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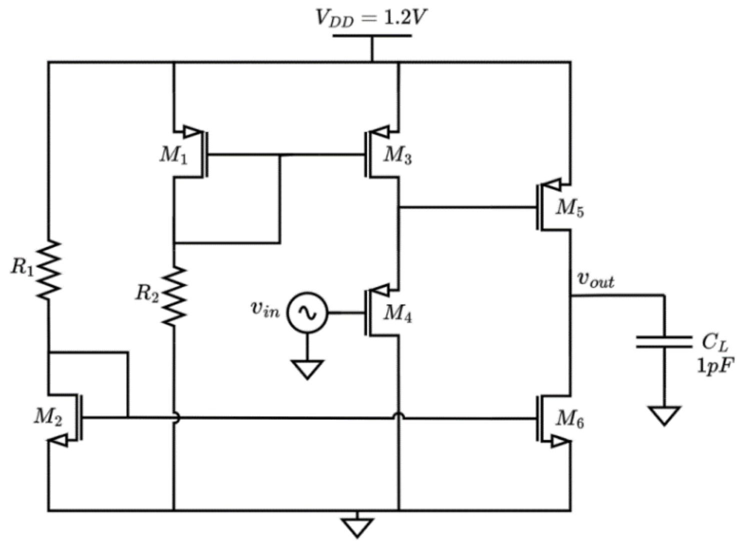
Design Exercise 1
Wi-Fi 6 Baseband Amplifier

Wi-Fi 6 is the latest wireless communication standard designed to enhance data throughput, reduce latency, and improve energy efficiency in high-density environments. A critical component in Wi-Fi 6 systems is the baseband amplifier, which plays a vital role in amplifying the baseband signals processed in the transmitter and receiver paths.

In this project, our objective is to design and optimize the baseband amplifier depicted in the provided schematic diagram:



The design specifications are:

	DC Gain	3-dB BW	Max Power consumption
Value	$20 \pm 0.1\ dB$	$20 \pm 0.1\ MHz$	$200\ \mu W$

The design of the baseband amplifier involves carefully selecting the dimensions of the transistors and the values of the passive components to meet the performance requirements and operating region of the transistors.

Resistor Selection (R1 and R2)

Purpose: Resistors R1 and R2 determine the DC biasing points of the amplifier and influence the overall gain and bandwidth.

Rationale for Selected Values: A higher resistance increases the gain by increasing the output resistance of the circuit, which directly impacts the transconductance-to-output resistance ratio ($g_m \cdot R_{out}$). However, excessively high values can reduce bandwidth due to the RC time constant (combined with C at the output node).

Transistor Width (W) and Length (L)

The width (W) and length (L) of the MOS transistors affect the transconductance (g_m), operating region, and parasitic capacitances, which collectively influence the gain, bandwidth, and power consumption.

Width (W): Larger widths increase the transconductance (g_m), which enhances the gain. However, larger widths also increase parasitic capacitances, potentially reducing the bandwidth.

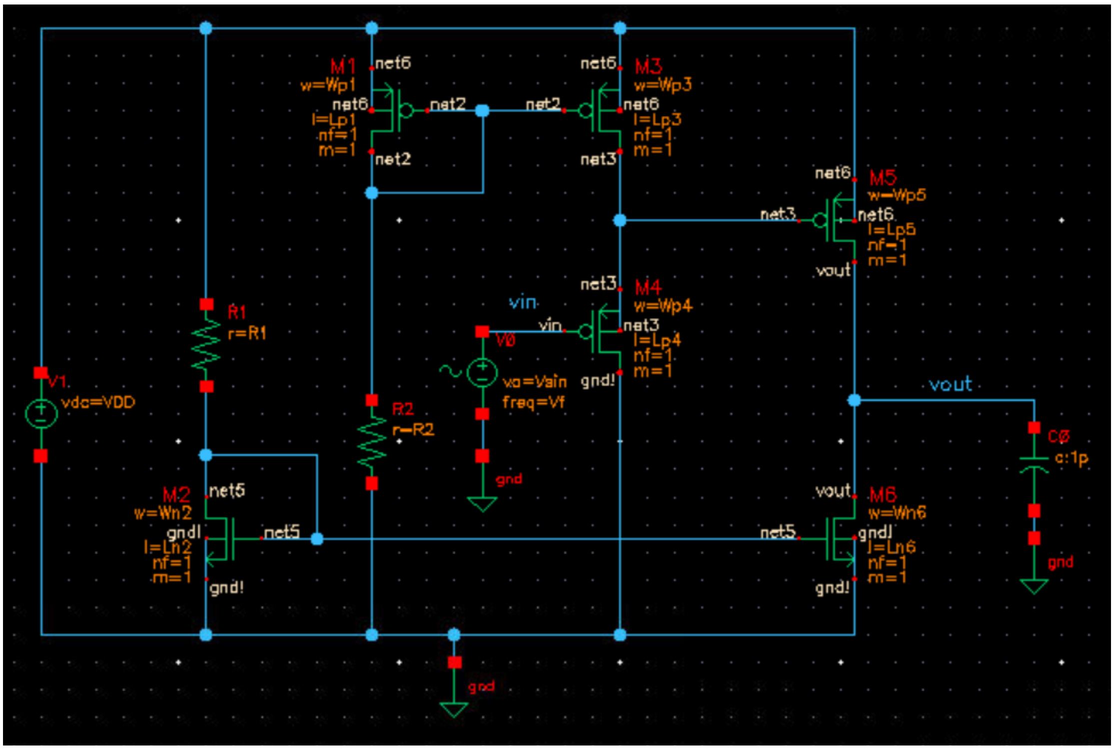
Length (L): Shorter lengths reduce the channel resistance, leading to higher current drive capability. However, it is essential to ensure the length is long enough to maintain adequate device matching and avoid velocity saturation effects in submicron processes.

Capacitor C_L $(1\ pF)$

Purpose: C_L represents the load capacitance at the output node and directly impacts the bandwidth.

A value of 1 pF was selected based on the Wi-Fi 6 system requirements and practical design constraints. It represents the typical parasitic capacitance at high frequencies.

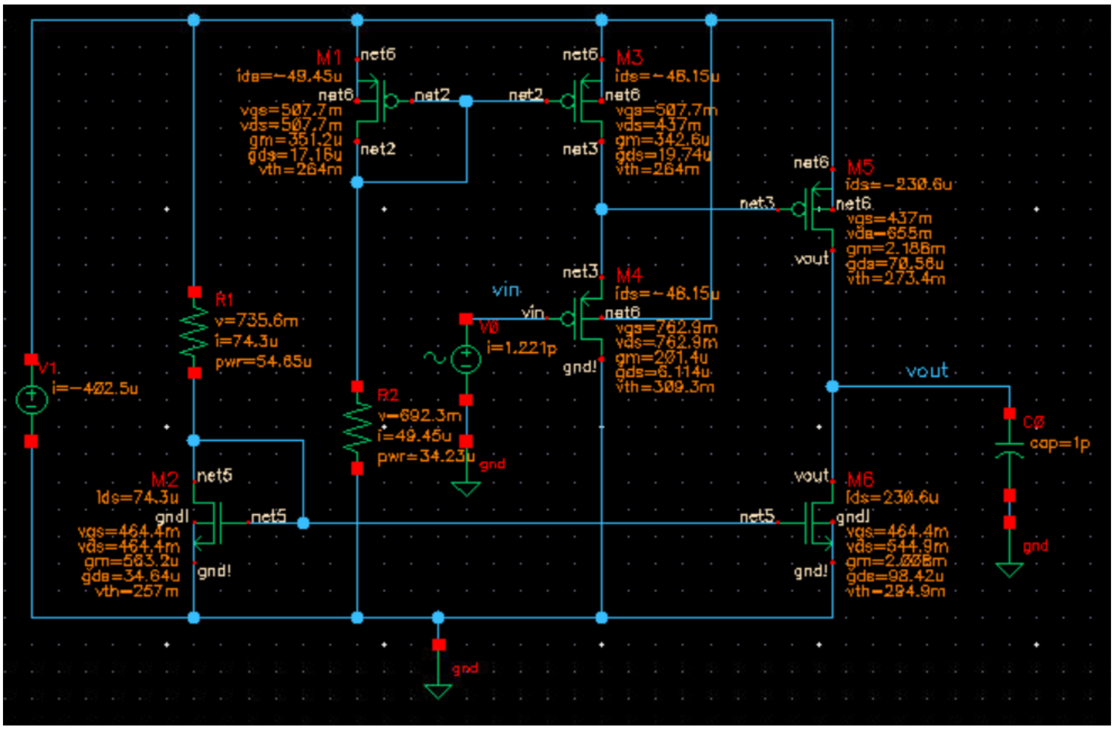
Circuit Schematic



Device Dimensions table

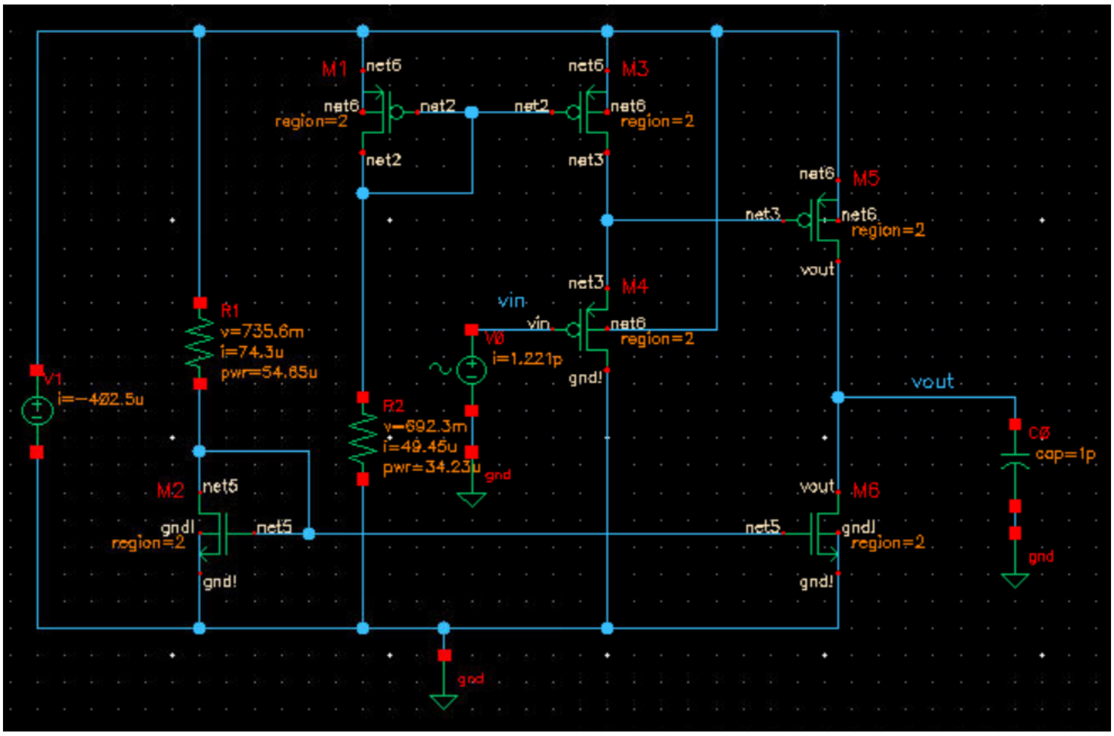
	Total width (μm)	Length (μm)	V_{GS} (V)	V_{DS} (V)	g_m (Ω^{-1})	g_{ds} (Ω^{-1})	Resistance (Ω)
M_1	10	0.5	507.7m	507.7m	351.2u	17.16u	
M_2	4.8	0.9	464.4m	464.6m	563.2u	34.64u	
M_3	10	0.5	507.7m	437m	342.6u	19.74u	
M_4	7.9	1.2	762.9m	762.9m	201.4u	6.11u	
M_5	64.3	0.4	437m	655m	2.186m	70.56u	
M_6	9.7	0.4	464.4m	544.9m	2.008m	98.42u	
R_1							9.9K
R_2							14K

Circuit Operation Point



Cadence provides a feature to annotate the operating region of the transistors directly on the schematic. This is an excellent way to ensure that the transistors are in the desired operating region, such as saturation, during simulation.

In the following schematic print we can see clearly that all the transistors are in region 2 which corresponds to the saturation region:

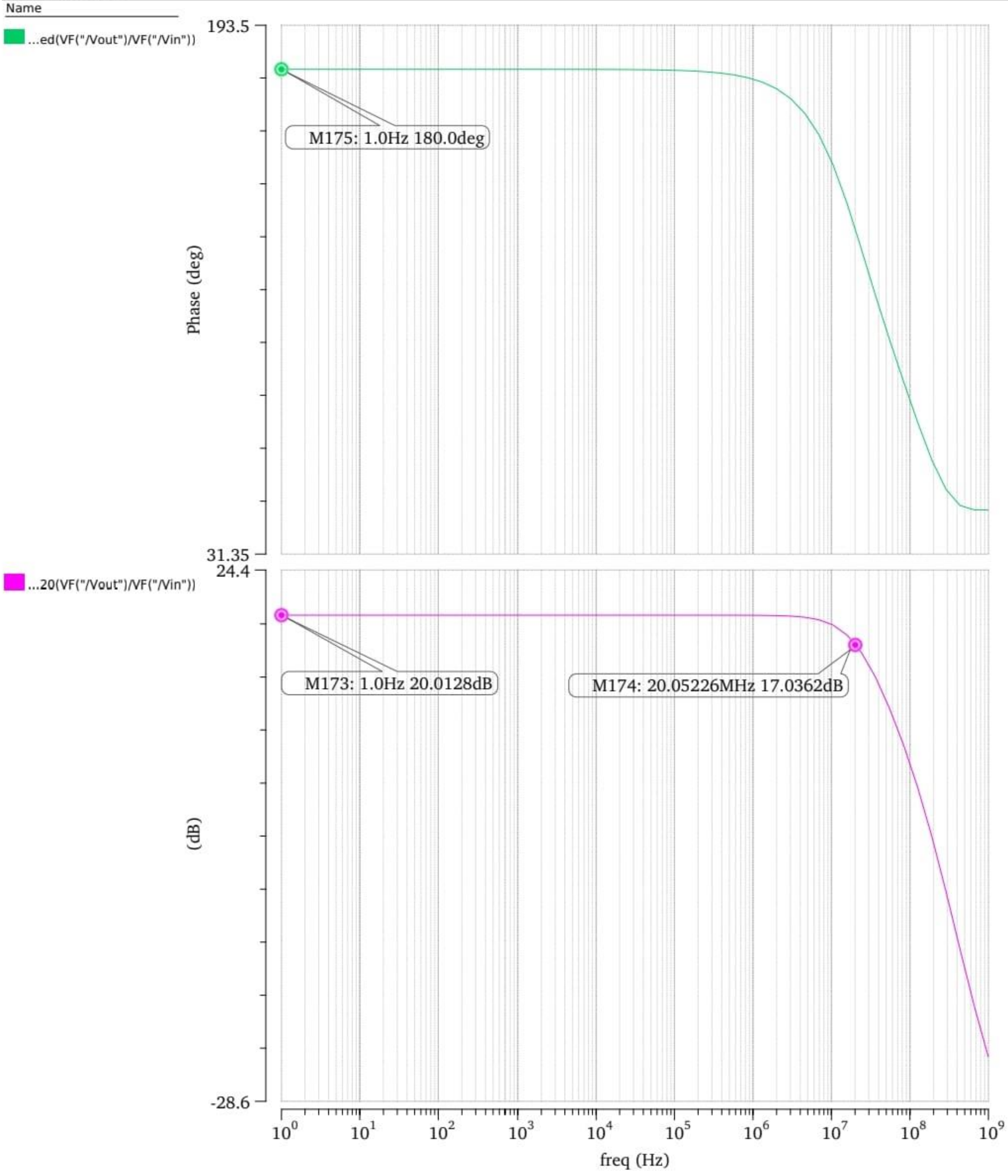


Gain Plot

The gain plot demonstrates the frequency response of the designed baseband amplifier. It highlights the amplifier's gain across a range of frequencies, allowing us to verify that the design meets the specified requirements of $\mathbf{20 \pm 0.1\, dB}$ **gain** and $\mathbf{20 \pm 0.1\, MHz}$ **bandwidth**, as evident from the attached plot.

These results validate the effectiveness of the design choices, including the transistor dimensions and biasing resistors.

AC Response

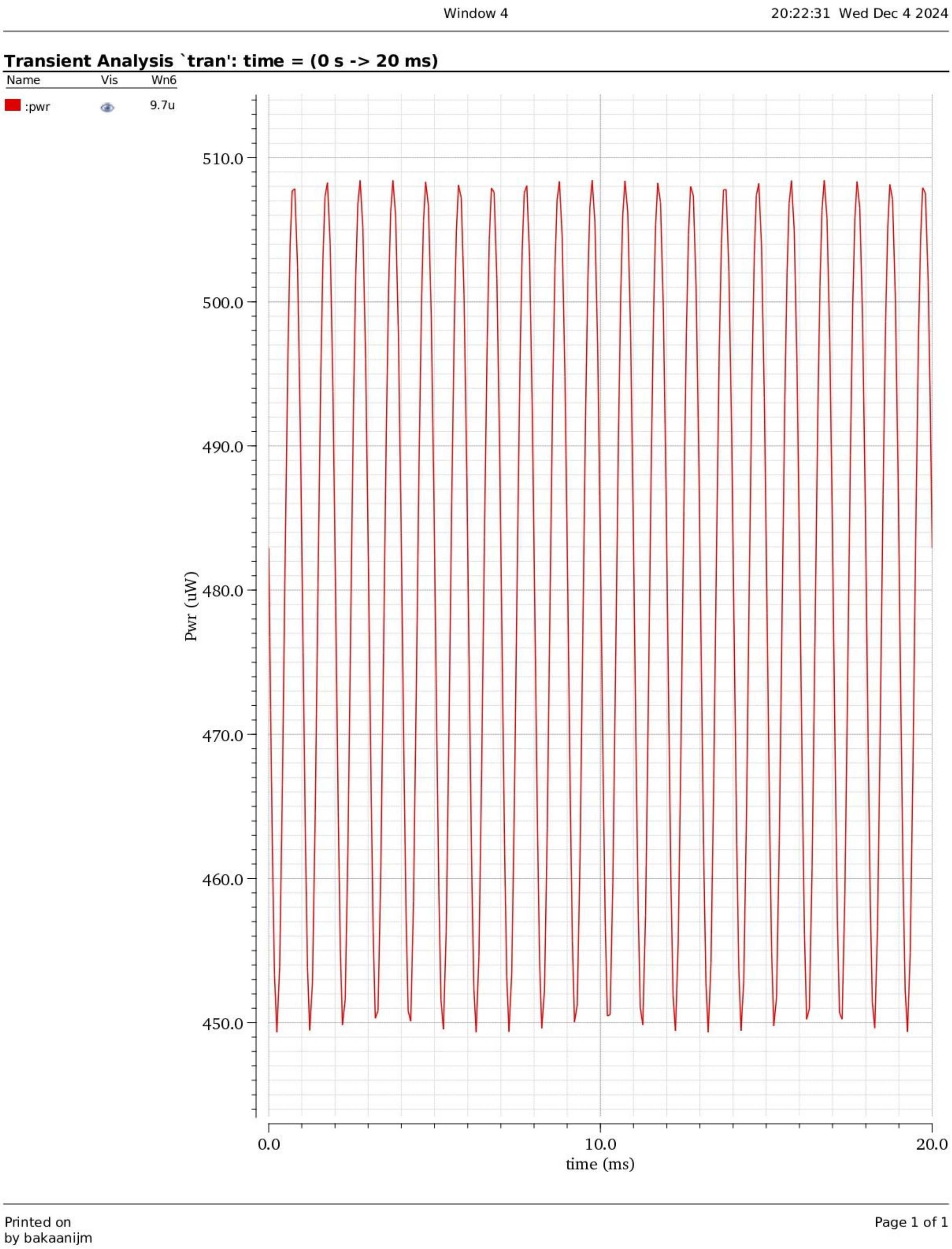

Name
...ed(VF("/Vout")/VF("/Vin"))
...20(VF("/Vout")/VF("/Vin"))
193.5
31.35
Phase (deg)
M175: 1.0Hz 180.0deg
24.4
-28.6
(dB)
M173: 1.0Hz 20.0128dB
M174: 20.05226MHz 17.0362dB
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9
freq (Hz)

Power Consumption

To evaluate the circuit's efficiency, a power consumption analysis was performed, focusing on both the DC and total power requirements to assess compliance with the design specification of a maximum 200 μW.

average(getData(":pwr" ?result "tra...

	Expression	Value
1	average(getData(":pwr" ?result "tran"))	480.9E-6



The simulation results indicate that the power consumption of the designed Wi-Fi 6 baseband amplifier is approximately $\mathbf{480\ \mu W}$, which exceeds the target specification of $\mathbf{200\ \mu W}$. While significant efforts were made to optimize the circuit for lower power consumption, achieving the target value proved challenging due to the inherent trade-offs between power, gain, and bandwidth in the amplifier design.

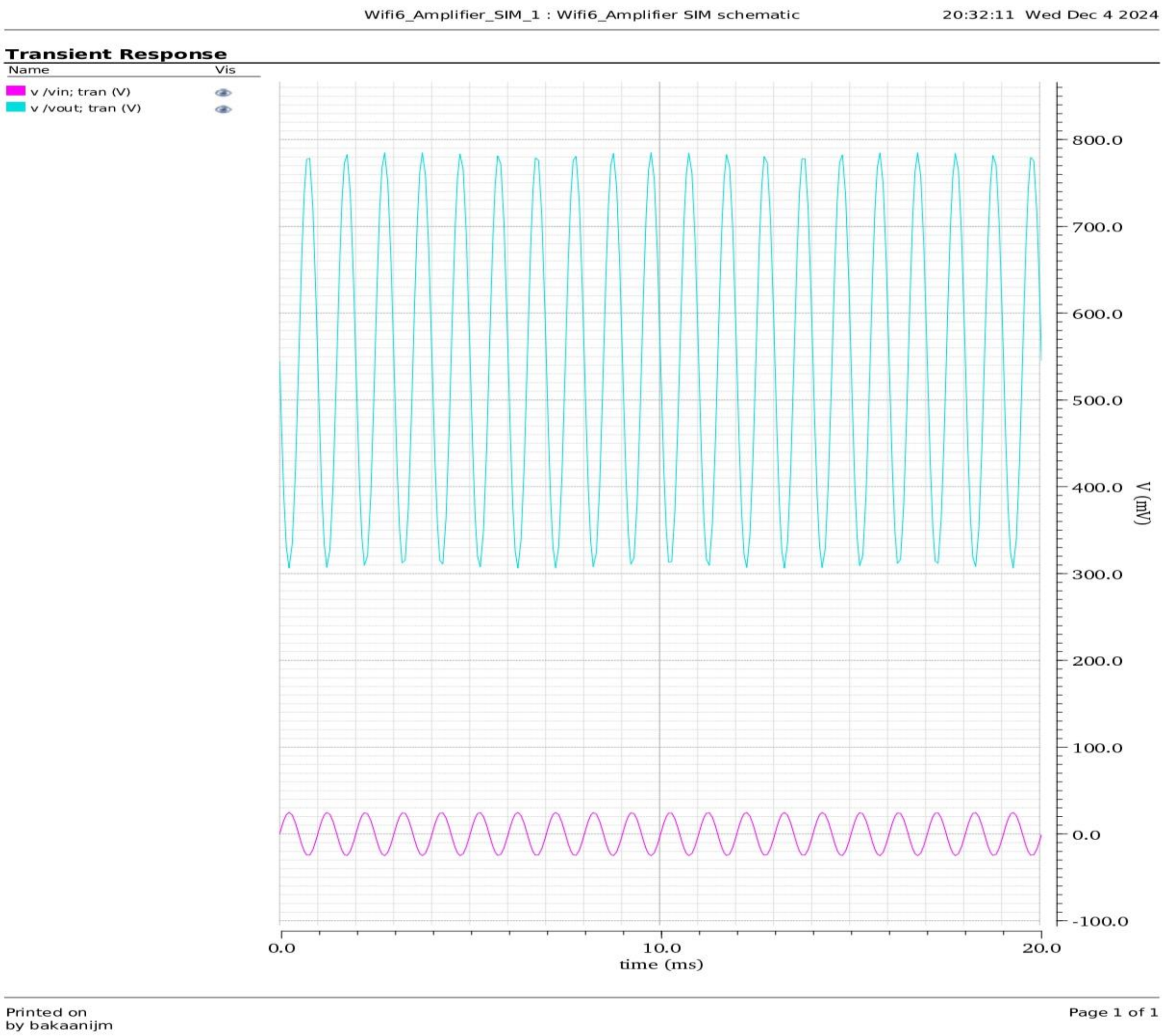
To meet the stringent requirements of $\mathbf{20dB}$ **gain** and $\mathbf{20\ MHz}$ **bandwidth**, the circuit required higher bias currents and carefully selected transistor dimensions. These adjustments, while improving gain and bandwidth, also contributed to the increase in power consumption.

To achieve the target power consumption of $200\,\mu W$, several strategies could be implemented. Reducing the bias currents by increasing the values of the biasing resistors R_1 and R_2 would lower power, though this must be balanced to avoid compromising gain and bandwidth. Adjusting the transistor dimensions, such as decreasing the W/L ratio, could also reduce power consumption while ensuring the transistors remain in saturation.

Example of an output transient voltage

Given 1KHz input with an amplitude of 25mV.

The transient simulation demonstrates the time-domain behavior of the designed Wi-Fi 6 baseband amplifier. The input signal V_{in} and output signal V_{out} are plotted over the same time interval to verify the amplifier's functionality.



From the results, it is evident that the circuit successfully amplifies the input signal, achieving the desired gain. The output signal maintains the same frequency as the input, with a small phase shift introduced by the amplifier. This phase shift is expected due to the circuit's reactive components and does not impact the amplifier's ability to perform baseband signal amplification effectively, confirming that the amplification is linear and preserves the integrity of the original signal.

This simulation validates that the circuit meets the primary design objective of providing sufficient amplification for the baseband signal while maintaining low distortion.

Summery

	DC Gain	3-dB BW	Max Power consumption
Required Value	$20 \pm 0.1\ dB$	$20 \pm 0.1\ MHz$	$200\ \mu W$
Design Achieved Value	$20.01\ dB$	$20.05\ MHz$	$480\ \mu W$