RF MICROELECTRONICS

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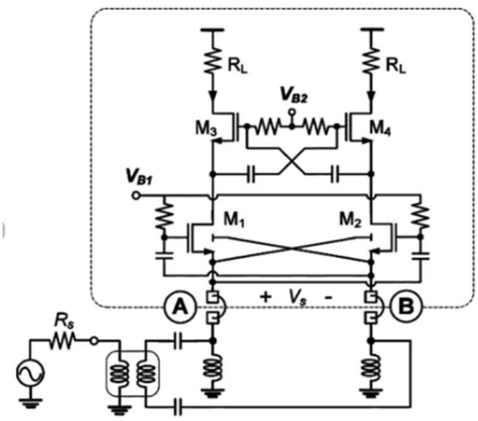
"A) Analyse mathematically, the LO leakage from the output to input of a differential LNA of a receiver when the input is a pure pulse-train corrupted by BPF

B)Model, simulate and graph the signals at all nodes in situation

(a) when the input noisy pulse-train has a small secondary sinusoidal signal at a slightly different frequency. Analyse the simulated nodes in the report."



(a)

Introduction

Differential LNA (Low-Noise Amplifier) is a type of amplifier used in electronic circuits to amplify weak signals while maintaining a low level of noise. The primary function of a differential LNA is to amplify the voltage difference between two input signals while minimizing the introduction of additional noise. It typically consists of a pair of transistors configured in a differential configuration, where the input signal is applied to the bases or gates of these transistors. The differential nature of the amplifier provides several benefits, including common-mode rejection, improved linearity, and reduced noise figure. The receiver differential LNA utilizes a differential amplifier configuration, which consists of two amplification stages working in tandem. The LNA's input and output signals are differential, meaning they consist of a pair of signals with opposite polarities.

LO (Local Oscillator) leakage in a receiver's differential LNA can be caused by several factors, such as Imperfect Isolation, Nonlinearities, Unintended coupling, Crosstalk and Harmonic Generation. The primary concern is the LO leakage from the input to the output, which can couple into the LNA output due to imperfect isolation between the LO and the input signal path. However, in certain scenarios, there can be some level of leakage from the LNA output to the input. The LO signal is typically used in frequency conversion processes such as upconversion, downconversion, modulation, and demodulation. In differential LNA, there are two modes of operation Common Source (CS) and Common gate modes.

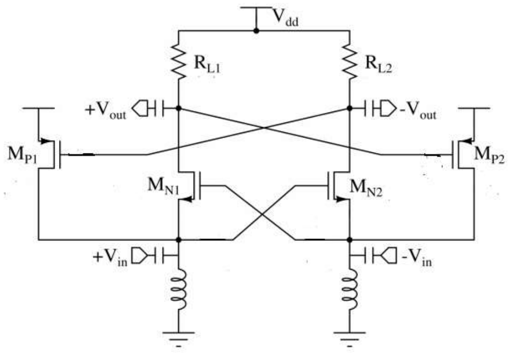


Fig1[4]

The ***LO leakage*** from the LNA output to the input is typically more prominent in the **common-gate (CG)** configuration compared to the common-source (CS) configuration. In the CG configuration, the input signals are applied to the sources of the transistors, and the gates are connected to a common node. This arrangement offers weaker isolation between the output and input paths, which can lead to a higher degree of LO leakage from the output to the input. On the other hand, the CS configuration provides better isolation between the output and input, making it less prone to LO leakage in the reverse direction. This enables us to observe the effects of LO leakages better.

A ***pure pulse train*** response consists of a series of pulses with a specific repetition rate or frequency. The pulses typically have a broad frequency spectrum, encompassing both low and high frequencies. When this pulse train is passed through a bandpass filter, the filter will selectively allow a range of frequencies to pass through while attenuating frequencies outside that range. Overall, the application of a bandpass filter to a pure pulse train response can result in frequency selection, pulse shape modification, attenuation of unwanted frequencies, and preservation of desired frequency components

Design

As discussed in Fig1 from [4], it is a CG-PN differential LNA module with additional bias Current or Ib added in accordance to it being a receiver circuit as described in [5].

The cross-coupling capacitance value is set vary large compared to gate-source capacitance Cgs of the CG transistor, so that ANEG=1. The bias current Ibias in each branch of differential CG LNA is set to 1.96 mA to get gm=20mS. However, the finite channel length modulation effect equation [4] is used to provide the input matching. Without the channel length modulation effect, the value of gm needed for input matching will be 10 mS. Thus, the effective transconductance (Gm) of CG transistor is set to 40 mS to reduce the channel noise of CG transistor. The inductance values are also accordingly set.

For 1.2V supply and RL1,2=500Ω, VDS=260mV and further increase in bias current to increase the gm, will move the CG transistors out of saturation. This limits the NF improvement of the CG LNA topology. All component references are according to Fig1.

Band Pass Filter

It is formed by cascading a low pass and high pass filters respectively. Central frequency (ideal) is assumed to be around -3dB and +3dB and the component values are selected accordingly.

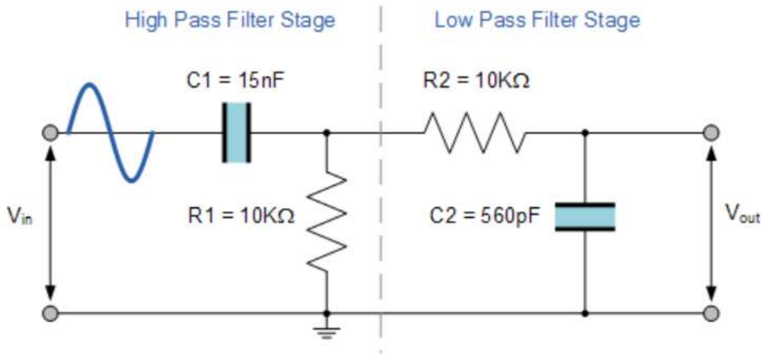


Fig2

In Fig 2 the values of R1 and C1 required for the high pass stage to give a anticipated cut-off frequency are: R1 = 10kΩ and to the nearest preferred value, C1 = 15nF by reference of [8]. Likewise, the values of R2 and C2 required for the low pass stage are, R = 10kΩ and C = 530pF. However, the nearest preferred value of the calculated capacitor value of 530pF is 560pF, so this is used instead.

The values for the **secondary sinusoidal** voltage input to the noisy pulse train for part (B) of the question is selected to be 1mV with an offset of 0.4533V(DC). This has a different frequency of 10^{-3}MHz. This is in accordance to calculations provided in [10].

Formulation

We have assumed non -linearity only due to cross coupling interaction and no other factors have been taken into consideration.

We have begun by drawing the CG differential-LNA circuit and applying pure-Pulse train with noises induces by the Band Pass Filter we have designed. We can calculate LO – leakage values from design parameters theoretically by calculations from formulae derived in [6],[7] and [11]:

VLO-leakage = A * VLO   and PLO_leakage = A^2 * PLO

Relationally, PLO = (VLO^2) / (2 * RLO) (rms calculations)

P_LO_leakage = (V_LO_leakage^2) / (4 * R_leakage)

V_LO_leakage = (I_LO_leakage / (2 * pi * f_LO * C_coupling))

Using initial value consideration and values given in [4],

I_LO_leakage= gm * V_{DS}

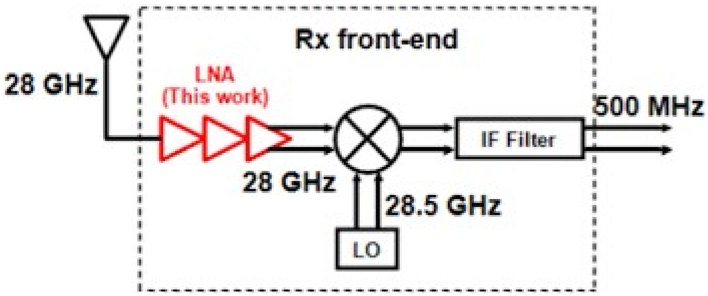
$V_{DS}=V_{DD}-I_{bias}\cdot R_{L1,2}$ = 1.2 -1.96m*500 =1.102V

I_LO_leakage= gm * V_{DS} = 10m * 1.102 = 0.01102A

V_LO_leakage = (0.01102A/ (2 * π* 3kHz * 4pF)) values from [4] and [5]
V_LO_leakage = 0.208V
P_LO_leakage = (0.208V) / (4 * 5Ω) from [4]

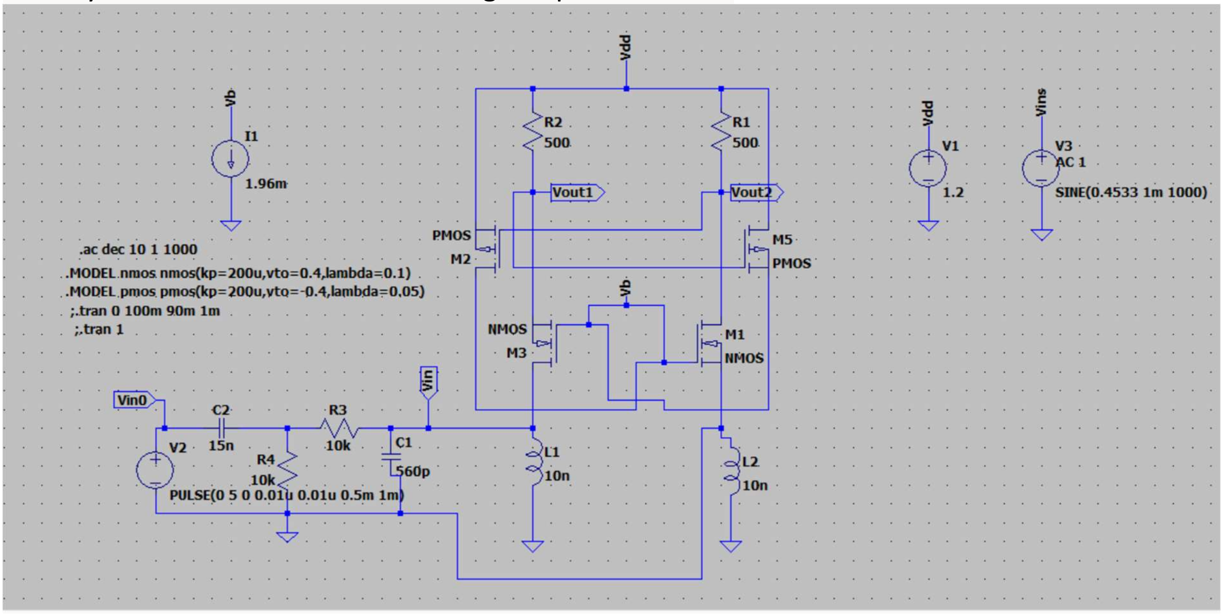
P_LO_leakage = 0.00186 =1.86mW

A represents the amplification factor or gain of the differential LNA, LO_Gain represents the LO gain, which quantifies the strength of the LO signal,VLO represents the LO voltage, PLO represents the power of the LO signal, RLO represents the characteristic impedance of the LO source or the load impedance, R_leakage represents the resistance value of the coupling path for the LO leakage, I_LO_leakage represents the current of the LO leakage, f_LO represents the frequency of the LO signal and C_coupling represents the capacitance of the coupling capacitor.



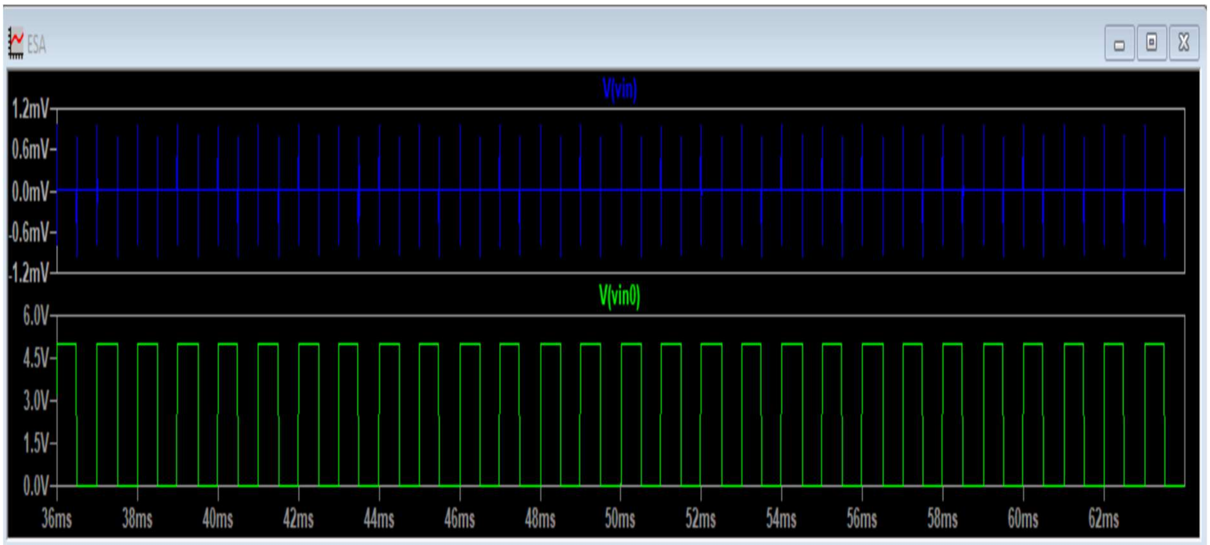
Circuit

A circuit in accordance to the requirement as an integration of the various subcircuits already discussed is constructed using LTSpice Software

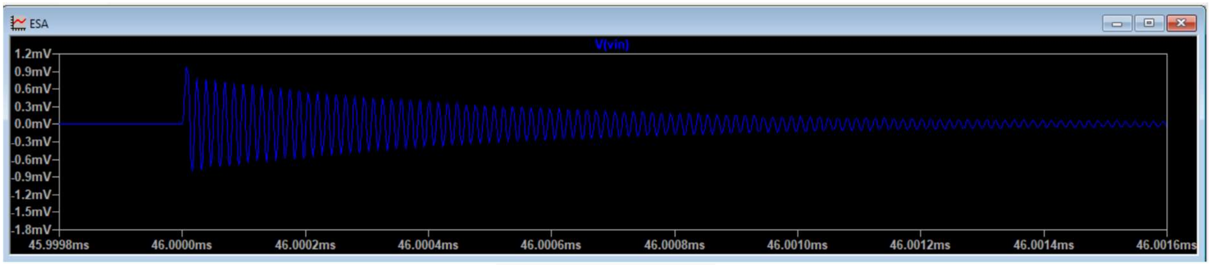


Here, R1 and R2 are the differential resistances corresponding to R_{L1} and R_{L2}, M1 and M3 are NMOSs, M2 and M4 are PMOSs, Vb is the bias current, L1 and L2 are differential inductances. Vin0 is the pure-pulse train. Vin is the final input voltage after adding the bandpass disturbances.

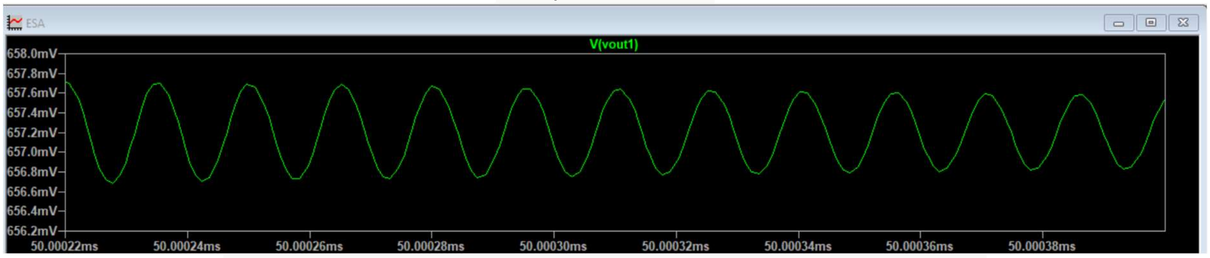
Note: Vins is the secondary sinusoidal voltage which will be connected and used for part B.



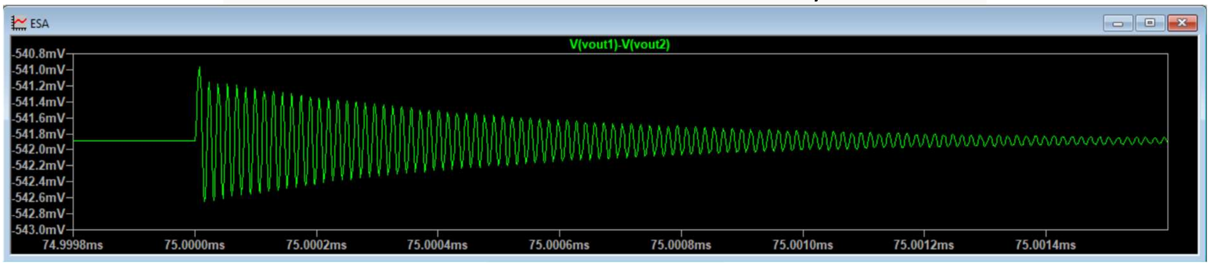
Input voltages



BPF pulses detail



Vout 1 and Vout 2 refer to Vout+ and Vout- by convention.



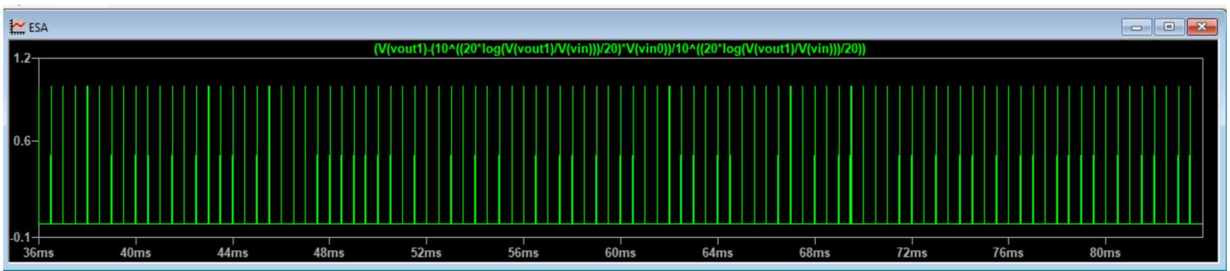
Total output wave

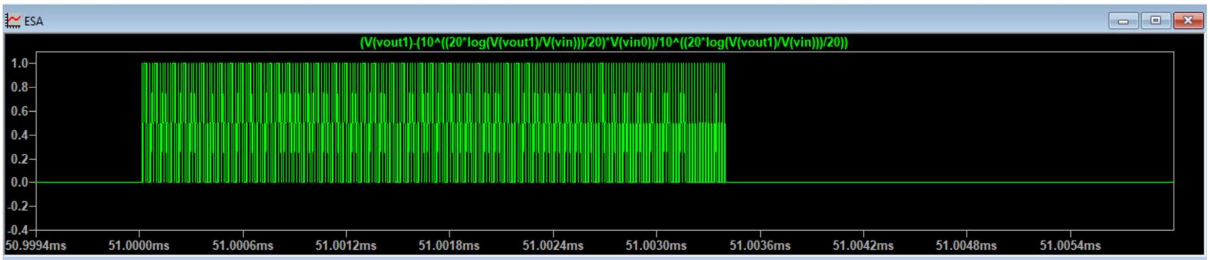
The above graphs are all results of transient analyses. Now using formulae

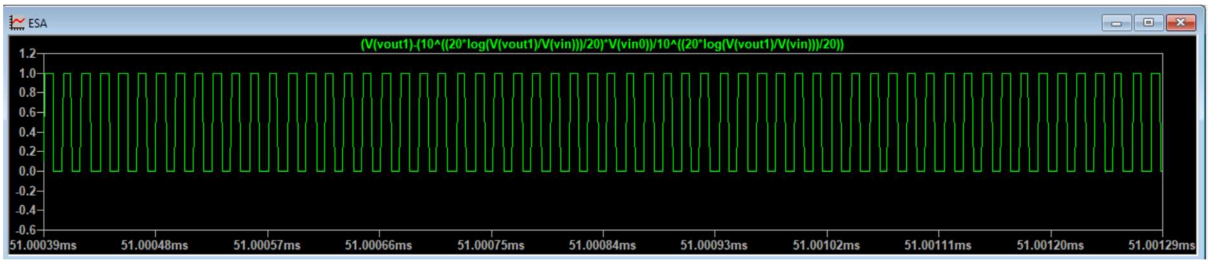
Av=20 log10(Vout/Vin), A=10^(Av/20), LO_leakage=(Vout-A*Vin0)/A

We get

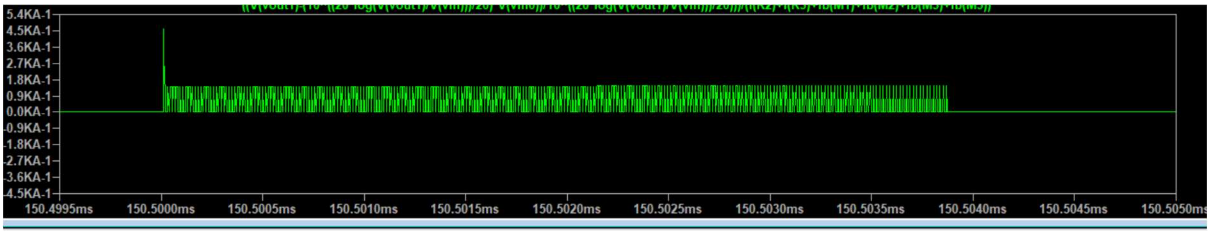
LO_leakage=(V(vout1)-(10^((20*log(V(vout1)/ V(vin)))/20)* V(vin0))/10^((20*log(V(vout1)/ V(vin)))/20)) That plotted is







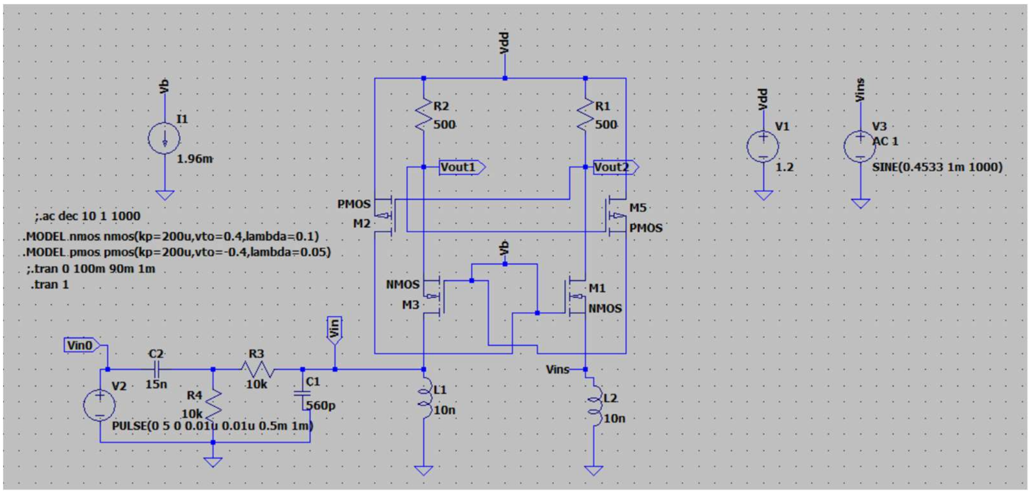
V_LO_leakage = 1V



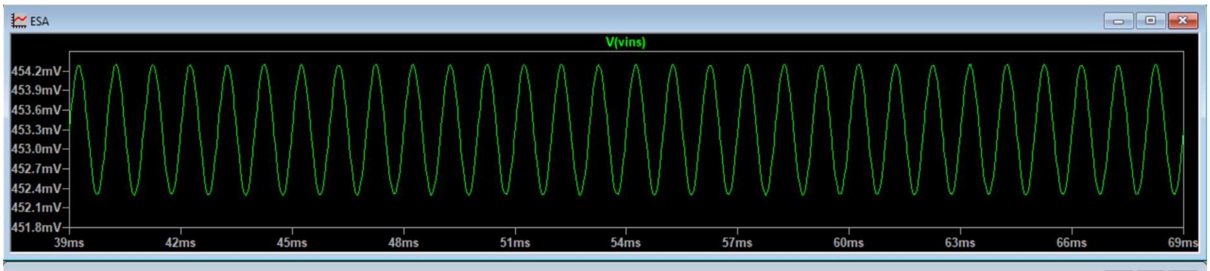
with I_LO_leakage =1.6KA

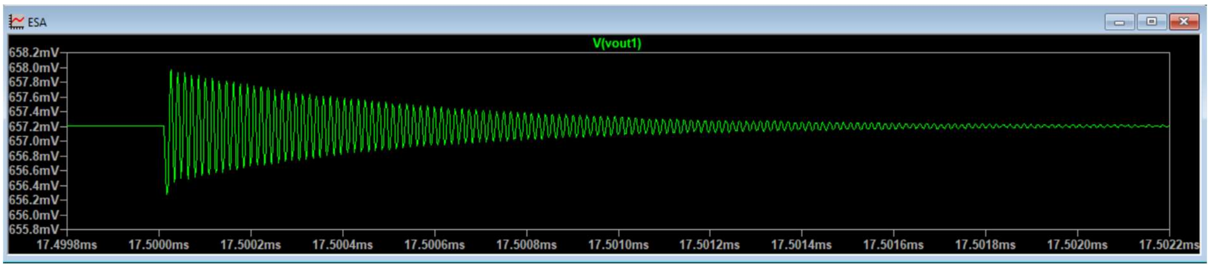
P_LO_leakage= V_LO_leakage* I_LO_leakage
=1 * 1.6K= 1.6KW

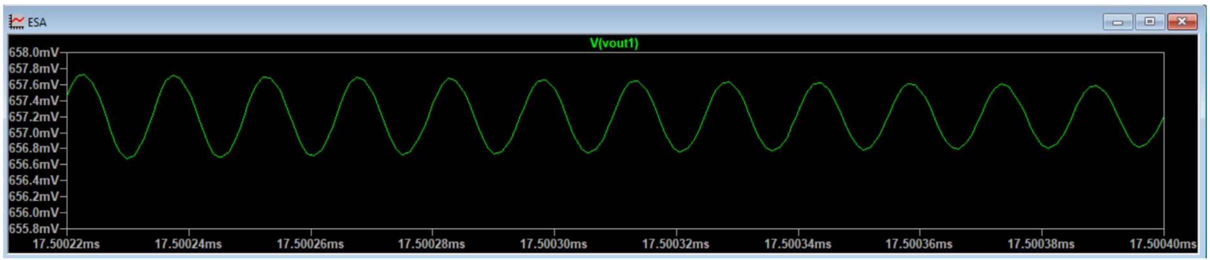
B) When the input noisy pulse-train has a small secondary sinusoidal signal at a slightly different frequency. Analyse the simulated nodes in the report.”



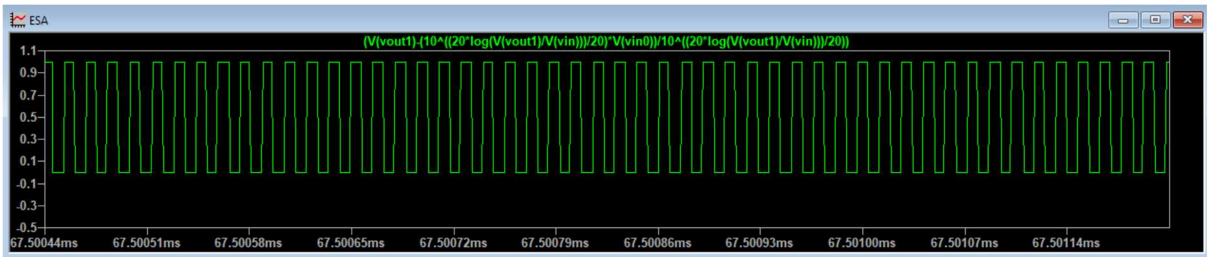
Vins has been connected to Vin- as a secondary input

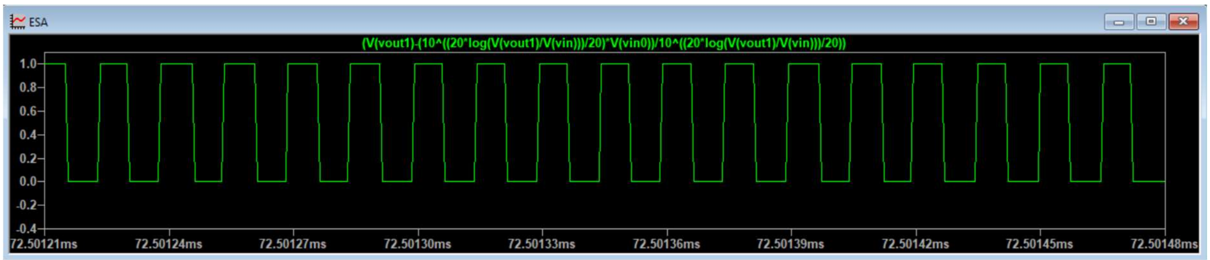




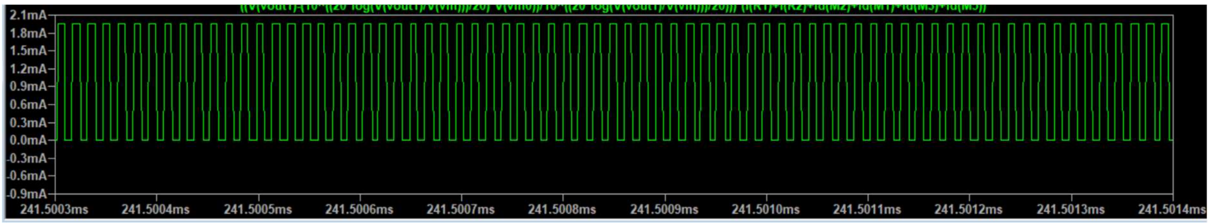


Note that in comparison to the output without the sinusoidal disturbances where Vout was 1.0mV this is 1.2mV





The change in V_LO_leakage seems to be too negligible to be noted on thre graph for the given frequency difference at remains constant at 1V but uncontrolled amplification has been observed at the output graph which fails to reflect in the final voltage output.



Therefore in both cases, with I_LO_leakage =2.1mA

P_LO_leakage= V_LO_leakage* I_LO_leakage

=1 * 2.1m= 2.1mW

Attribute	Theoretical	A)BPF	B)BPF+sinusoidal
I_LO_leakage	1.102V	1.6KA	2.1mA
V_LO_leakage	0.208V	1V	1V
P_LO_leakage	1.86mW	1.6KW	2.1mW

Conclusion

A) The effects of BPF disturbances on pure pulse train input have on the lo leakage of the differential LNA are as follows. The BPF attenuates frequencies and only lets signals within a given range to pass. The LNA then transforms the the impulse train of sinusoidal waves to regular square pulse output. It causes distortion of pulse shape to an extent of changing square waves to sinusoidal ones. The LNA interferes with the functioning of the BPF and we see the unprecedent spike. The output does not seem to be matching the theoretical output owing to the extremely low frequency assigned) Introducing a secondary sinusoidal wave seems to have an interfering effect. It affects the total input wave due to overlapping. The higher frequency assigned acts in our favour and the overlapping causes the total frequency to regularise leading to a value similar to the theoretical value calculated. It also cuts the stray noises previously present. But when frequency is reduced, it affects the system negatively and causes erratic output including irregular waveform. Also

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Appendix

Effects of the Receiver :-

include Signal Reception The receiver is responsible for capturing and processing the incoming signal. It receives the signal from the transmission medium, which could be wired or wireless, and extracts the desired information. The quality and efficiency of the receiver impact the overall system's ability to detect and recover the transmitted signal,Amplification: The receiver typically includes amplification stages, such as Low-Noise Amplifiers (LNAs), to boost the weak received signal. The amplification stage affects the signal-to-noise ratio (SNR) and sensitivity of the system. A well-designed receiver amplification stage can improve the system's ability to detect and process weak signals, Filtering-The receiver may employ filters to select the desired frequency band and reject out-of-band interference. These filters can include Low-Pass Filters (LPFs), High-Pass Filters (HPFs), or Band-Pass Filters (BPFs). The filtering process helps improve the system's selectivity, reducing unwanted noise and interference.Demodulation and Signal Processing. The receiver performs demodulation and signal processing operations to extract the original transmitted information from the received signal. This involves decoding the modulation scheme and applying appropriate signal processing techniques such as filtering, equalization, error correction, and data recovery. The effectiveness and accuracy of these operations impact the quality and reliability of the received data.

Effects of Choosing CS or CG:-

The CG stage is known for its inherent high input impedance and low output impedance. It provides voltage gain and is often used as the first stage in a differential LNA. The CG stage can help in isolating the LO signal from leaking back into the input, thereby reducing LO leakage. Its high input impedance minimizes the coupling of the LO signal to the input, limiting the leakage path.

On the other hand, the CS stage is often employed as the second stage in a differential LNA. It provides current gain and has a relatively higher output impedance compared to the CG stage. The CS stage can further attenuate the LO leakage by preventing the leakage signal from propagating back to the input. The higher output impedance of the CS stage helps in reducing the backward coupling of the LO signal.

Cross coupling:-

Cross coupling refers to the undesired transfer of signals or energy between different channels, components, or stages within a system. In the context of amplifiers or integrated circuits, cross coupling can occur between different sections of a circuit, such as between input and output paths or between various stages. Employing techniques like balanced signal routing, differential signaling, and the use of differential components can enhance common-mode rejection and reduce the impact of cross coupling. The introduction of isolation structures or shielded regions between different sections of the circuit can also mitigate cross coupling by minimizing electromagnetic coupling.