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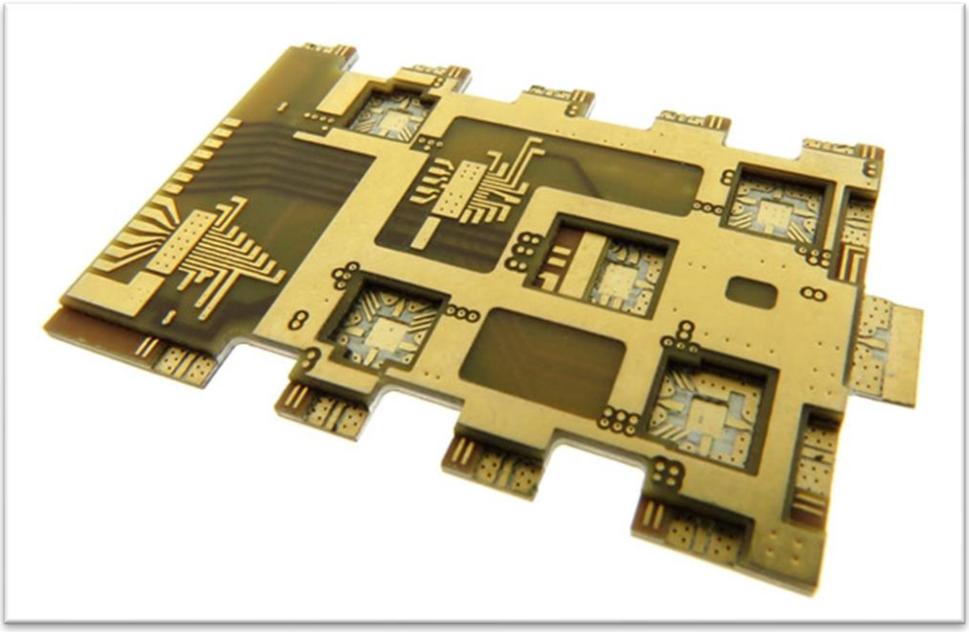
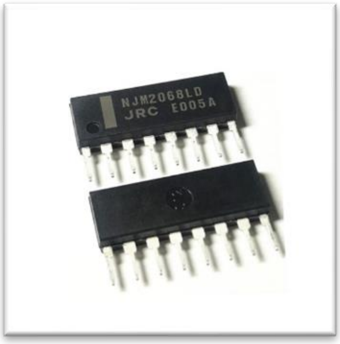


Introduction: Low Noise Amplifier (LNA)

Typically, a low noise amplifier serves as a high-frequency or intermediate-frequency preamplifier for different kinds of radio receivers as well as amplification circuits for high-sensitivity electronic detection apparatus. When boosting weak signals, the amplifier's noise output may significantly interfere with the signal.

In order to increase the output's signal-to-noise ratio, it is desired to reduce this noise. The noise figure F is typically used to describe how the amplifier affects the signal-to-noise ratio.

A crucial part of the receiver circuit, which analyses and transforms the received signal into information, are low-noise amplifiers. To minimise interference loss, LNAs are designed to be placed close to the receiving apparatus. Since any additional noise (useless data) will substantially impair the already compromised signal, they only add a little amount to the received signal. When power needs to be raised and the signal-to-noise ratio (SNR) needs to be reduced by around 50%, an LNA is used. The LNA plays a crucial role in communications because it is the first part of a receiver to catch a signal.



Analog Devices (Company) is one of the companies that manufactures LNAs. The frequency range of Analog Devices low noise amplifiers extends from DC (IF) through RF Microwave and W-Band (95 GHz). They offer MMIC-based (*Monolithic microwave integrated circuit, these devices typically perform functions such as microwave mixing, power amplification, low-noise amplification, and high-frequency switching*.) solutions that have noise values as low as 0.7 dB while covering a range of gains and bandwidths. They offer some of the lowest noise and best linearity available in the market

Many of their designs have an internally matched 50-ohm resistance and a self-biased topology.

LNA: General Considerations

LNAs play a critical role in the overall performance and their design is governed by the following parameters.

Noise Figure:

- Noise factor is defined by the ratio of output SNR and input SNR. Noise figure is the dB form of noise factor.

$$Sensitivity = \underbrace{Noisefloor(dBm)}_{-174\,dBm + 10\log BW} + SNR + NF_{tot}$$

- Typical RX noise figure is 6 to 8 dB.
- Antenna switch or duplexer contributes about 0.5 to 1.5 dB to the overall noise figure.
- LNA contributes about 2 to 3 dB to the overall noise figure.
- The remaining stages in the RF chain contribute about 2.5 to 3.5 dB to the overall noise figure.
- Noise partitioning among stages in the RF chain is flexible and depends on their individual performance. In modern RF electronics, LNAs are rarely designed in isolation, but rather as part of the overall RF chain.
- A noise figure of 2 dB can be achieved through careful design and optimization of the RF chain.
- Configurations like emitter or source followers are not possible because only one transistor typically the input device, can be the primary contributor to NF.

Gain:

- The gain of the LNA should be large enough to minimize the noise contribution of subsequent stages, particularly the down conversion mixer/mixers.
- The choice of LNA gain involves a trade-off between noise figure and linearity of the receiver, as higher gain can increase nonlinearity in subsequent stages.
- In modern RF design, the LNA directly drives the down conversion mixer/mixers with no impedance matching in between.
- Performing chain calculations in terms of voltage gain, rather than power gain, of the LNA is more meaningful and simpler. LNA gains divide the noise and IP3 (third-order intercept point) of the stage after the LNA.

Input Return Loss:

- The LNA is designed for a 50-Ohm resistive input impedance. They are typically designed to maximize voltage swings rather than power transfer
- Return Loss: defined as the reflected power divided by the incident power, return loss is given by:

$$\Gamma = \left|\frac{Z_{in} - R_S}{Z_{in} + R_S}\right|^2$$

Zin denotes Input Impedance and Rs is Source Impedance.

- In practice, a return loss of about -15 dB is targeted so as to allow margin for package parasitic and other parameters.

Stability:

- LNA must remain stable for all source impedances at all frequencies
- Stern Stability Factor:

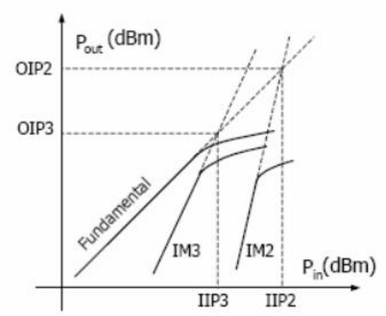
$$K = \frac{1 + |\Delta|^2 - |S_{11}|^2 - |S_{22}|^2}{2|S_{21}||S_{12}|} \qquad \Delta = S_{11}S_{22} - S_{12}S_{21}$$

- K > 1 and Δ < 1, then the circuit is unconditionally stable meaning it does not oscillate with any combination of source and load impedances
- Because of the packaging's ground and supply parasitic inductances, LNAs may become unstable.

Linearity:

- Substantial undesired signal handling without a lot of distortion

- Relationship between IIP3 and P1dB:
  For one tone test: IIP3-P1dB=10dB
  For two tone test: IIP3-P1dB=15dB



Bandwidth:

- The LNA should have a relatively flat response within the frequency range of interest.
- Ideally, the gain variation of the LNA should be less than 1 dB.

- The -3 dB bandwidth of the LNA should be substantially larger than the actual band of interest.
- The roll-off at the edges of the band should remain below 1 dB
- LNA designs that need to attain a sizable fractional bandwidth may make use of a mechanism to change the operating frequency.

Power Dissipation:

- The LNA typically has a trade-off among noise, linearity, and power dissipation.
- In the majority of receiver designs, the LNA only uses a little portion of the total power.

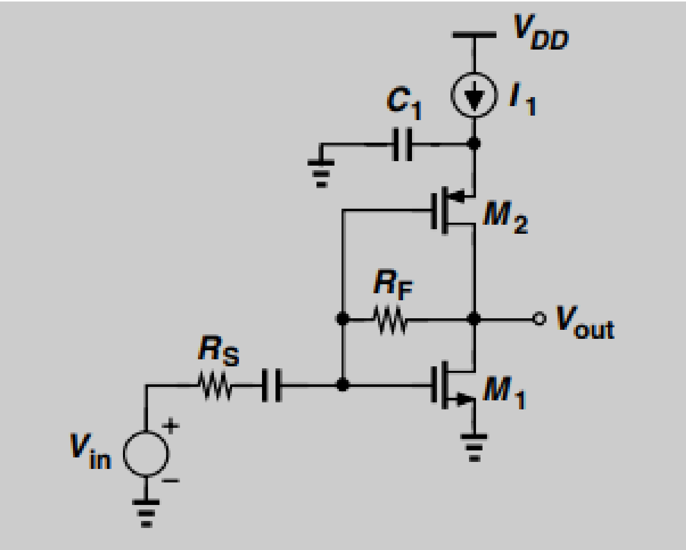
LNA: Applications

LNAs have a wide variety of uses, some of which are given below:

- Telecom
- Instrumentation
- Military/Aerospace
- 4G/5G
- WIFI/WLAN

Circuit Design: Circuit Diagram

The aim is to design a common source stage LNA with resistive feedback and active-load.



- The PMOS current source acts as an active load. It amplifies the input signal.
- There is a feedback resistor RF which senses the output voltage and returns a current to the input side.
- Current source I1 defines the bias current and Capacitor C1 establishes an ac ground at the source of M2

Circuit Design: Theoretical Calculations (Noise Figure)

For small-signal operation, M1 and M2 appear in parallel

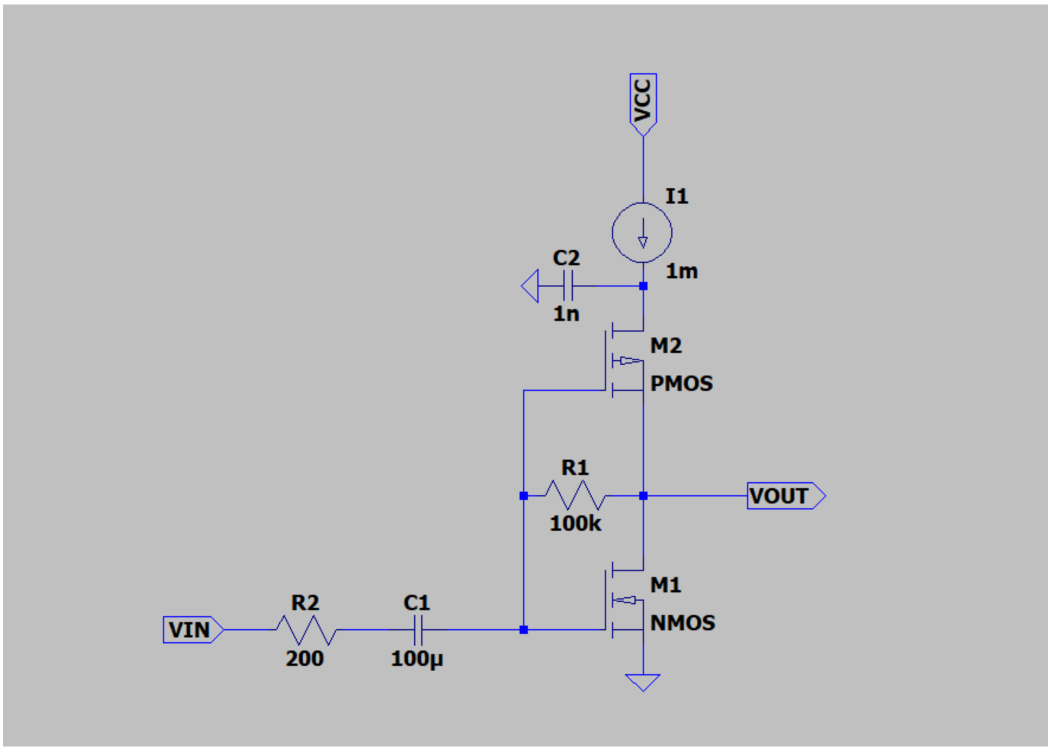
So transconductance = gm1 + gm2

For Input Matching, gm1 + gm2 = 1/Rs

With a supply voltage equal to VGS1 1 |VGS2| 1 VI1, where VI1 denotes the voltage headroom necessary for I1, Noise Factor is equal to,

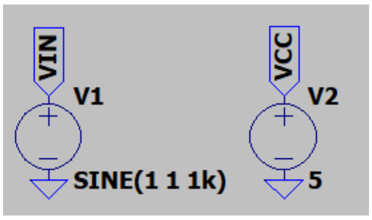
NF = 1 + 4Rs/Rf + (gm1 + gm2)Rs

Circuit Simulation: LT-Spice Schematic

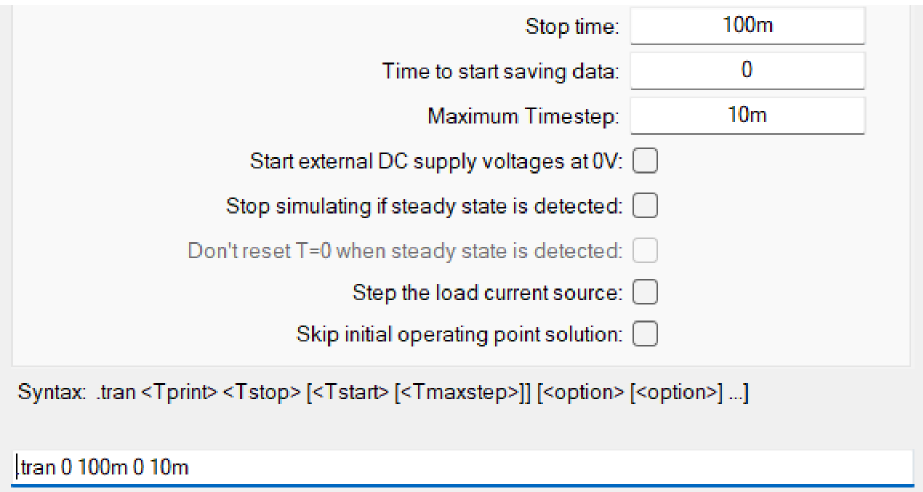


Circuit Simulation: Simulation Settings

Voltage Settings: Supply voltage settings for the testing.



Transient Analysis Settings: Performs a non linear, time domain simulation.


Stop time: 100m

Time to start saving data: 0

Maximum Timestep: 10m

Start external DC supply voltages at 0V:

Stop simulating if steady state is detected:

Don't reset T=0 when steady state is detected:

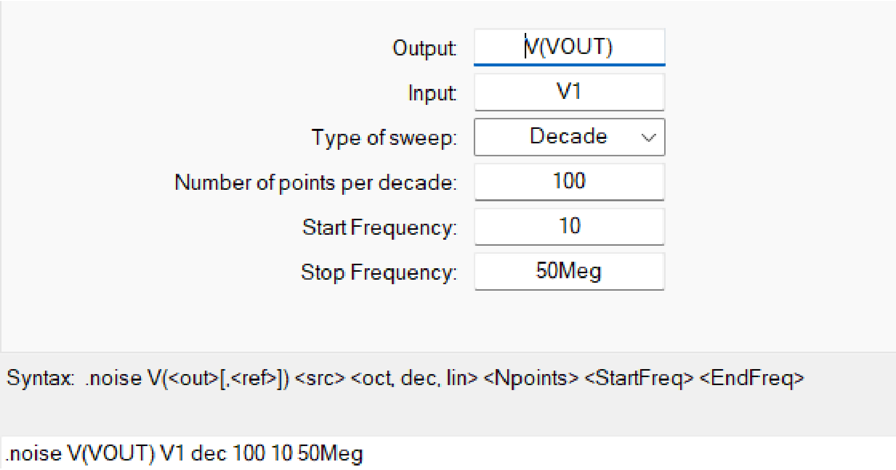
Step the load current source:

Skip initial operating point solution:

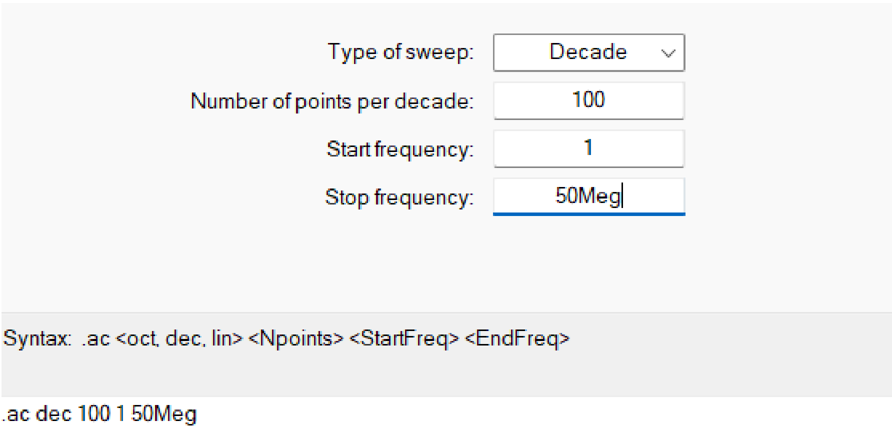
Syntax: .tran <Tprint> <Tstop> [<Tstart> [<Tmaxstep>]] [<option> [<option>] ...]

.tran 0 100m 0 10m

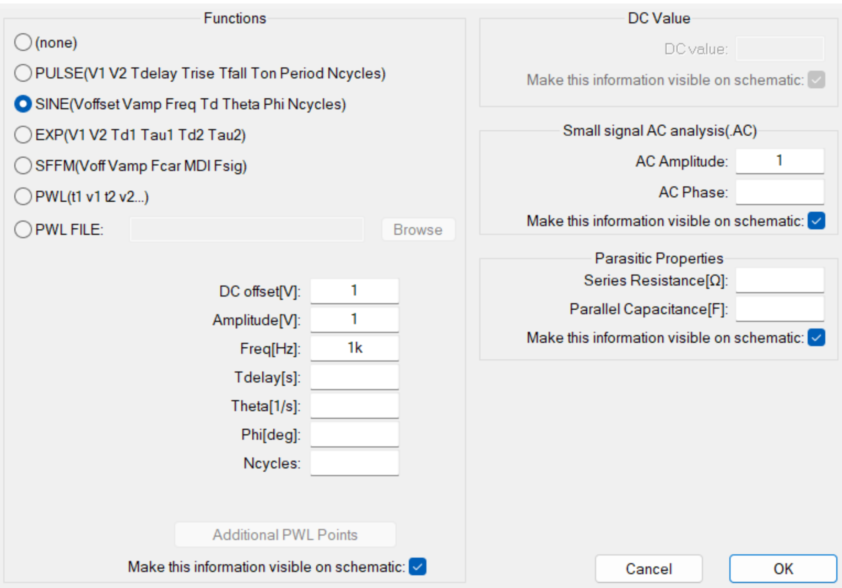
Noise: Perfroms a stochastic noise analysis of the circuit linearized about its DC operating point.



AC-Analysis: Computes the small signal AC behaviour of the circuit linearized about its DC operating point.

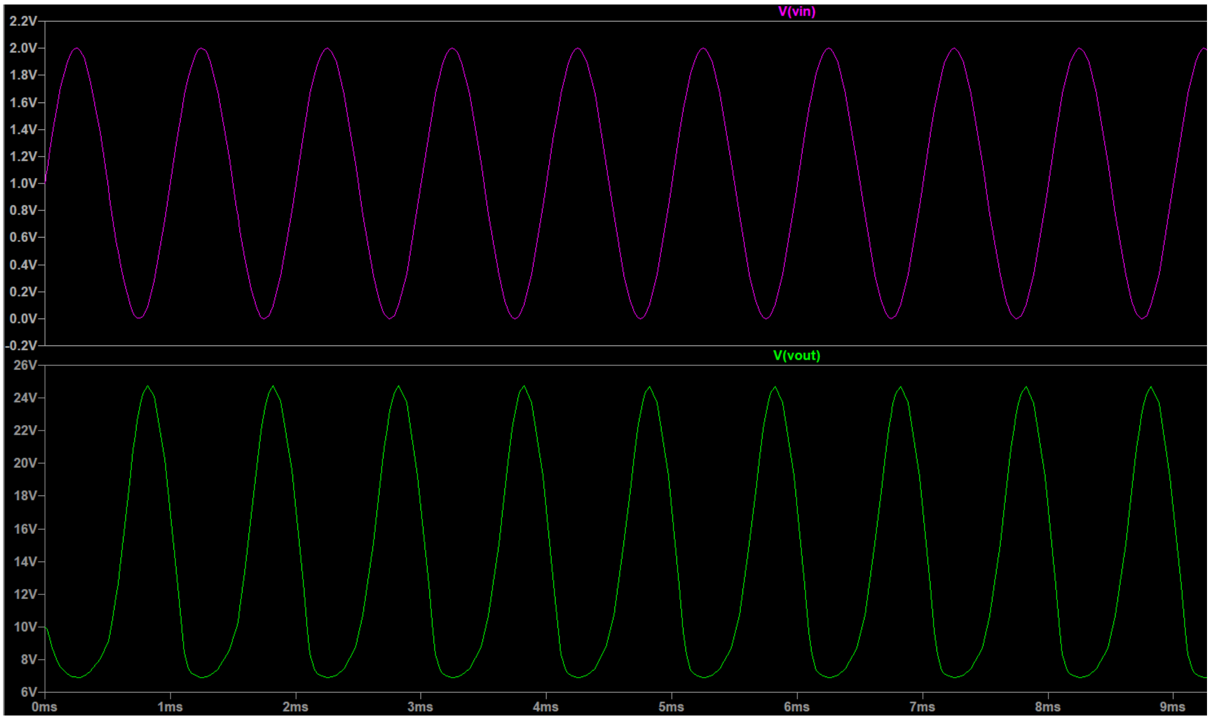


To perform AC-Analysis, set AC amplitude to 1V

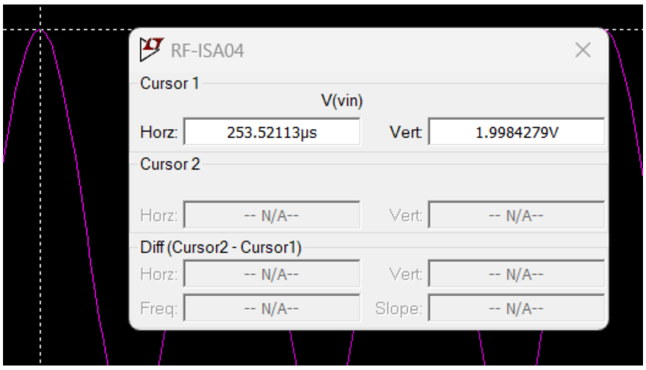


Circuit Simulation: Output Graphs

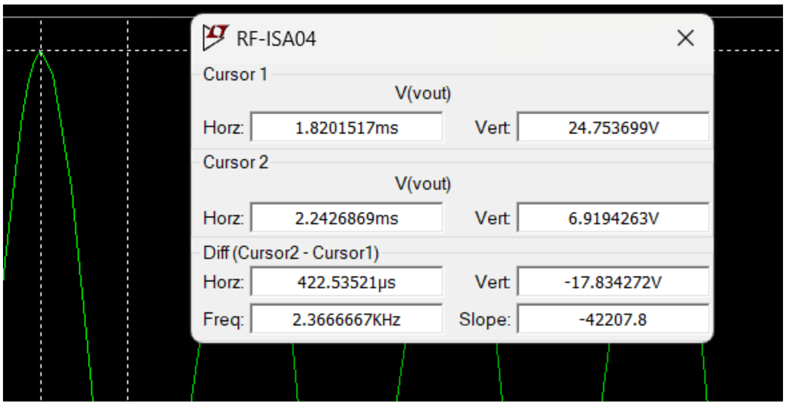
Transient Analysis:



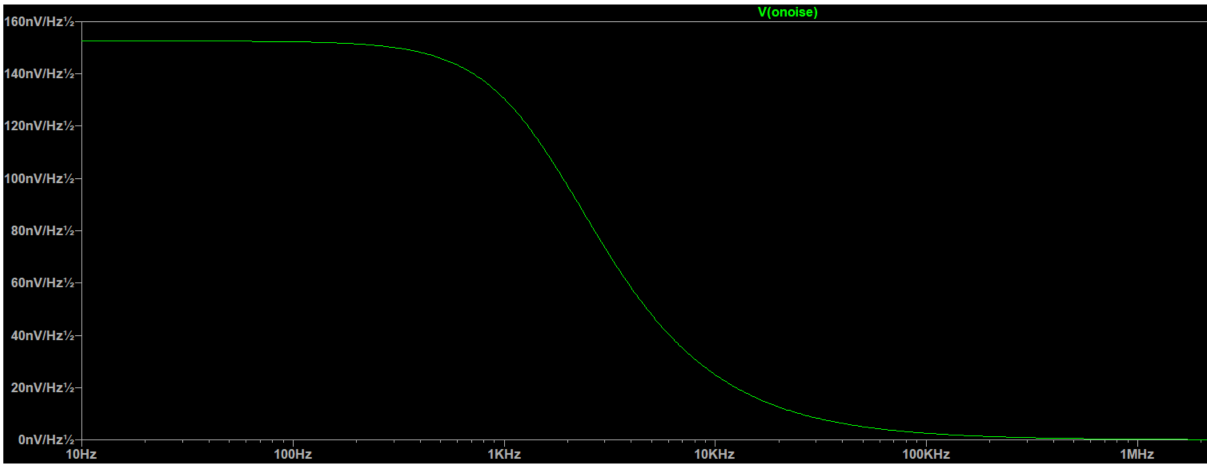
Input Voltage Measurements:

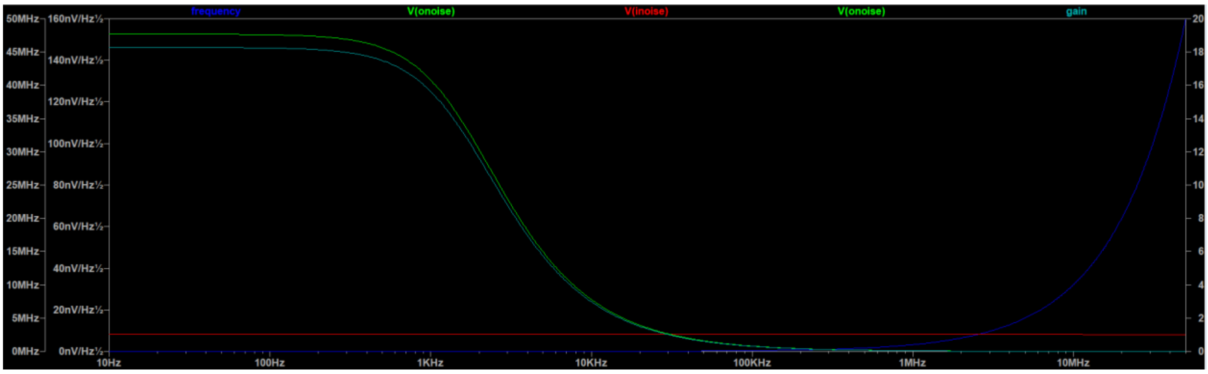


Output Voltage Measurements:

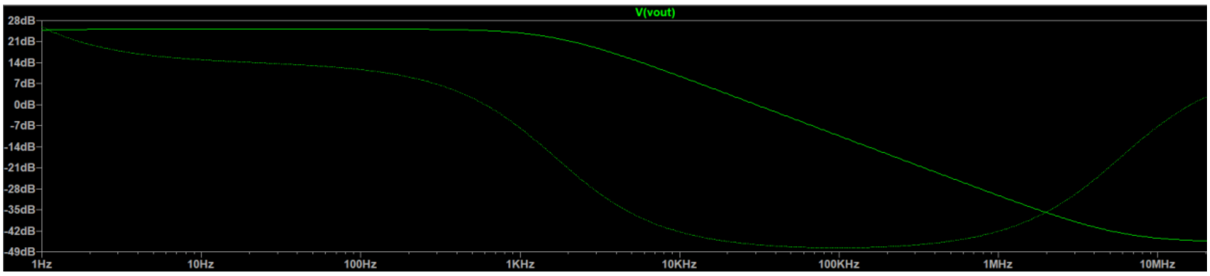


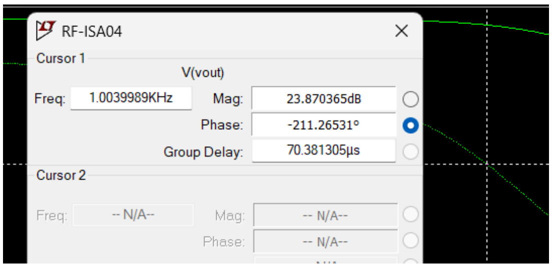
Noise Plot:

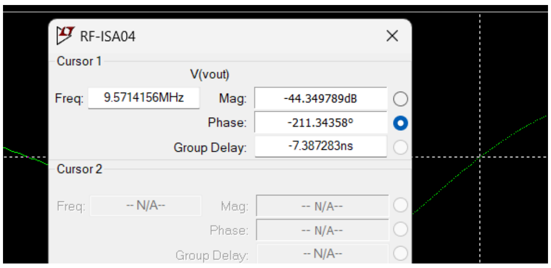




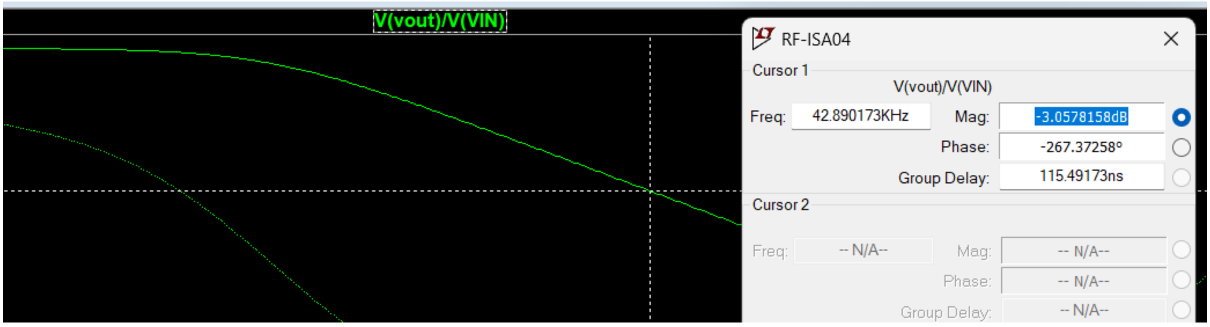
AC-Analysis:







With a few adjustments, we can also determine the circuit's frequency response using the AC-analysis settings.



Conclusion: Results

LT-Spice, a simulation program, was used to analyse and plot the circuit's various parameters. The characteristics of the circuit based on the simulation data are as follows:

Input Voltage	2V
Output Voltage	17.84V
Gain	9
Operational Bandwidth	1KHz to 9.54MHz
Frequency Response(-3dB)	42.89KHz

References:

Textbook: RF-Microelectronics, Second Edition: Behzad Razavi

Introduction: Low Noise Amplifier (LNA)	1) Utmel (2021) *Understanding the low noise amplifier (LNA)*, *Utmel*. Utmel Electronics. Available at: https://www.utmel.com/blog/categories/amplifiers/understanding-the-low-noise-amplifier-lna (Accessed: April 11, 2023). 2) AG, I.T. (no date) *Low noise amplifier LNA ICS*, *Infineon Technologies*. Available at: https://www.infineon.com/cms/en/product/rf/low-noise-amplifier-lna-ics/ (Accessed: April 11, 2023). 3) *ECEN 665 (ESS) : RF Communication Circuits and systems - texas A&M ...* (no date). Available at: https://people.engr.tamu.edu/s-sanchez/Heng_LNA.pdf (Accessed: April 12, 2023). 4) *Low noise amplifiers* (no date) *Low Noise Amplifiers | Analog Devices*. Available at: https://www.analog.com/en/product-category/low-noise-amplifiers.html (Accessed: April 11, 2023).
LNA: General Considerations	1) *ECEN 665 (ESS) : RF Communication Circuits and systems - texas A&M ...* (no date). Available at: https://people.engr.tamu.edu/s-sanchez/Heng_LNA.pdf (Accessed: April 12, 2023). 2) Textbook: Chapter-5, Low-Noise Amplifiers, Pg. No(255-263)
LNA: Applications	1) *Low noise RF amplifiers (lnas)* (no date) *Castle Microwave :: The UK's first choice for the supply of high technology and leading-edge RF and Microwave products*. Available at: https://www.castlemicrowave.com/technologies/lna/ (Accessed: April 12, 2023).
Circuit Design and Theoretical Calculations	Textbook: Chapter-5, Low-Noise Amplifiers, Pg. No(269-272)