Analog Lab (EE2401)
Experiment 7 : Mixer

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1 Aim

our aim here is to design Mixer for frequency translation for a given input signal and a known periodic signal.

2 Problem statement

1. Frequency translation is an important operation in wireless systems. As we already know, a linear time-invariant system can never produce a signal with frequency different from the input signal frequency. Mixing is a process of multiplying different signals to obtain a signal at new frequency. In this experiment, our aim is to design a circuit which can multiply an input voltage signal with a known periodic signal to result in a known frequency translation of the input signal. Use the following constraints to design a mixer circuit:.

. • Input signal frequency: 1 kHz.

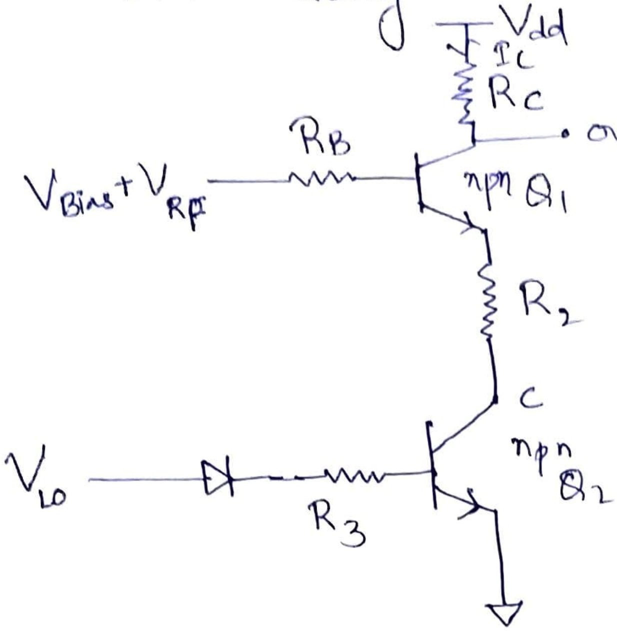
. • Known periodic signal: 10 kHz output from the oscillator designed in Exp. 5.

. • Use these devices for mixer circuit: BJTs (2N3904, npn and 2N3906, pnp), diode (1N4148) in addition to ideal passive components.

(Hint: V-I relationship of semiconductor devices when expressed as a polynomial has many high order terms. Use it to get current which depends on product of voltages and then convert the current back to voltage.)
Use FFT function in LTspice to find frequency component of various signals.

Method 1

Mixer using transistor as switch.

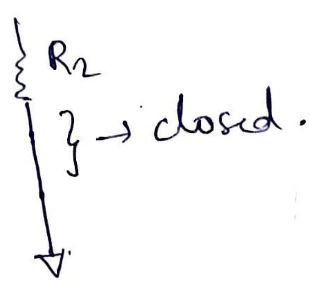


$V_{RF} \rightarrow$ input signal

$V_{LO} \rightarrow$ oscillator output

Now when $V_{LO} = 3.5$, Q_2 acts like a closed switch,

Case ①: $V_{BE} > 0.7$, $V_{CE} \approx 0$



$$I_C = \frac{V_{Bias} + V_{RF} - V_B}{R}$$

$$\Rightarrow V_{out} = V_{dd} - I_C R_C$$

$$= V + K.V_{RF}$$

Case ②: And when $V_{LO} = -3.5$, Q_2 acts like an open circuit

open

$\Rightarrow I_C \approx 0$

$V_{out} \approx V_{dd}$

Therefore we can say $V_{out} = V_{bias} + K V_{RF}\, Sgn(V_{LO})$

$$Sgn(V_{LO}) = \begin{cases} 1, & V_{LO} > 0 \\ 0, & V_{LO} = 0 \\ -1, & V_{LO} < 0 \end{cases}$$

Since frequency of V_{LO} = $Sgn(V_{LO})$ frequency.

$V_{RF}\, Sgn(V_{LO})$ has peaks at $f_{RF} + f_{LO}$, $f_{LO} - f_{RF}$, $f_{RF} + 3f_{LO}$, $f_{RF} - 3f_{LO}$ because of harmonics of pulse.

We also need to make sure Q_2 is in Saturation when $V_{LO} = 3.5V$.

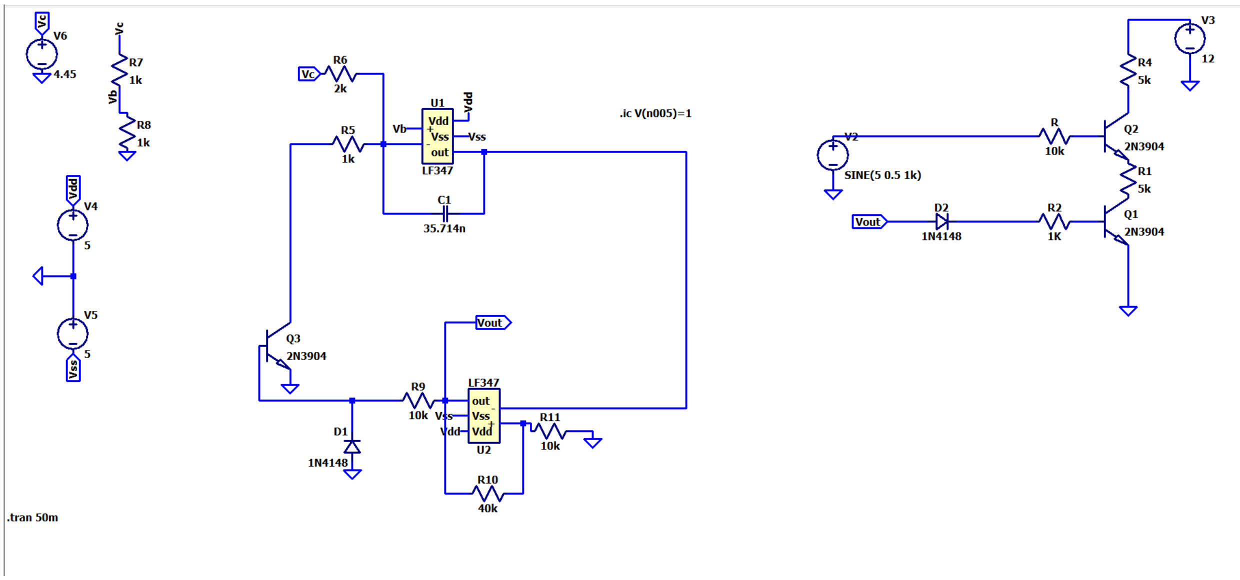
$$\Rightarrow \quad I_B > \frac{I_C}{\beta} \qquad \frac{\overset{3.5 - 0.7}{V_{LO} - V_{BE}}}{R_3} > \frac{I_C}{\beta}$$

$$\Rightarrow \quad R_3 \leq K R_2 \qquad \Rightarrow \boxed{R_3 < \frac{\beta R_2}{2.8V}}$$

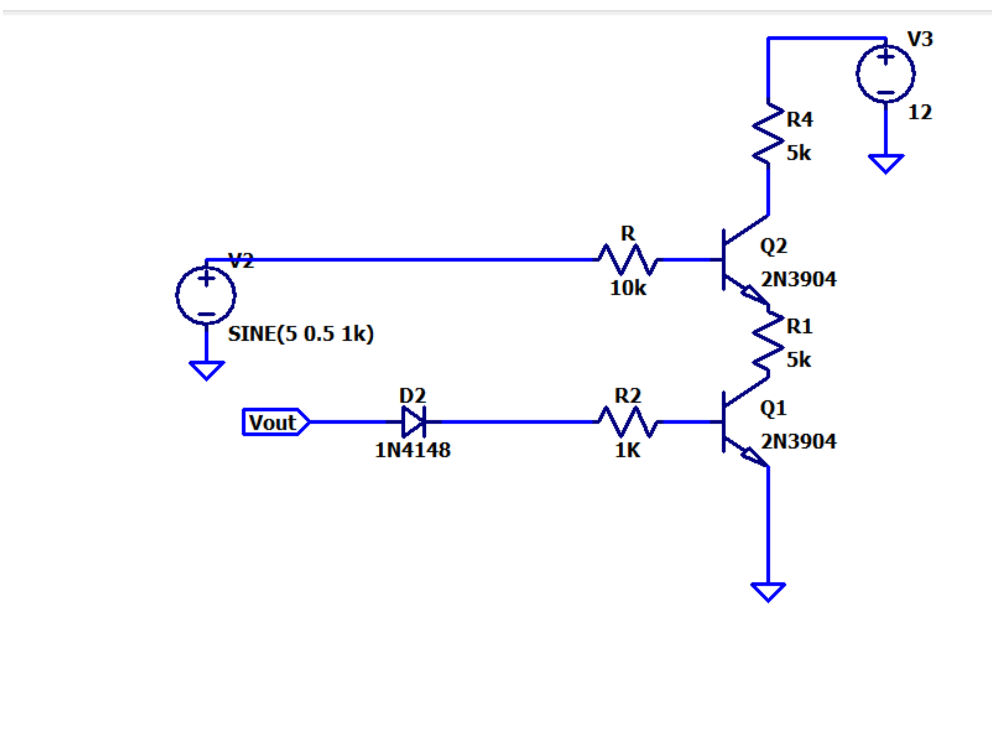
We also need to choose R_B and R_C such that it's Q_1 in linear region

3 Design schematics

Schematic of the Mixer using switching

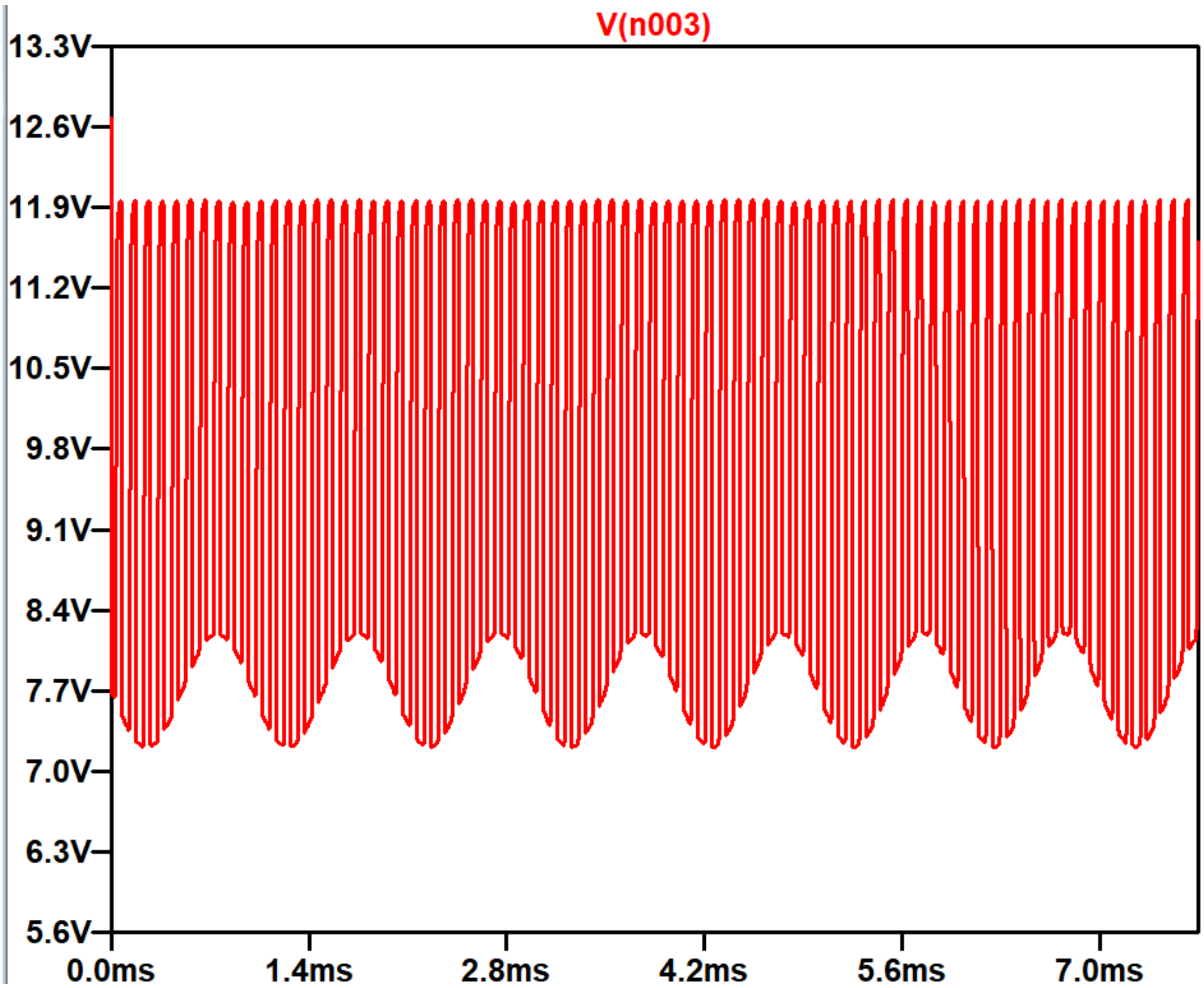


Mixer circuit



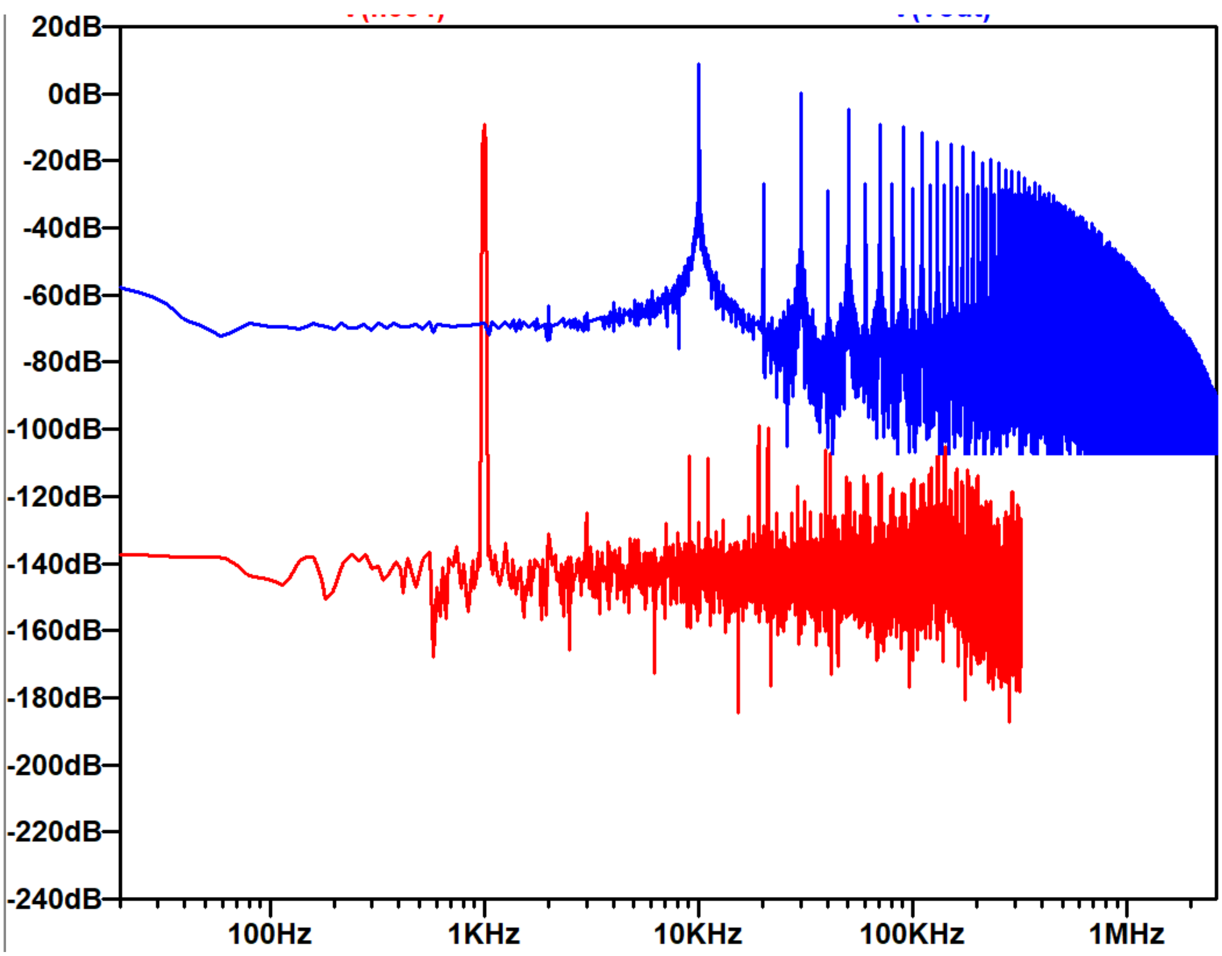
Circuit schematic where Vout is the Oscillator input

Output Time domain



Output at Q2 collector

Input FFT



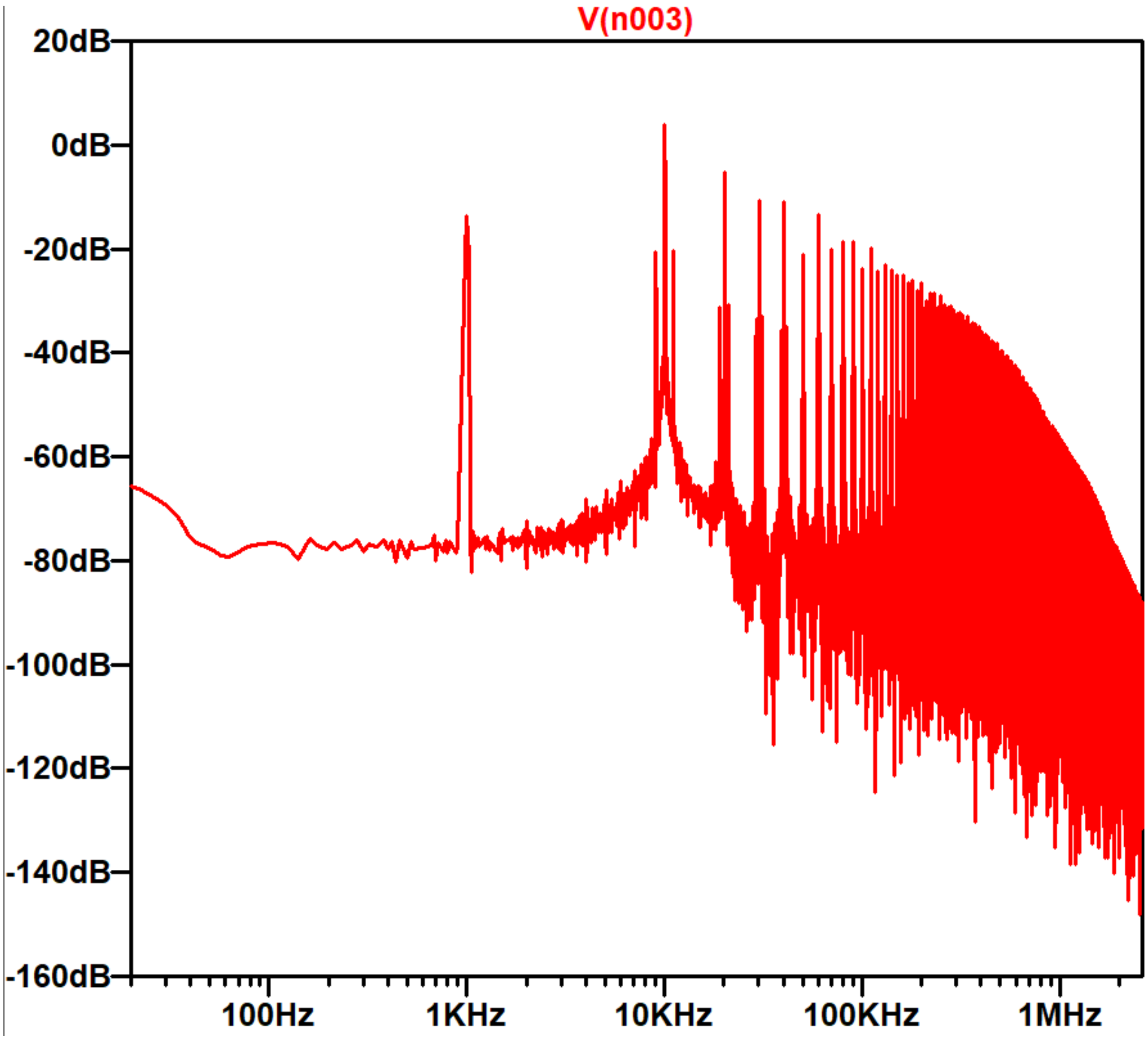
Input signal(Red) and Known input (Blue)

• The input is sinusoid with 1KHz and known input is oscillator output with 10KHz.

• The peak for sinusoid input FFT is at 1KHz and little peaks at some higher frequencies.

• The peak for oscillator input FFT is at 10KHz, 30KHz and little peaks at some higher frequencies.

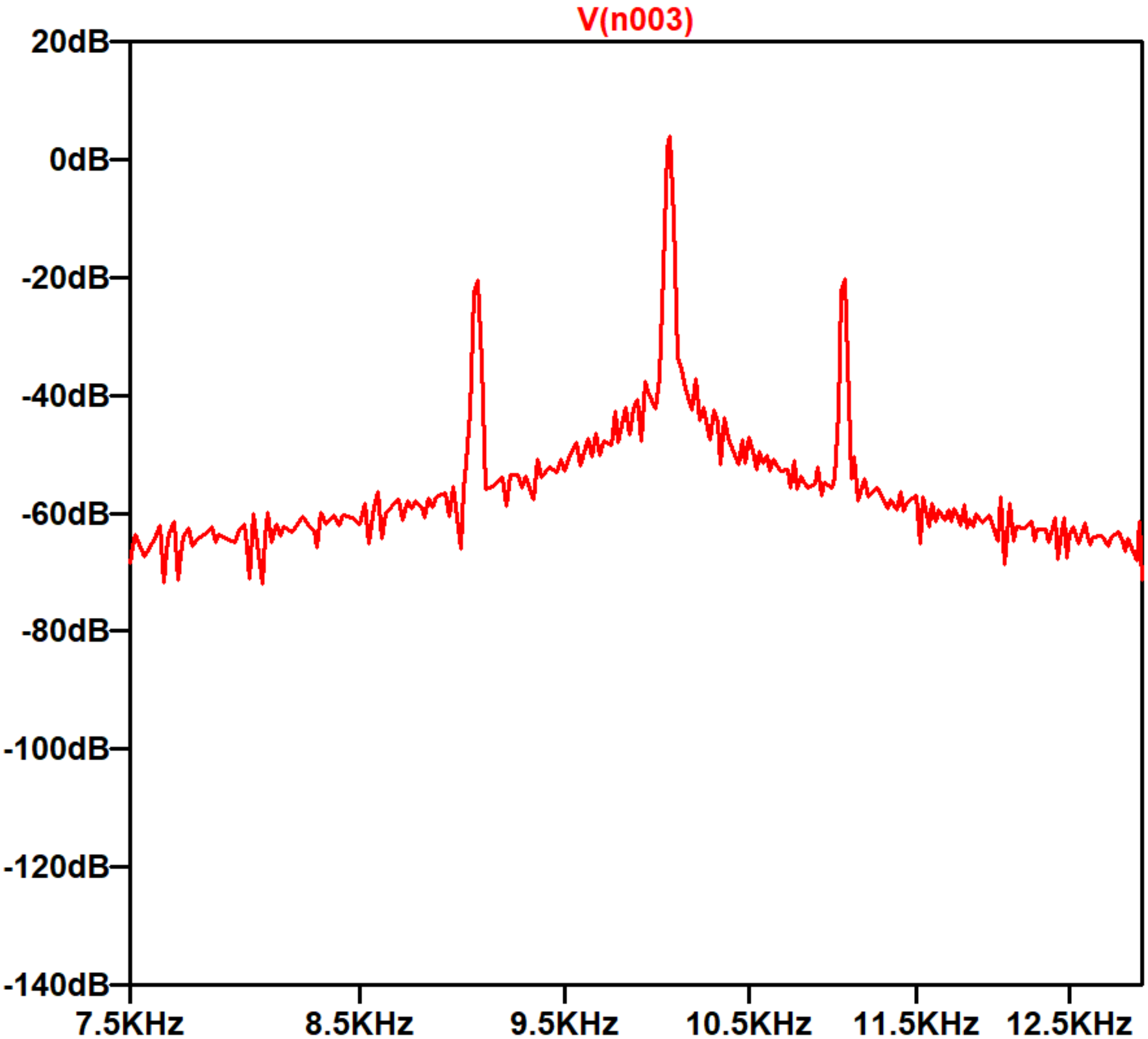
Output FFT



Output FFT

- The peak for output FFT is at 1KHz, 9KHz, 10KHz, 11KHz and peaks at some higher frequencies.

Output FFT

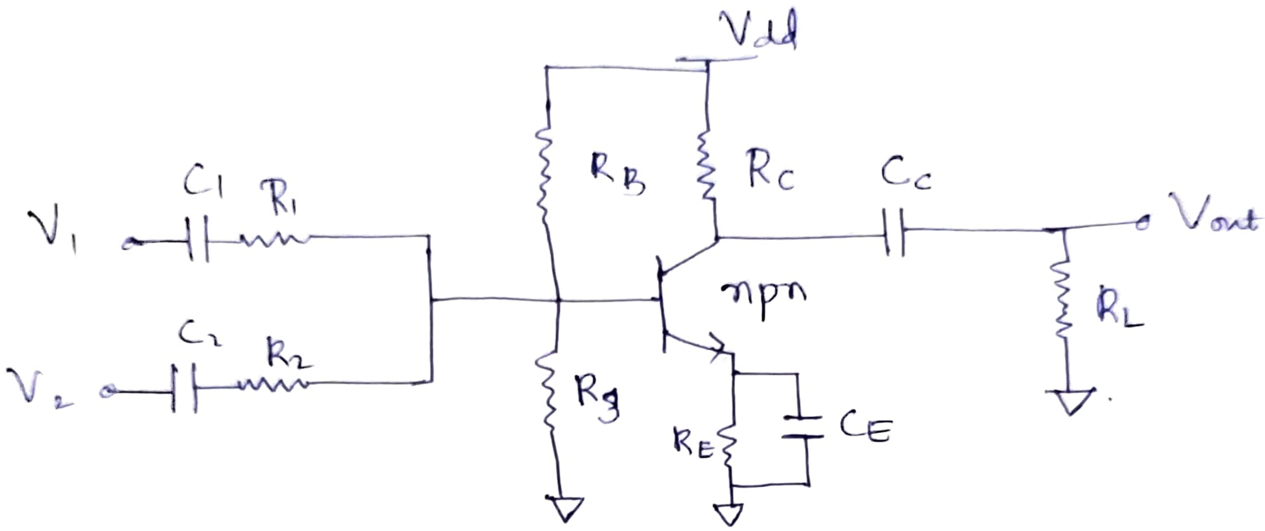


Output FFT

• Therfore we have seen peaks at f-f_0, f+f_0 which is what our aims is.where f and f_0 are input frequencies.

Method 2:

We now use diode characteristics to obtain product term of voltages.



$V_{Bias} \approx \dfrac{V_{dd} R_3}{R_B + R_3}$ = acts like voltage divider.

$V_{small} = K_1 V_1 + K_2 V_2$, K_1, K_2 are such that it's small compared to biased.

Therefore we need to choose $R_2, R_1 >> R_3$

$A_v = \dfrac{\alpha' R_C}{R_E}$ if C_E is not there.

$A_v = \alpha \dfrac{R_C}{Z_E}$, we use capacitor to increase the gain.

Also the $Z_E = \dfrac{R_E}{2j\omega C_E R_E + 1}$

C_E is large such that it becomes short.

and $V_E \approx 0$

$\Rightarrow V_{BE} = V_{bias} + K_1 V_1 + K_2 V_2$

$$I_B = I_{B_0} e^{V_{BE}/V_T}$$

$$I_C = \beta I_{B_0} e^{V_{BE}/V_T}$$

$$I_C = I_S e^{\frac{V_{bias} + K_1 V_1 + K_2 V_2}{V_T}}$$

$$= I_{C_0} + \frac{\partial I_C}{\partial V_{BE}} \times (K_1 V_1 + K_2 V_2)$$

$$+ \frac{1}{2} \frac{\partial^2 I_C}{\partial V_{BE}^2} (K_1 V_1 + K_2 V_2)^2$$

$$= \cdots\cdots + K V_1 V_2$$

Therefore we can get the required frequencies.

$V_{Bias} \approx 2.1$, we use $R_B = 10 R_3$, $R_1 = R_2 = 10 R_3$

We also use the filter C_c and R_L to Remove high frequency terms and DC values

$$\Rightarrow \boxed{W_{cut} = \frac{1}{R_L C_c}}$$

$\frac{1}{2\pi f C_c}$ is reactance to control for removing DC.

$W_{cut} > 100KHZ$, since wea are using oscillator 10KHZ, So we are making sure 10times the frequency is cutoff

$\frac{1}{2\pi f C_c}$ typical values are used. in circuit to block DC and Send AC.

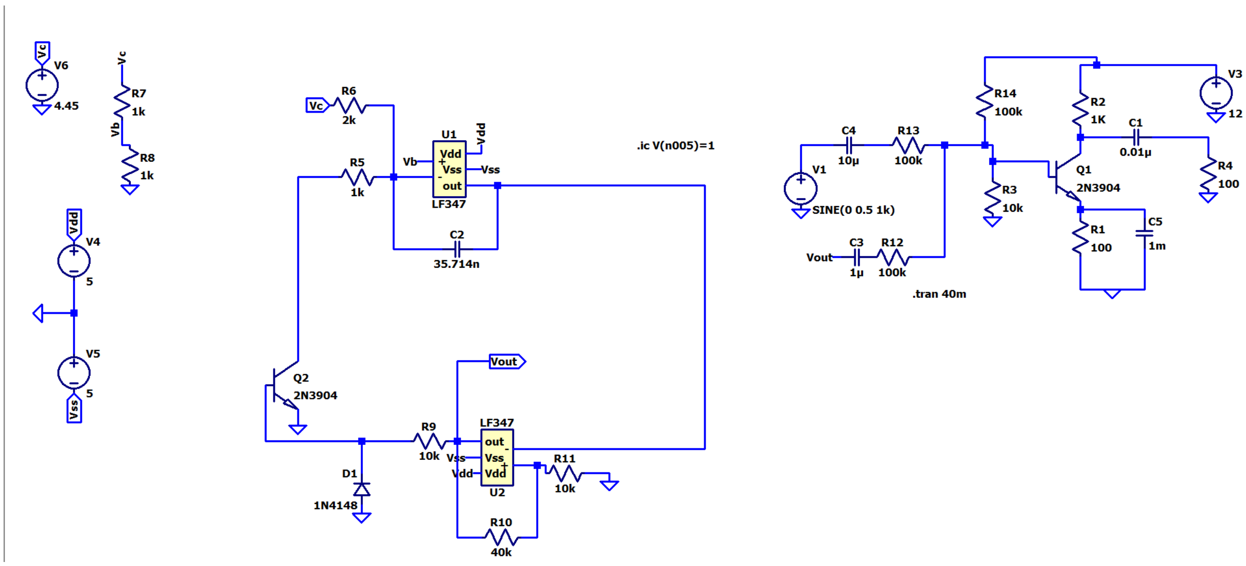
we choose R_C assuming $\beta = 100 \sim 300$ and make. it's in linear region.

$$\frac{R_B}{R_C + R_E} > \beta \text{ for linear.}$$

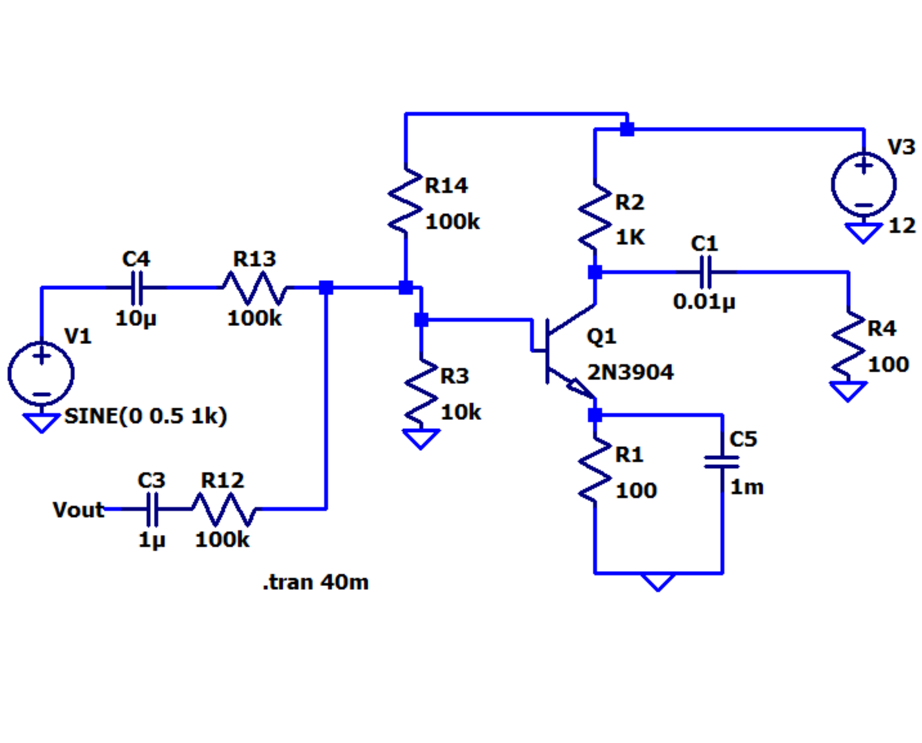
$\Rightarrow$ we choose R_B, $\beta = 100 \sim 300$ is typically in this range.

4 Design schematics 2

Schematic of the Mixer using current dependence on product of voltages



Mixer circuit



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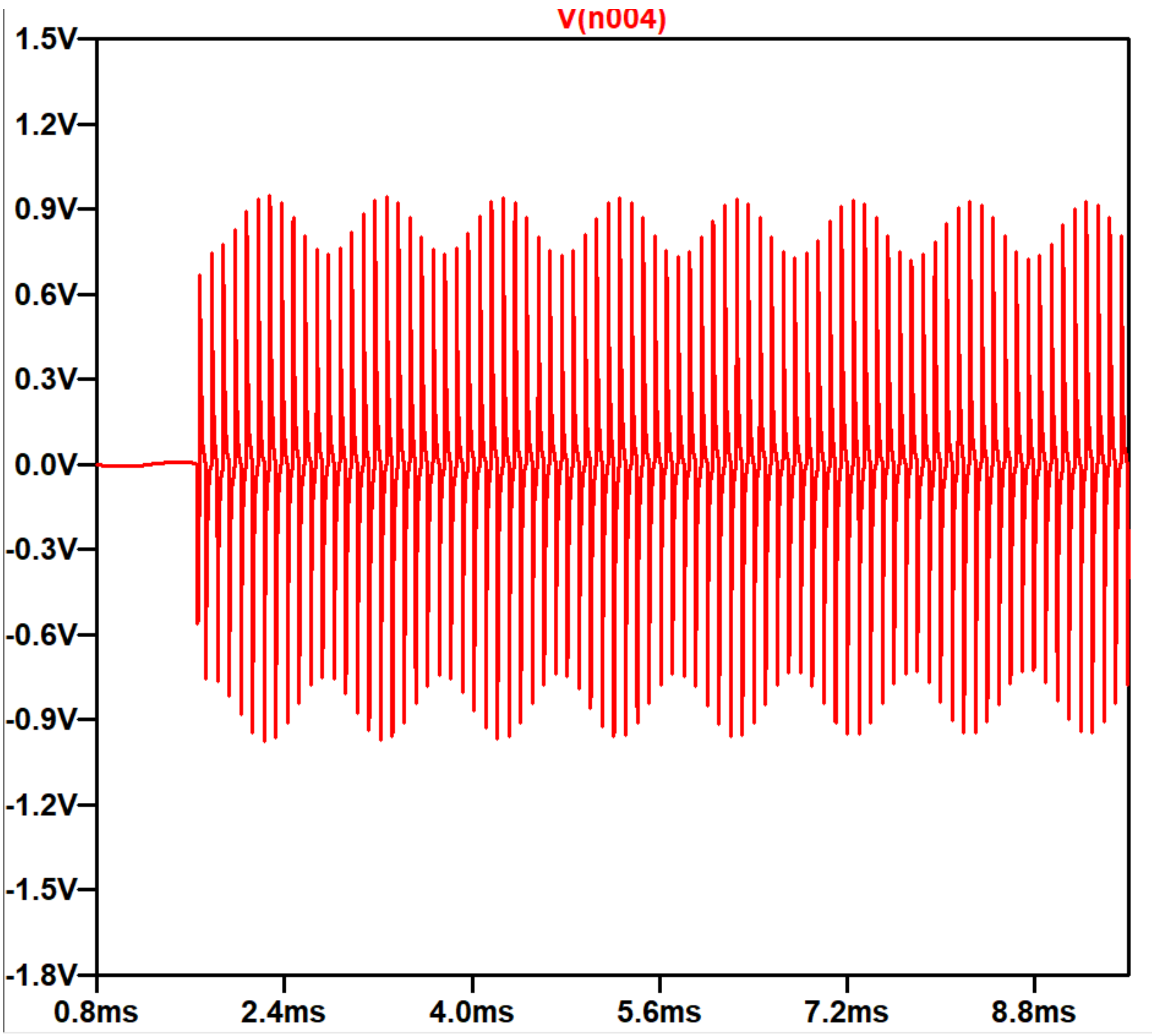
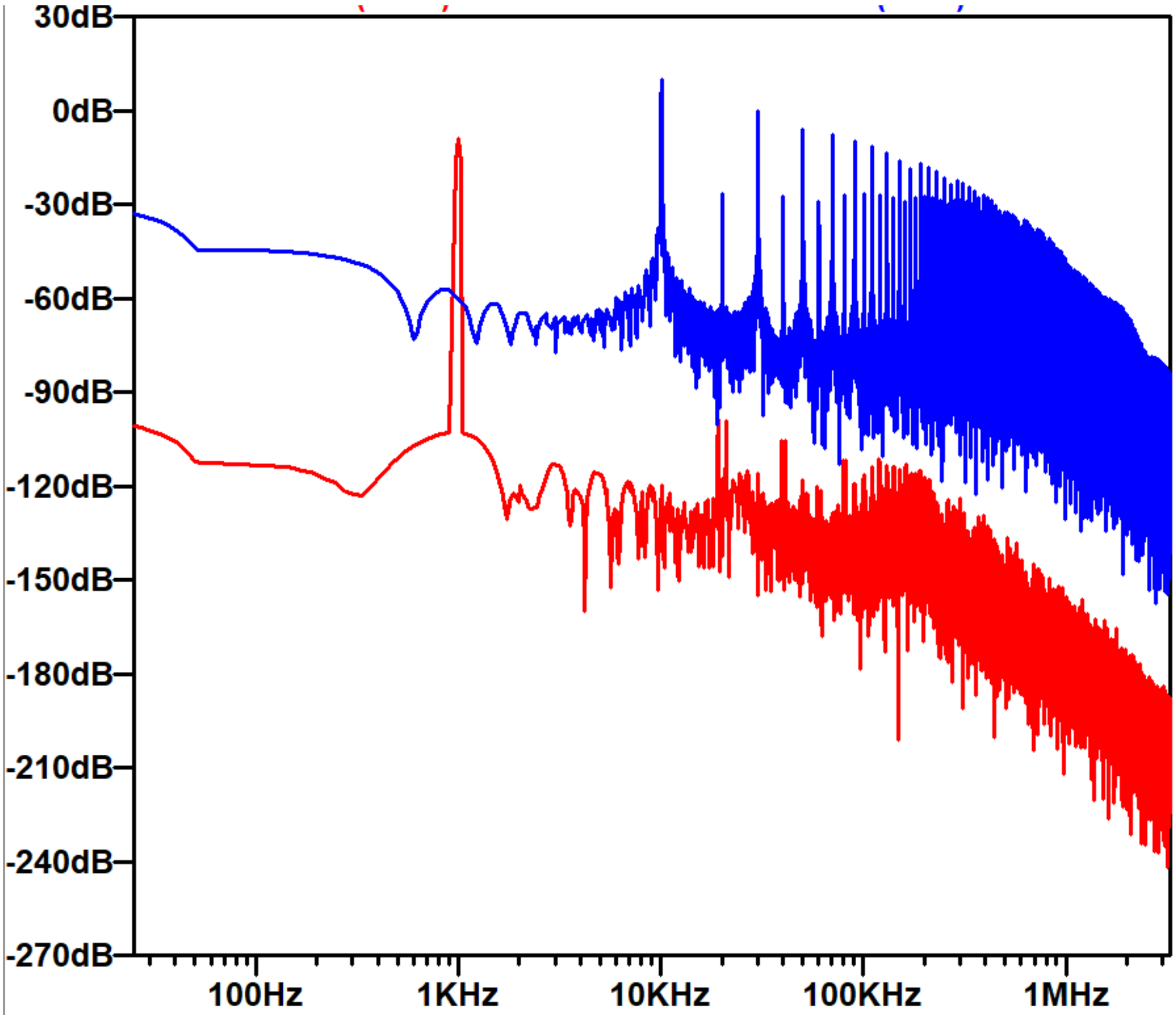


Output at Q2 collector

Input FFT



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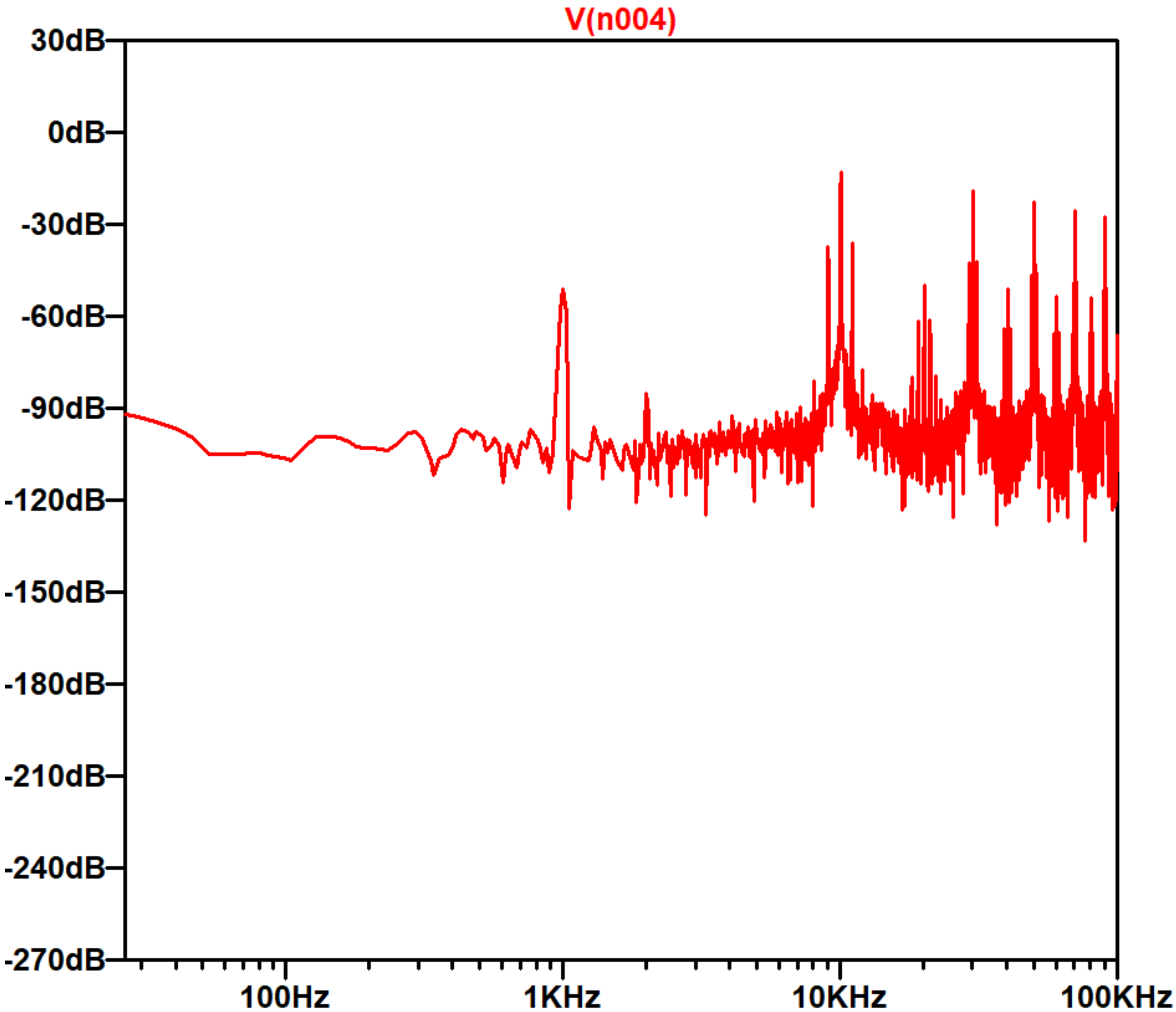
Output FFT



Output FFT

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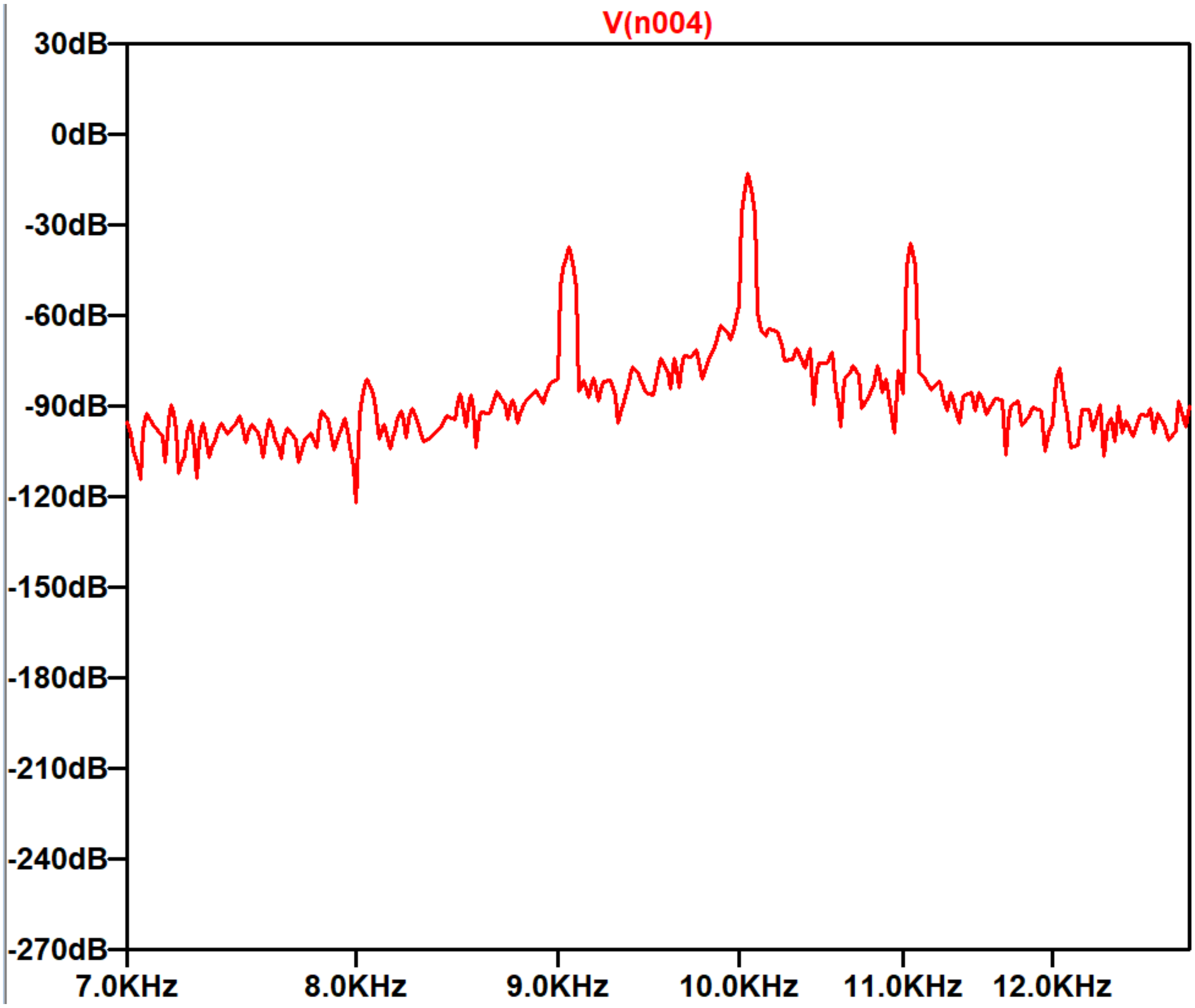
Output FFT



Output FFT

- Therfore we have seen peaks at f-f_0, f+f_0 which is what our aims is.where f and f_0 are input frequencies.

- Ther were no unusual observation in both methods.


thank you