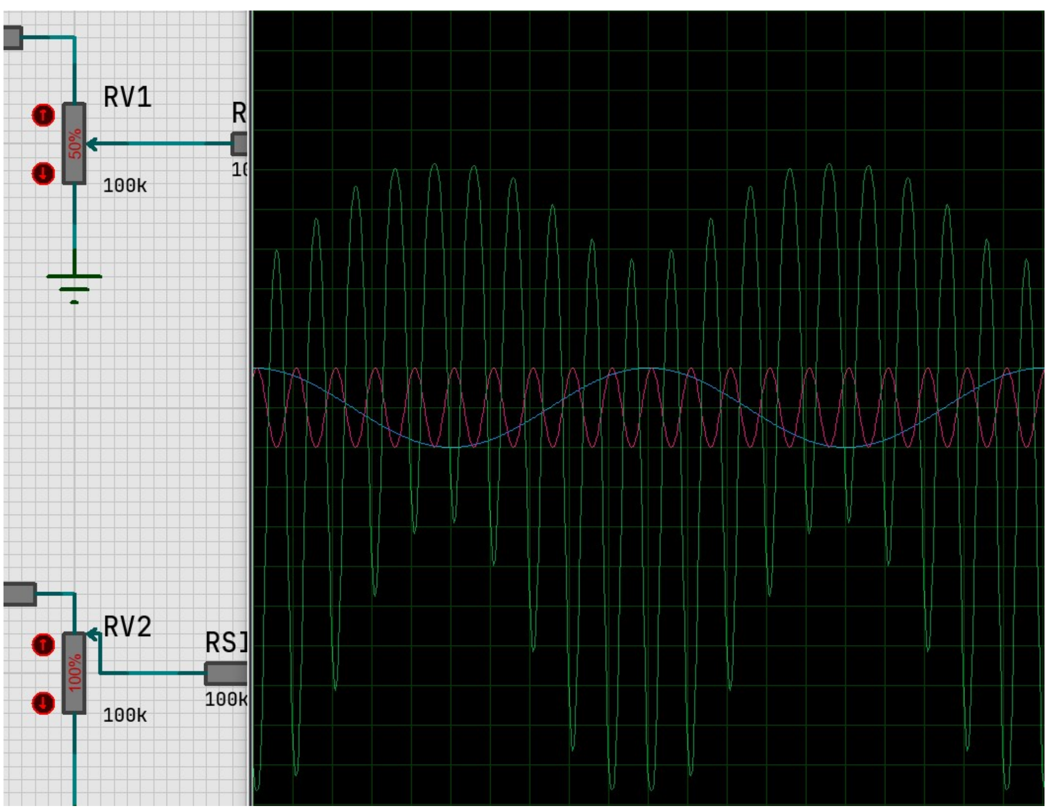


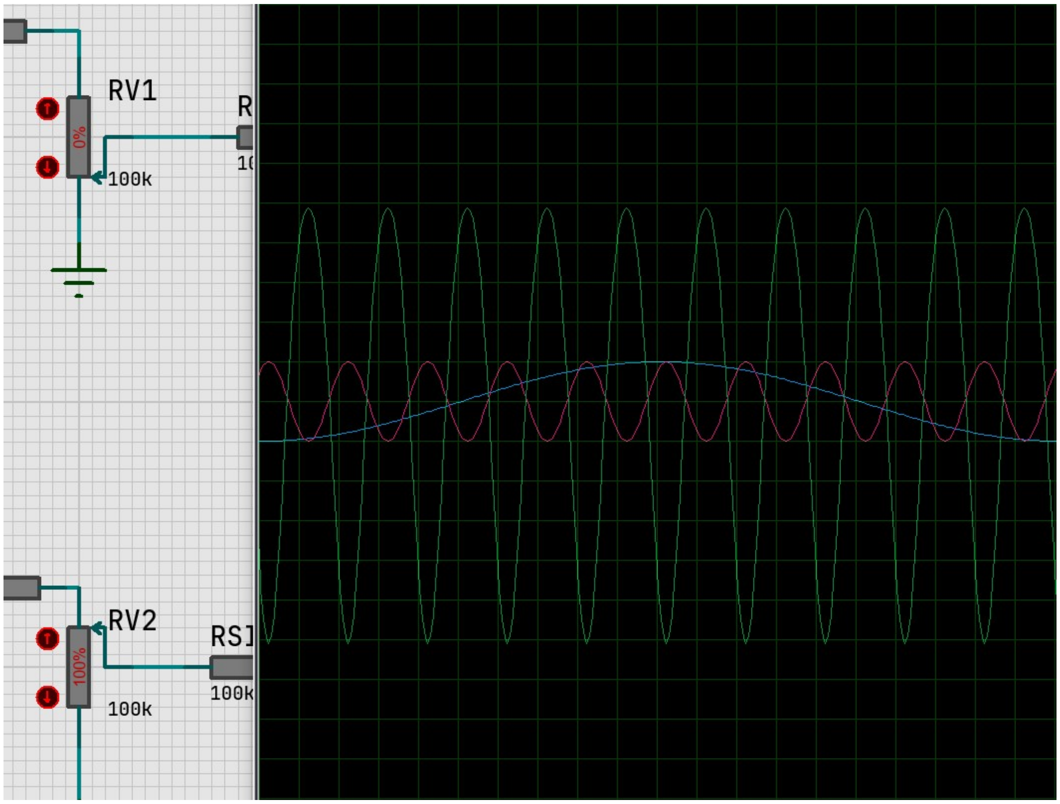
If we keep $\boldsymbol{f_1 = 100Hz}$ and $\boldsymbol{f_2 = 1kHz}$, and turn our attention to the volume control. Decreasing the potentiometer at one signal, say the $\boldsymbol{R_{V2}}$, the effect of the **first signal** will be more pronounced on the mixed signal.



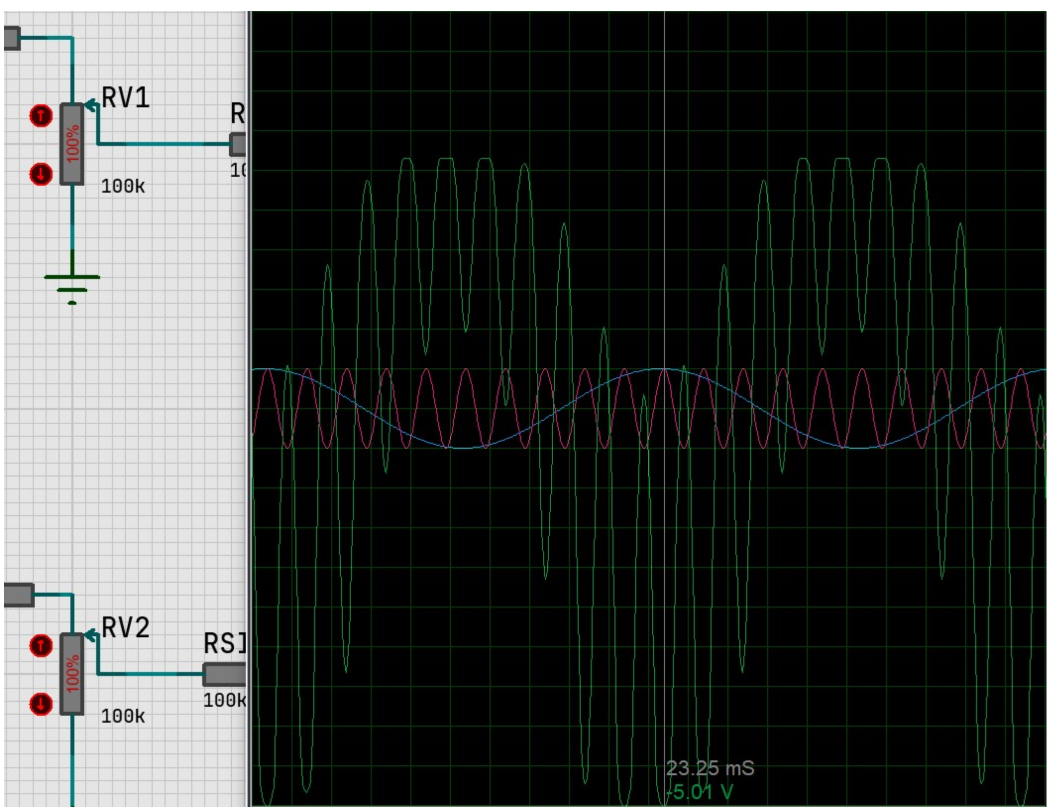


Similarly reducing $\boldsymbol{R_{V1}}$ will decrease its effects and let the **2nd signal** be the dominant one.

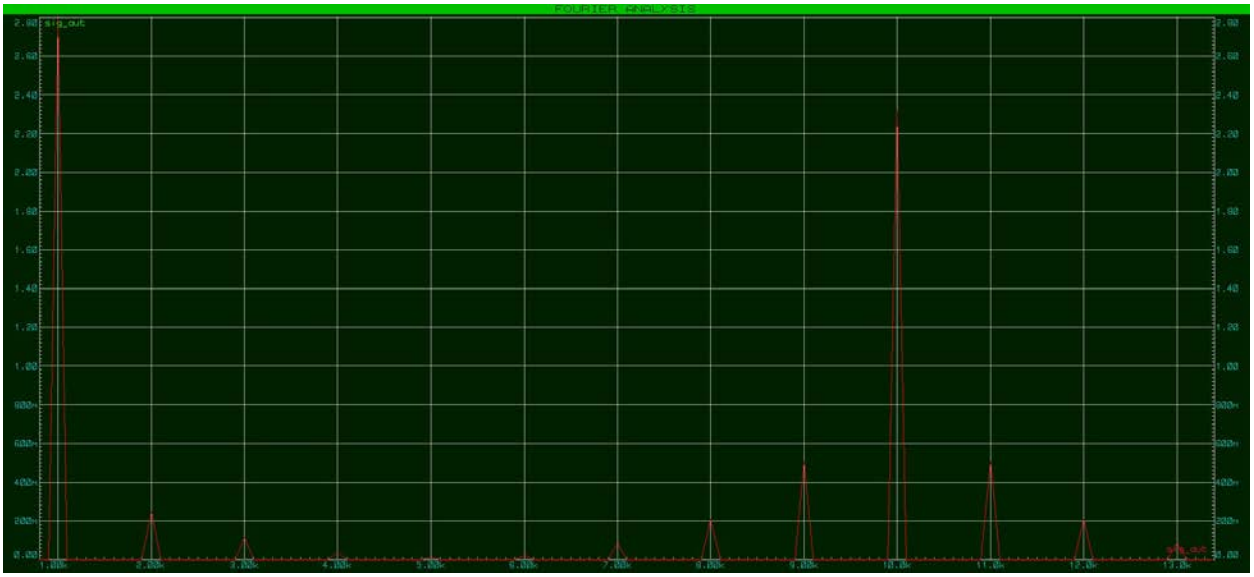




But with both at full strength, the result is equal. Notice also the gain is closer to the theoretical value here:



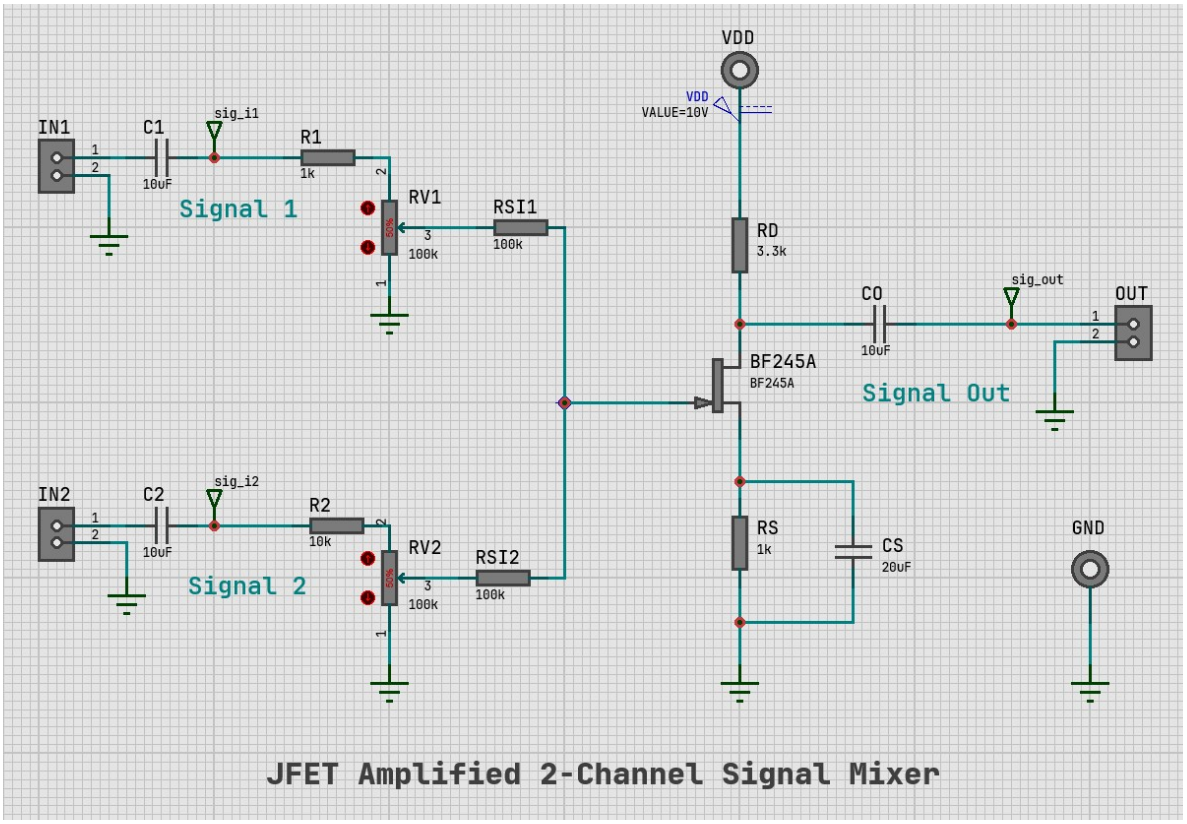
The frequencies of the output signal can be observed from spectral analysis:

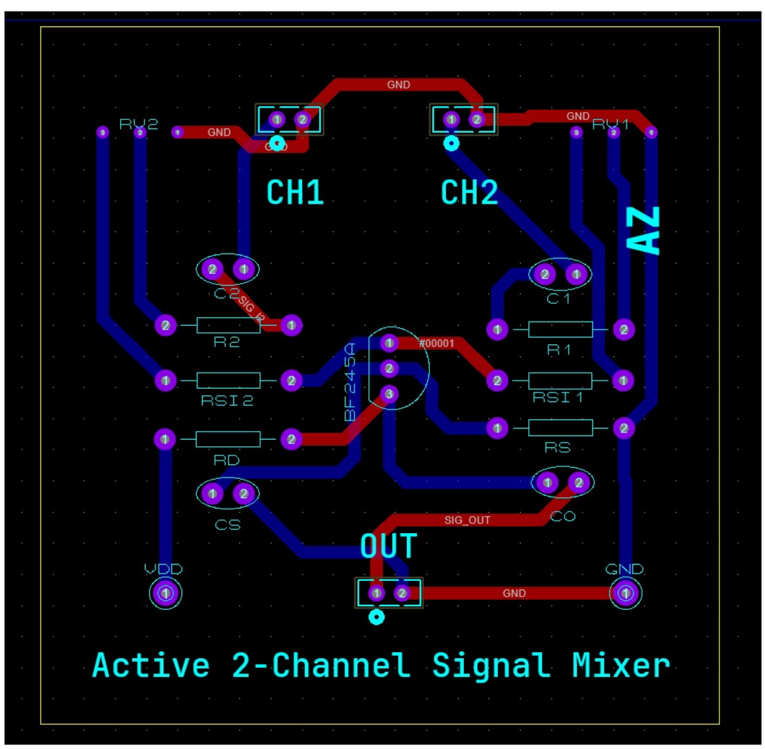


This is for the case when $f_1 = 1kHz$ and $f_2 = 10kHz$. We observe spikes at $1kHz$ and $10kHz$. And also some trailing ones at $1kHz$ intervals. Clearly they are a result of the algebraic addition and subtraction of these initial frequencies $f_1 \pm f_2$.

PCB

This is the designed PCB for the circuit.

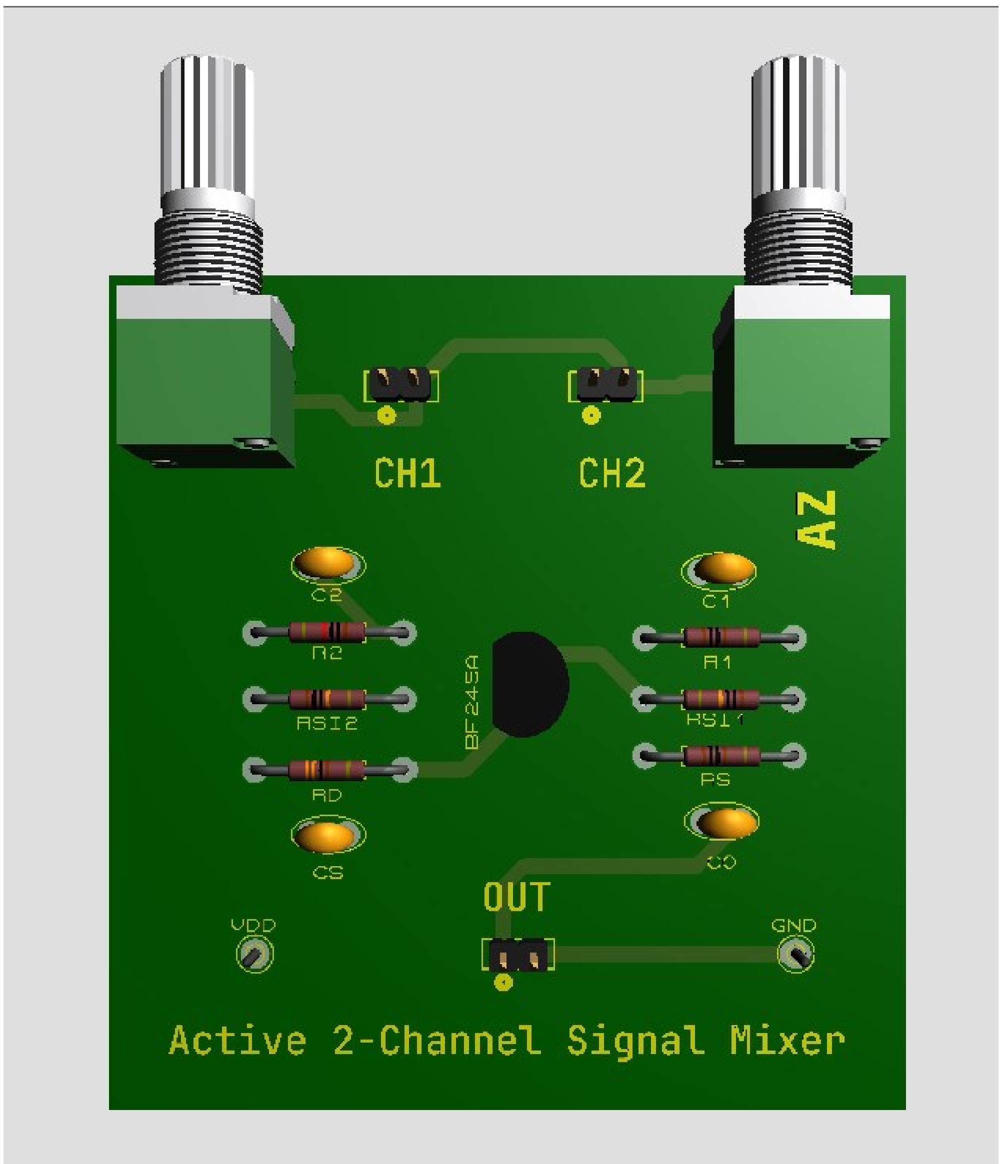


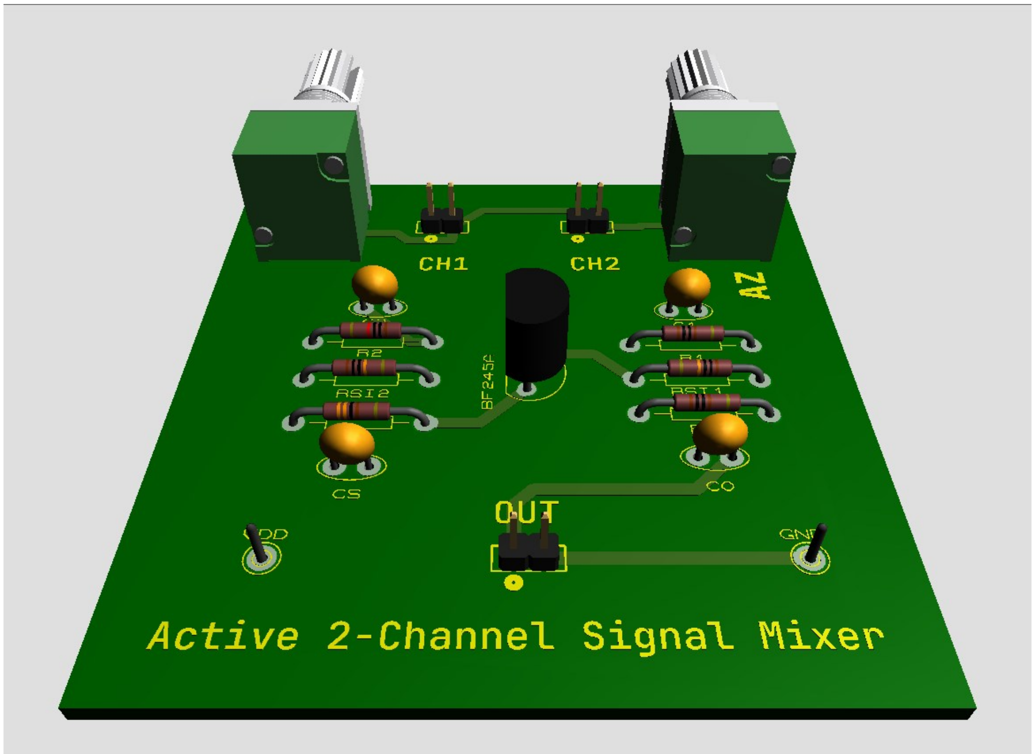


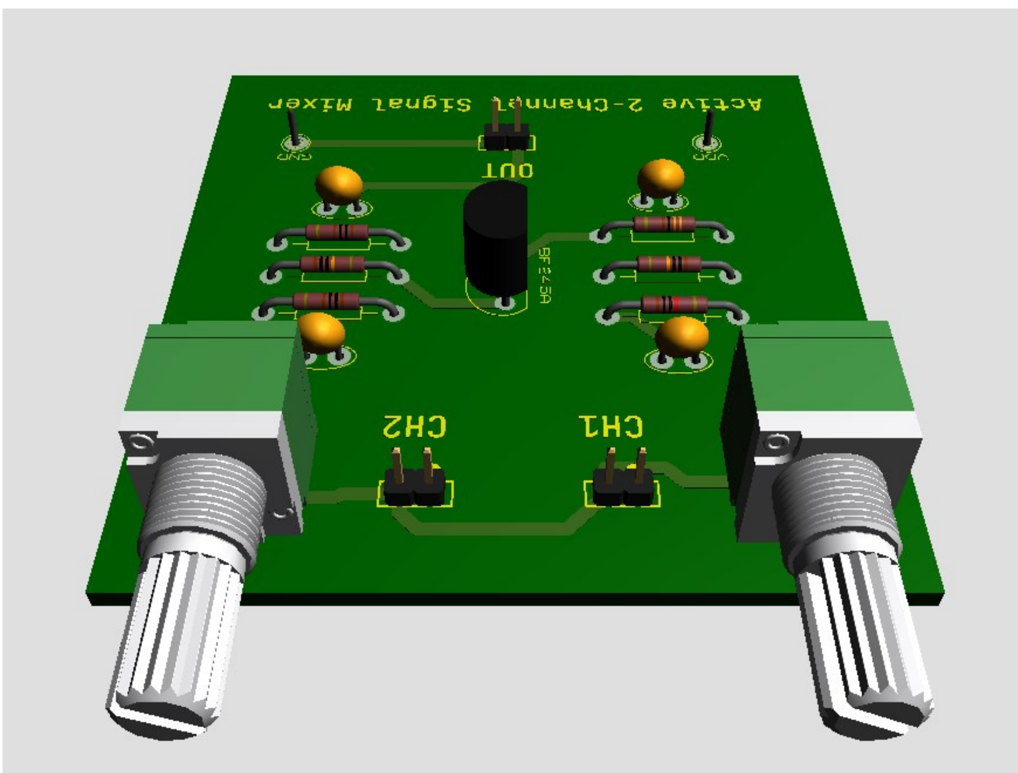
The components used are:

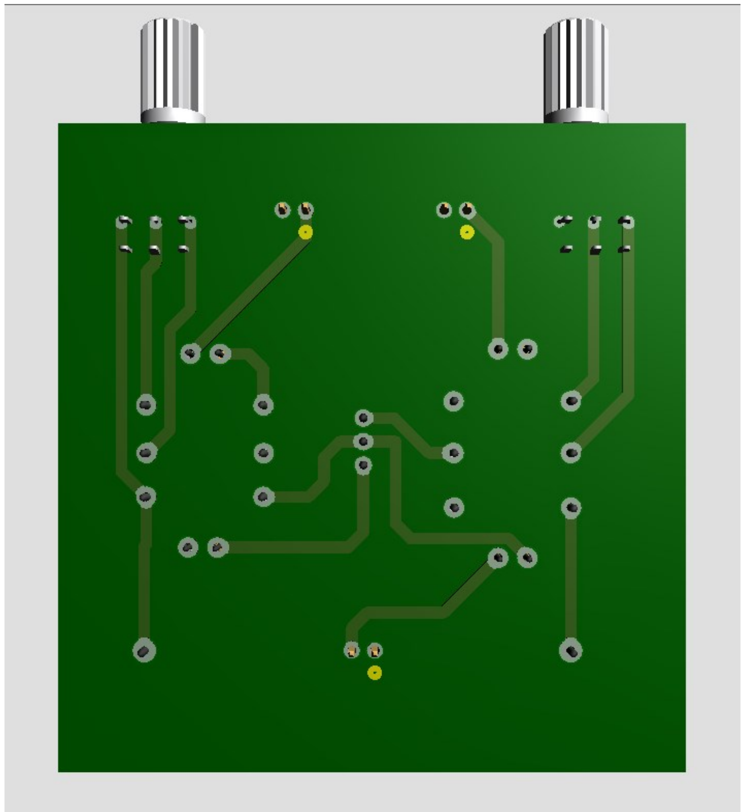
- 1 x B245A n-channel JFET
- 2 x 100k potentiometers
- 4 capacitors of values 10uF and 20uF or more.
- 4 resistors of values 1k, 3.3k and two 100k

Here is the final PCB 3D visualization in various perspectives:

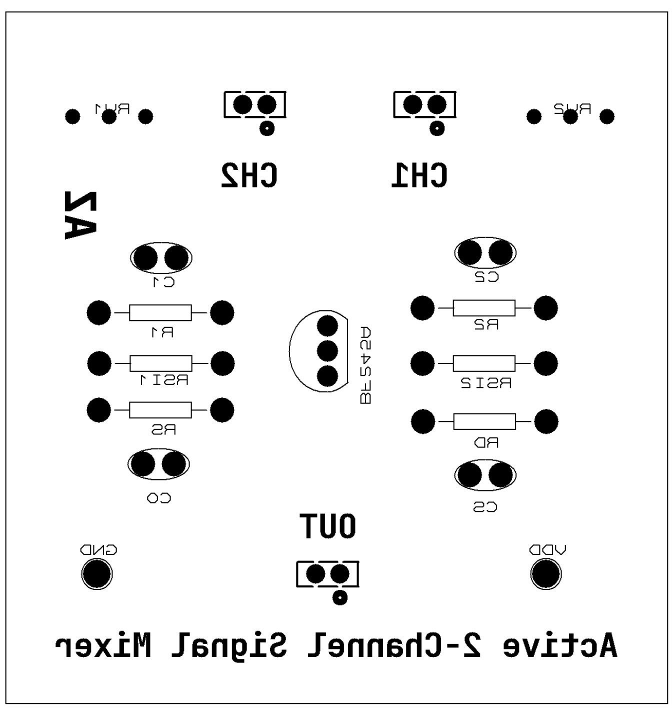


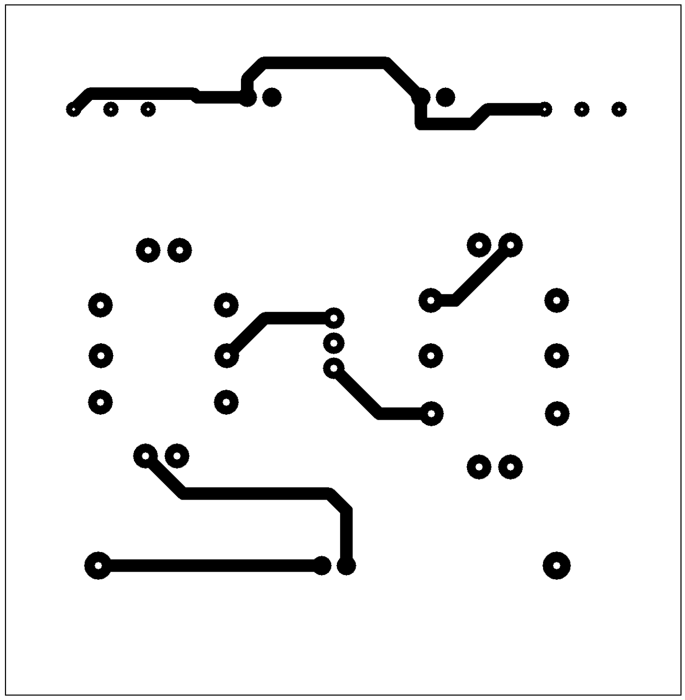

CH1
CH2
AZ
BF245A
R2
RSI2
RSI1
CS
CO
OUT
GND
Active 2-Channel Signal Mixer

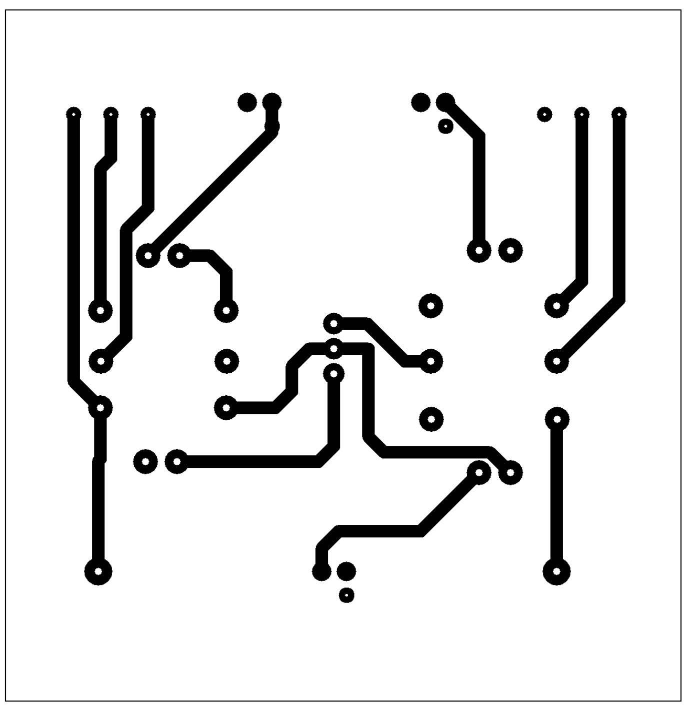




PCB Print-Outs



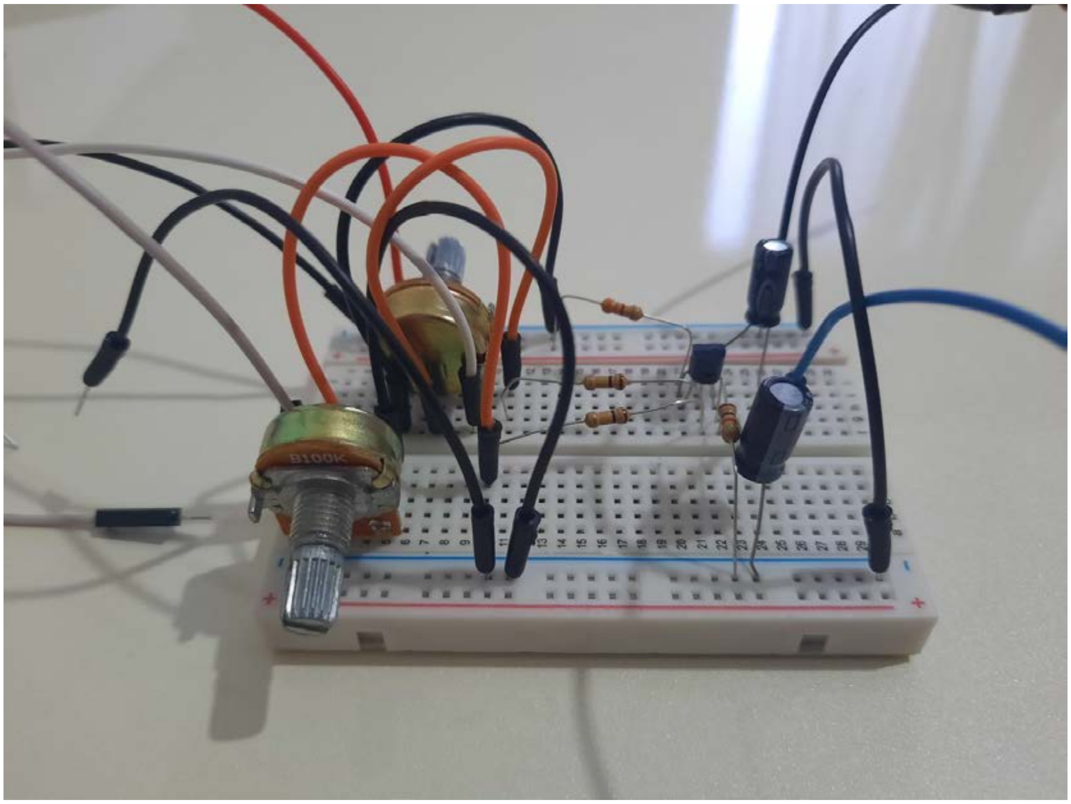


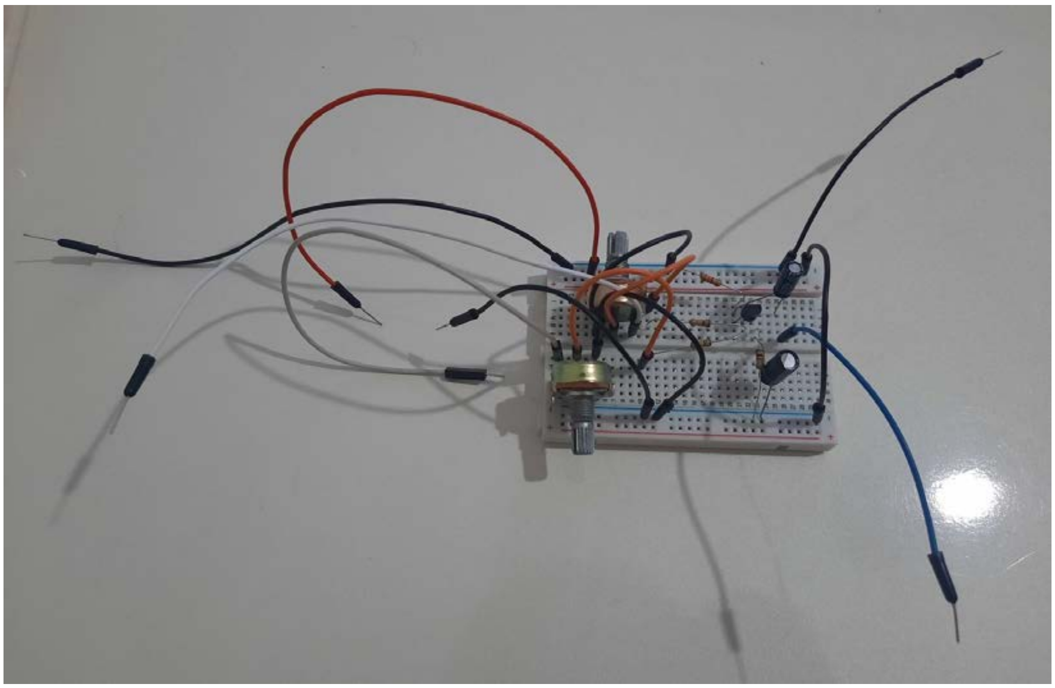


Top and Bottom copper respectively

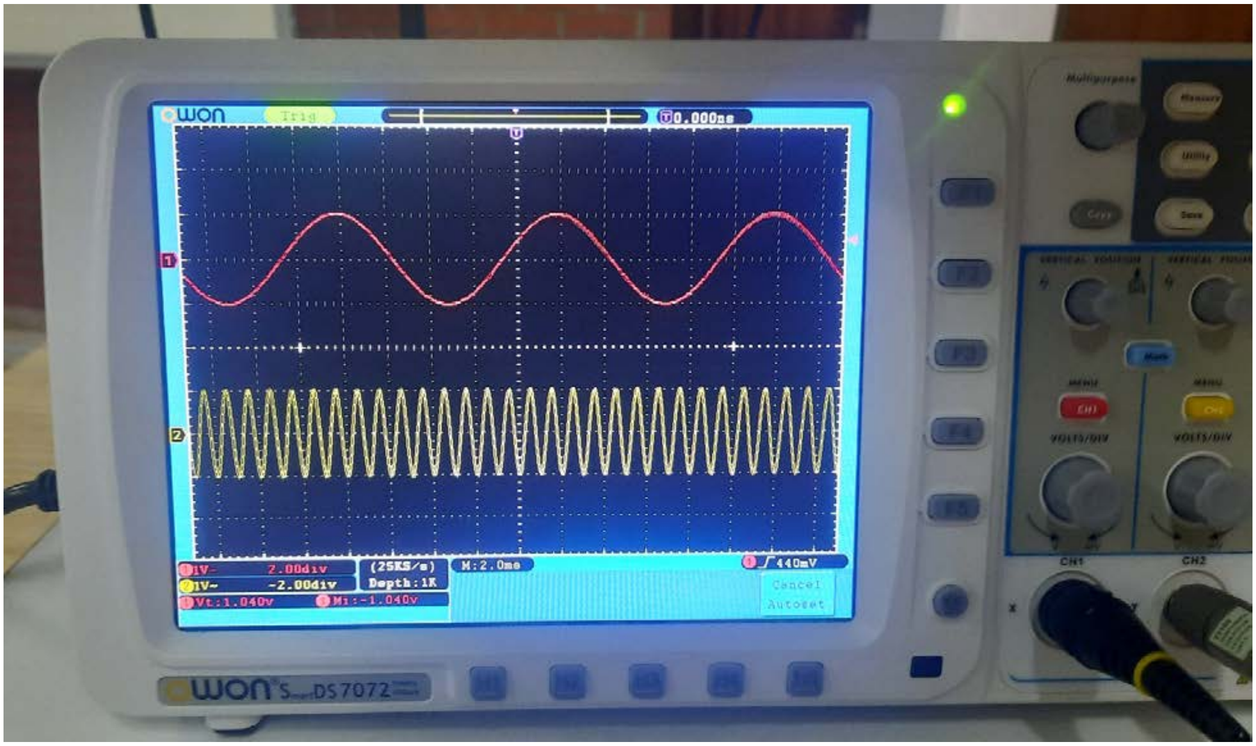
Experimental Results

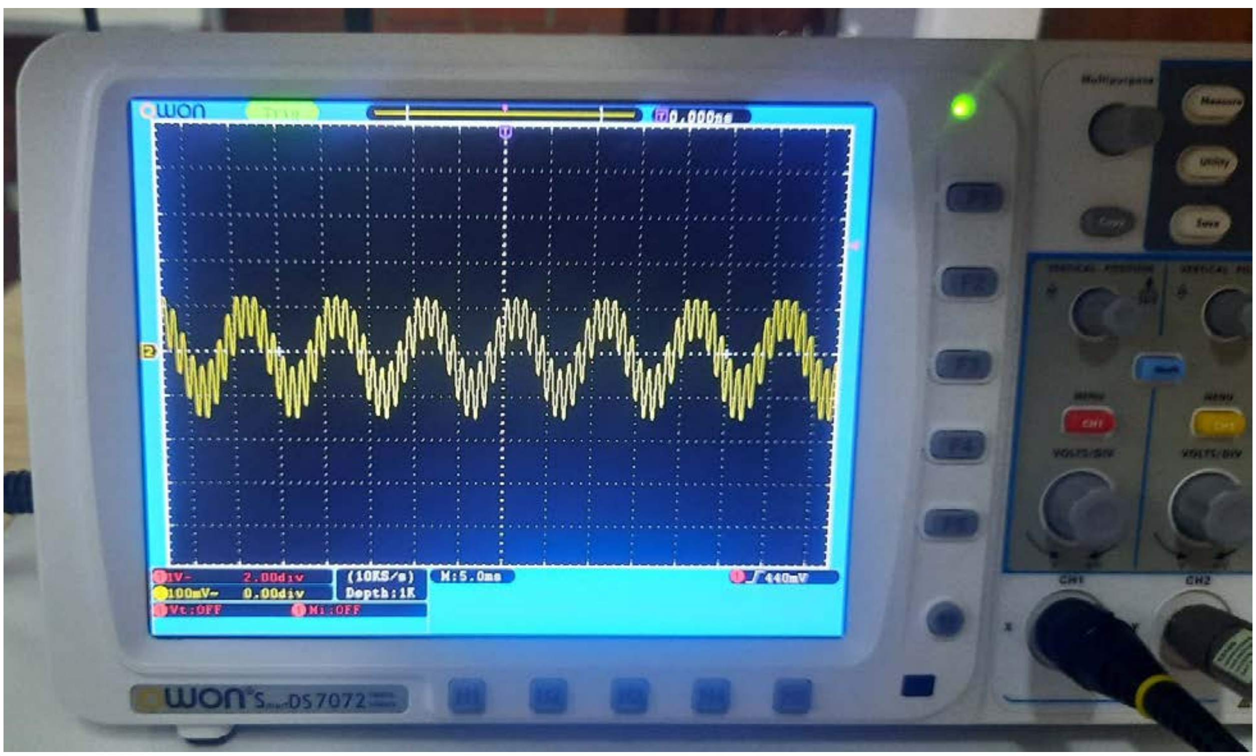
Circuit set on the breadboard, where white wires are for the two signals, and the blue wire is the output signal. Red for V_{DD} and black for GND.





On the oscilloscope, first the two input isgnals are shown. They have differing frequencies. The 2nd picture is of them being mixed in the output signal.





All files available:

https://github.com/az-yugen/EEE-2002-4-6.-LAB