SQA Summer Research Write Up

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1 Introduction

This document aims to be a brief summary of results, and instructions for how to access data. Files are mostly located at:

Room 101 `C:/Data/users/Cory`

2 Transistor Characterisation

Resistance, current and voltage measurements for the MOSFET transistor in operation.

2.1 Equipment

- Transistor: `CE3512K2`
- Source: Electrode 33
- Drain: Electrode 39
- Gate: Electrode 40

When applying voltages (drain-source, gate) it was connected such that:

- v_{DS} connected with positive on the source; negative/ground on the drain
- v_{gate} connected with positive on the gate
- Ground wire from v_{gate} output is connected to the ground of v_{DS}. This ensures that grounding is correct for the two voltages.

  See Figure 1 for circuit diagram.

- Connected using 2 SMUs and one variable DC Source (SMU1 - supply v_{DS} and measure I; SMU2 - measure v_{4-wire}; DC Source - supply v_{gate})
- It is possible using just 1 SMU, 1 DC source, and 1 voltmeter
- Ensure that the RF cable (e.g. to the VNA) is disconnected before running current sweeps; it adds quite a lot of noise to the measured current

2.2 Measurements

4-wire sensing measurements: Figures 2, 3, 5, 4. We see that the device can turn on (max current) and off (no current) by sweeping the gate voltage -2 to 0 V.

Some artifacts emerge due to the Yokogawa IM7651 changing range near -1 V.

3 Copenhagen Board

The board has DC resistance 1.2kΩ and 6.188kΩ for board `#25` and `#26`. This combines to a 7.388kΩ resistance in series with the transistor (e.g. for the source/drain).

4 Reflectometry

RF reflectometry to act as a probe for the resistance of the transistor.

4.1 Equipment

- `VNA4396B` used for measuring reflected power
- Set to `Start`: 1MHz and `Stop`: 250MHz
- Measuring A/B and Scale = `Auto scale`
- Connected to $M4$ on the CPH board

4.2 Measurements

Resonances with the transistor are observed at values as per Table 1. The large parasitic capacitance corresponding to the source electrode can be accounted for by considering that the transistor has a larger surface area than conventional quantum devices (with $C_p \sim$ 1pF).
Resonances without the transistor correspond to: 166, 198, 231, and 275 MHz.

Simulated resonance peaks are at Figure 6 and 7. Observed measurements are at Figure 8 and 9.

5 Shunt Capacitor

Adding a shunt capacitor in parallel to RLC circuit in order to shift the matching resistance and observe a larger change in amplitude.

5.1 Equipment

- Ensure that the capacitors are added onto the circuit board correctly; initially we didn't see any effect because $C7$ was missing

5.2 Measurements

Comparison (simulation) of transfer functions at Figure 12, and $S11$ as a function of shunt capacitance at Figure 13. Measured resonance peaks and transfer functions using $C_s = 10\text{pF}$ at Figure 14 and 15. Maps and transfer functions in more detail at Figures 16, 17, 18, 19.

We see minimal change in the observed resonances; in fact, the depth of the peak decreases with the shunt capacitor.

When larger capacitances are used, e.g. 220pF and 1nF, we do not observe any resonance peaks. This may be due to the idea that at larger impedances, the AC sees the shunt capacitor as a near-open path to ground (in comparison to the RLC circuit) - therefore avoiding resonance. This is shown in the simulated plot Figure 20.

6 2nd MOSFET

Attempted to use a variable capacitor on a second MOSFET device with smaller parasitic capacitance, larger resistance. However, the device leaked and we were unable to characterise the range of the variable capacitor using the Lockin.

7 Notes

In the future it would be beneficial to examine other devices which have successfully found resistance-matching and adjusted it using shunt capacitances; in particular, what are the impedance ratios of the device between the RLC and shunt paths?

7.1 Tidbits

MATLAB v2 Ensure that `dragonite-script-master` and `examples` are not in the path when executing

AWG Pulse Studio Read documentation if issues arise; To perform parametric lines, ensure that the name ends in `x`.

RF Switch Add DC blocks to all outputs and inputs to fix grounding issues.

SM2401 There are some subltleties when using the driver; ensure that the source and sense functions are in the correct modes and the compliance and limits are at the correct values

IM7651 Note that changing the range will result in an artifact on measurements; recommend to fix the range and turn off `auto` before sweeping

7.2 Directory Guide

Guide for the folders in `C:/Data/users/Cory`:

2102xxrf Measurements corresponding to resonance frequencies; not the most recent; corresponds to `script_03`

210202waveform Corresponds to `script_02`; It sweeps the transistor to measure current; *Not using 4-wire sensing*

210208resistance Performs 4-wire sensing of the transistor; corresponds to `script_05`, `script_06` and `script_07`;

210212rf Reflectometry measurements with various shunt capacitors; corresponds to `script_08`

210216rf With variable capacitor; corresponds to `script_09`

final_plots Output plots from various plotting scripts

final_plots/presentation_ready Same plots, but converted using `script_10` to make nicer for presentation

final_plots/script_11_presfigs Figures (line-cuts) from `script_11`

IM7651 Yokogawa Variable DC Source driver

SM2401 Keithley 2401 Source Meter (SMU) driver

VNA4396B VNA driver

script_04 Plots the data in `2102xxrf` to create transfer functions etc; *Not using 4-wire sensing*

script_07 Performs 4-wire sensing using the Yokogawa instead of the 2 SMUs

resistance_notes Notes and plots for figuring out 4-terminal measurements

8 Figures

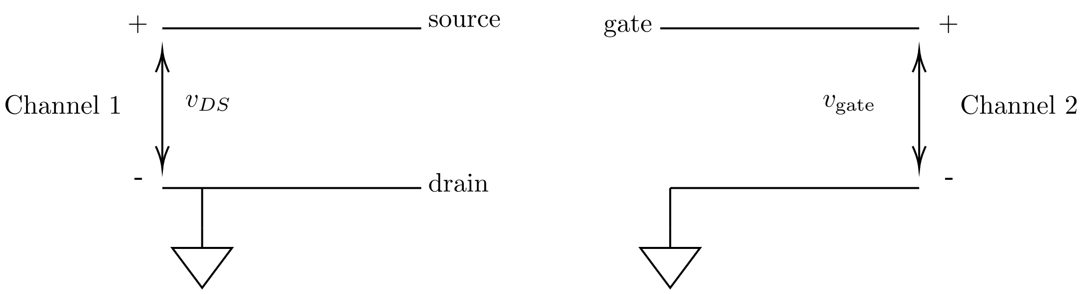

Figure 1: Diagram showing connections to the source and drain via DC.

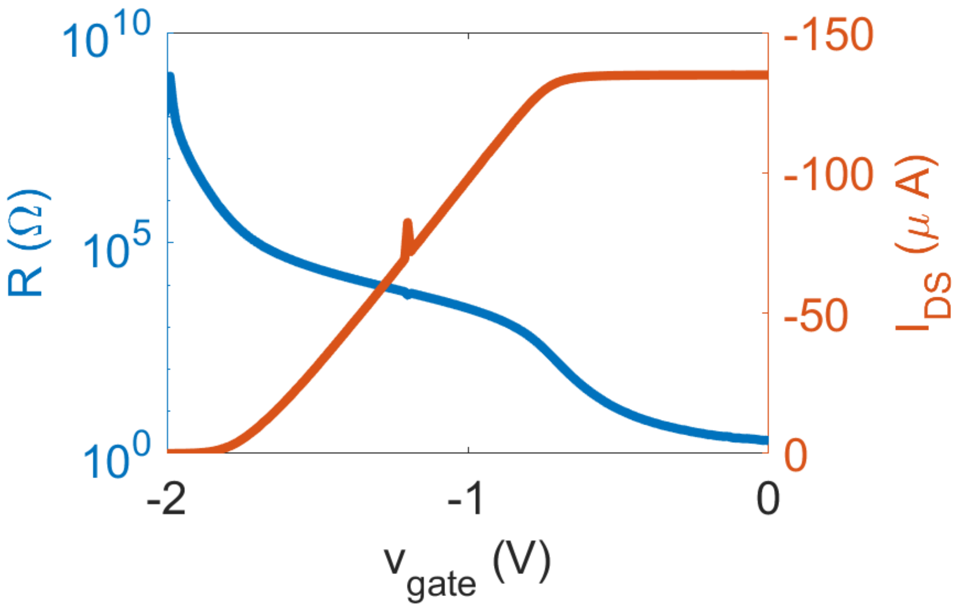

Figure 2: Current and resistance of the transistor as a function of gate voltage. Drain-source voltage is held constant at $v_{DS} = -1$V.

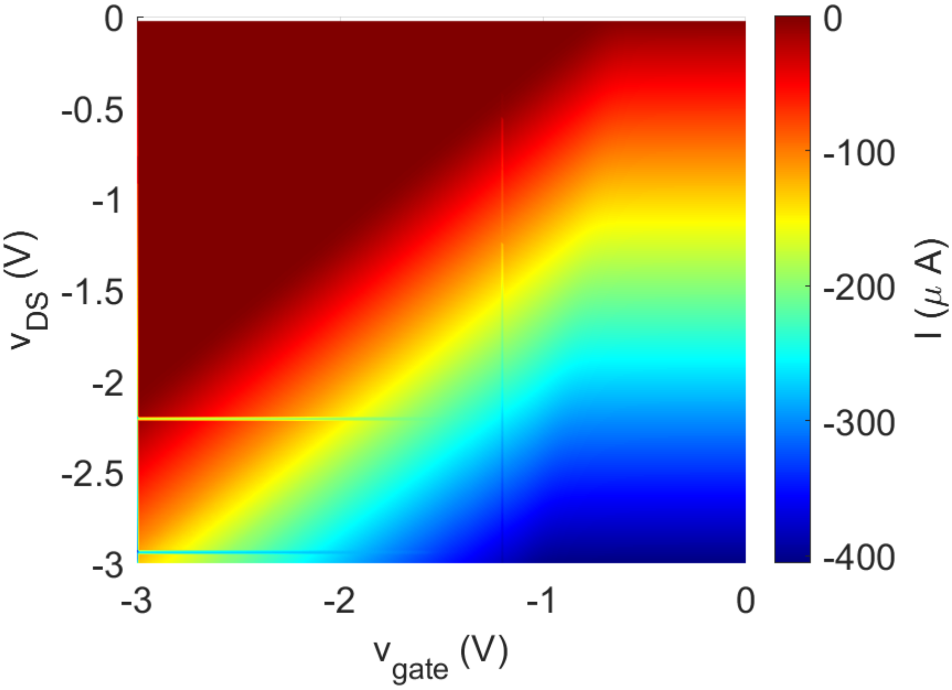

Figure 3: Current through the transistor as a map of drain-source and gate voltages.

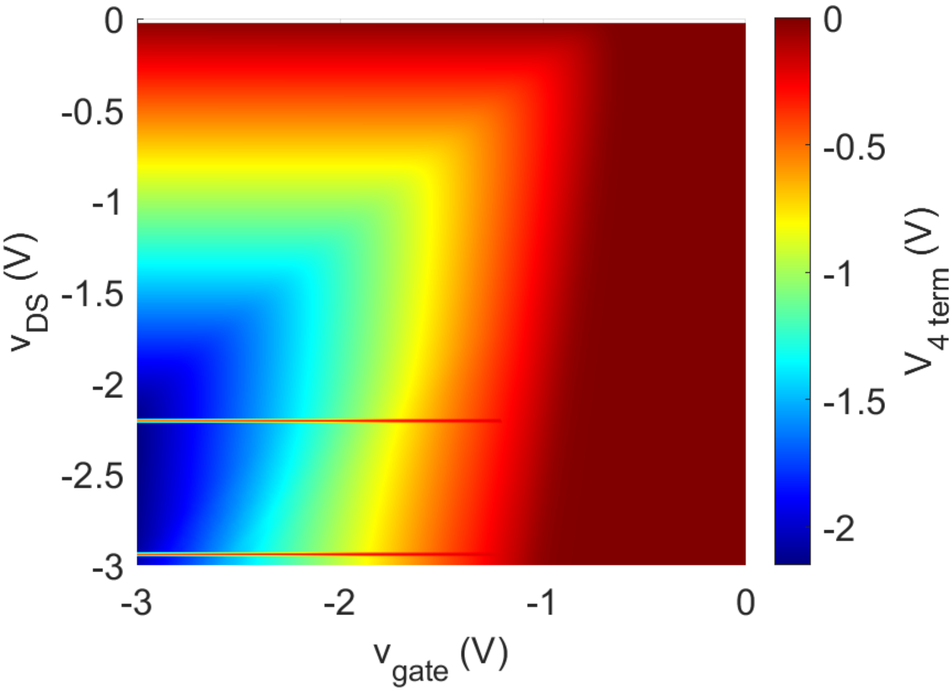

Figure 4: Voltage of the transistor, using 4-wire sensing

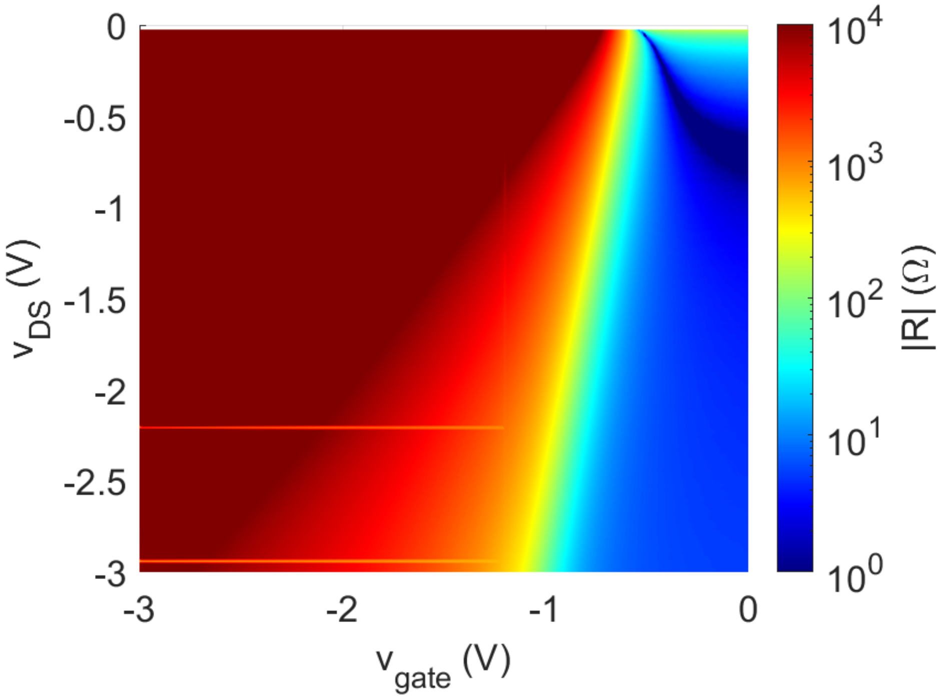

Figure 5: Resistance of the transistor, using 4-wire sensing

Inductor	f_{res} (MHz)	L (nH)	C_p (pF)	Status
$L1$	164	1200	0.79	-
$L2$	192	820	0.84	-
$L3$	186	560	1.3	Gate
$L4$	50	390	26	Source

Table 1: Measured resonant frequencies for each inductor on the Copenhagen board; Parasitic capacitance calculated using $f_{\text{res}} = 1/2\pi\sqrt{LC_p}$.

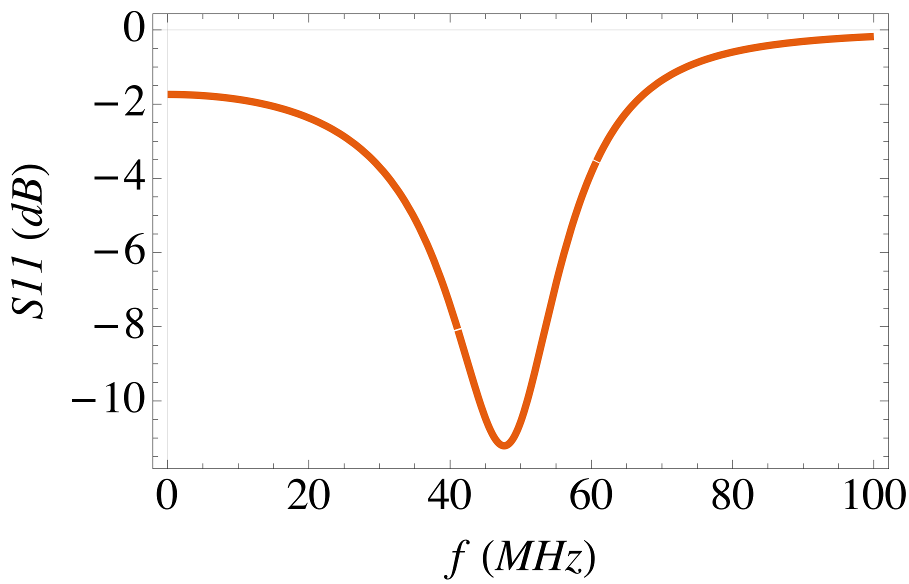

Figure 6: Simulated resonance peak at $R = 1\text{k}\Omega$ and $C_p = 26\text{pF}$. Resonance occurs at $f \approx 48\text{MHz}$.

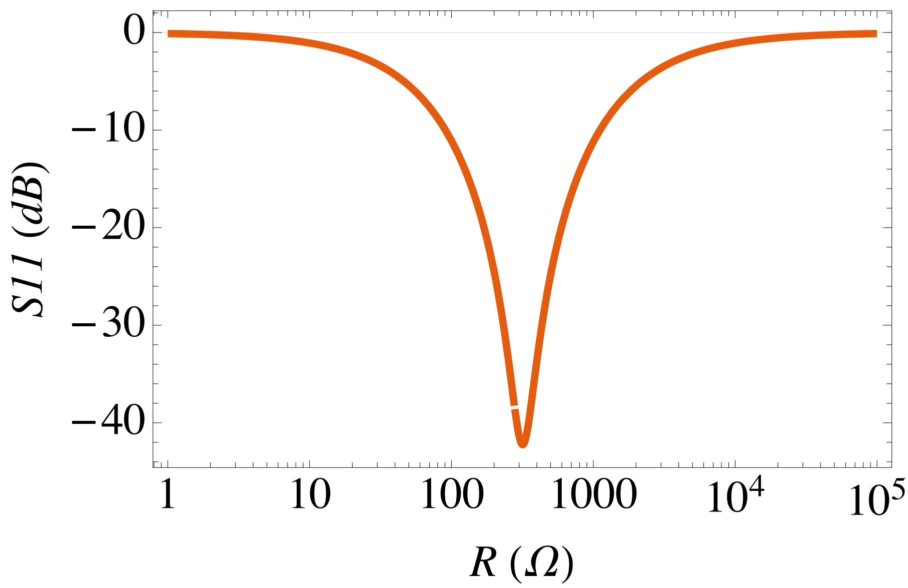

Figure 7: Simulated transfer function at resonant frequency.

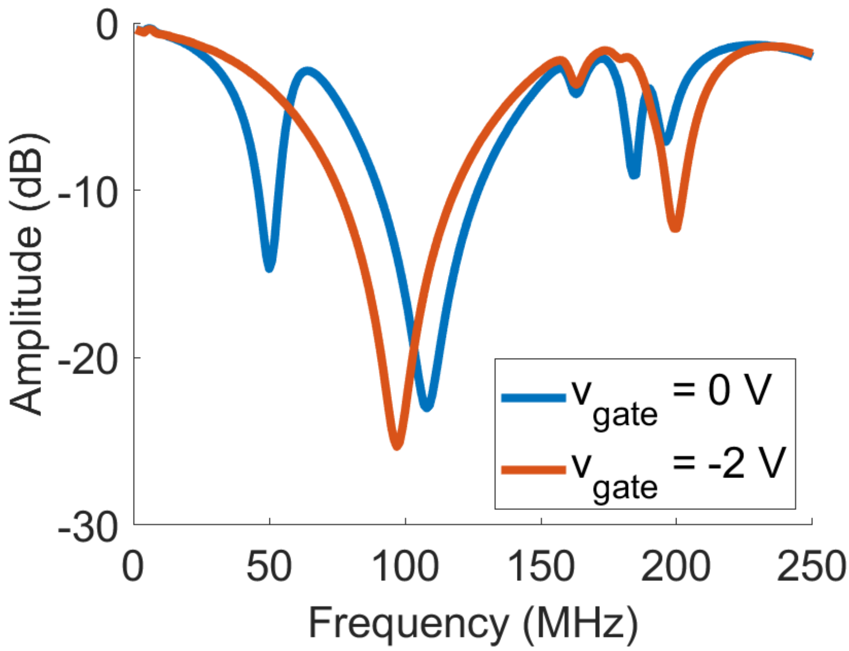

Figure 8: Resonance peaks at different gate voltages.

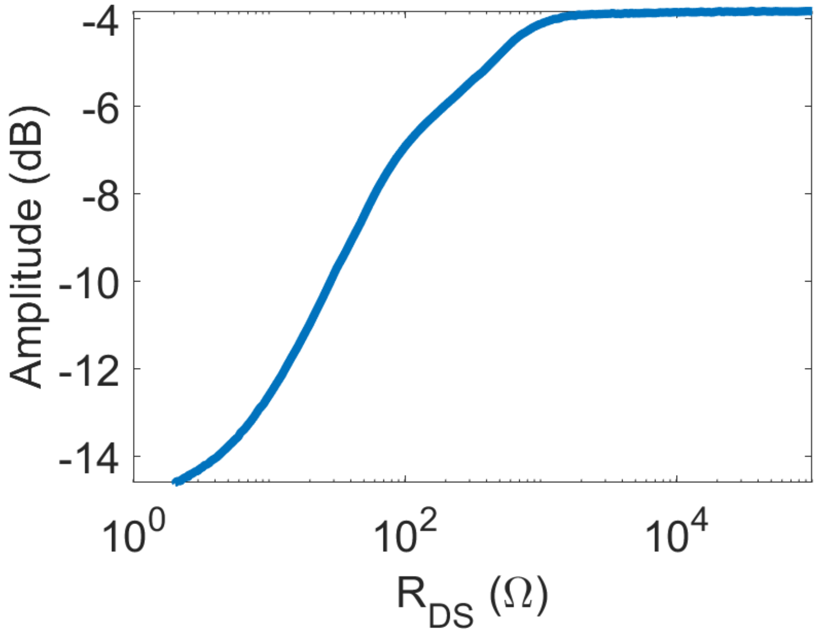

Figure 9: Transfer function at $f = 50$MHz and $v_{DS} = -1$V.

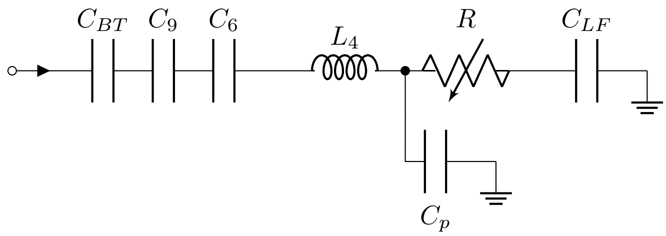

Figure 10: More accurate circuit diagram for the resonance circuit, with the transistor modelled as a variable resistor.

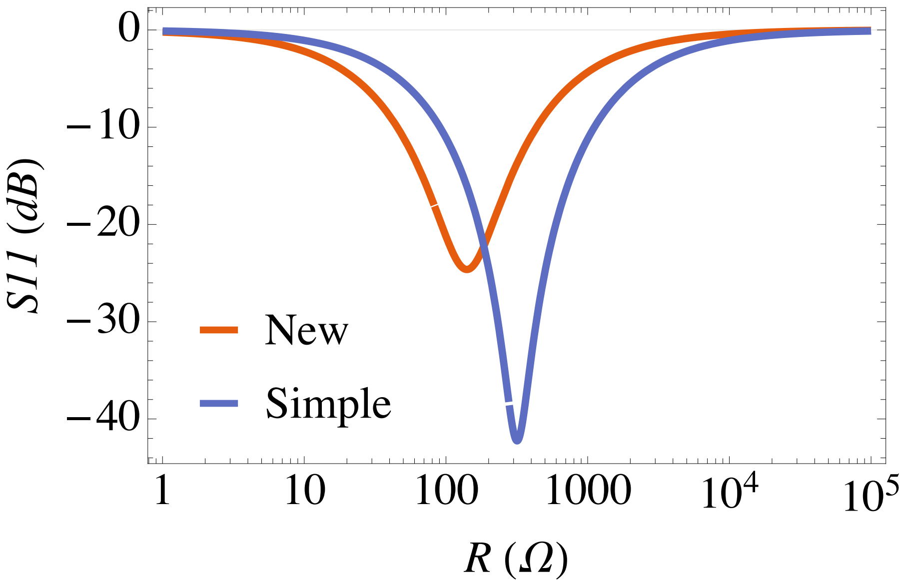

Figure 11: Simulated transfer function comparison between the model from Figure 10 and that in the simple RLC circuit.

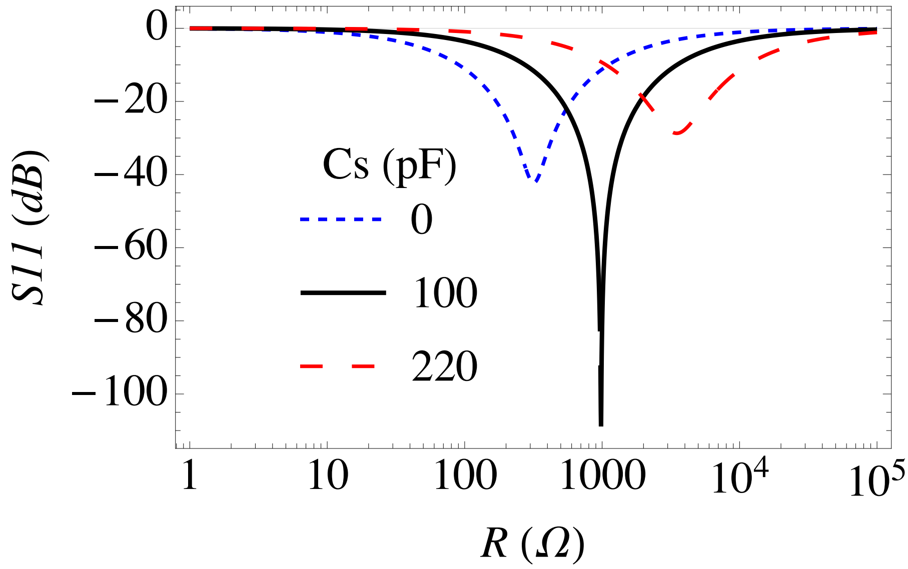

Figure 12: Comparison of transfer functions with shunt capacitors.

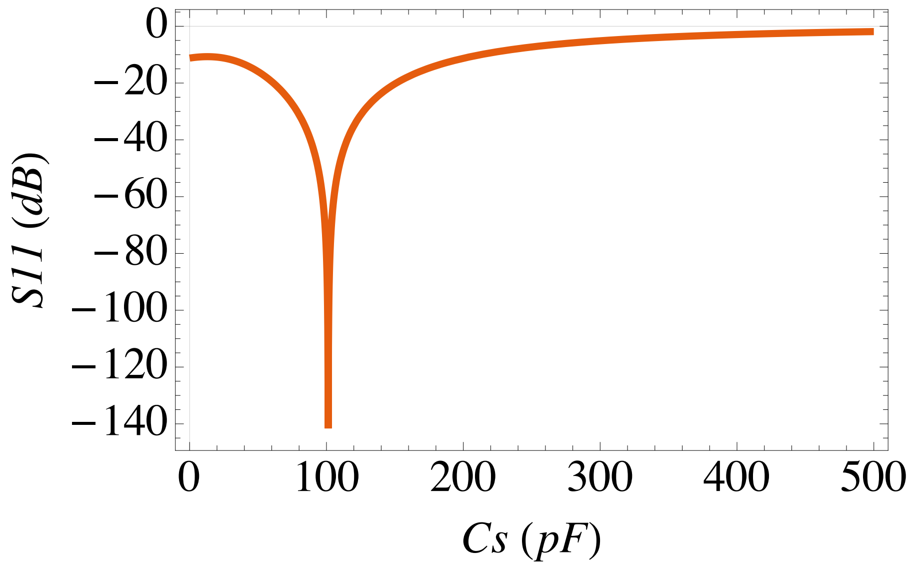

Figure 13: Simulation of S11 values as a function of the included shunt capacitance, at a fixed value of $R = 1\text{k}\Omega$.

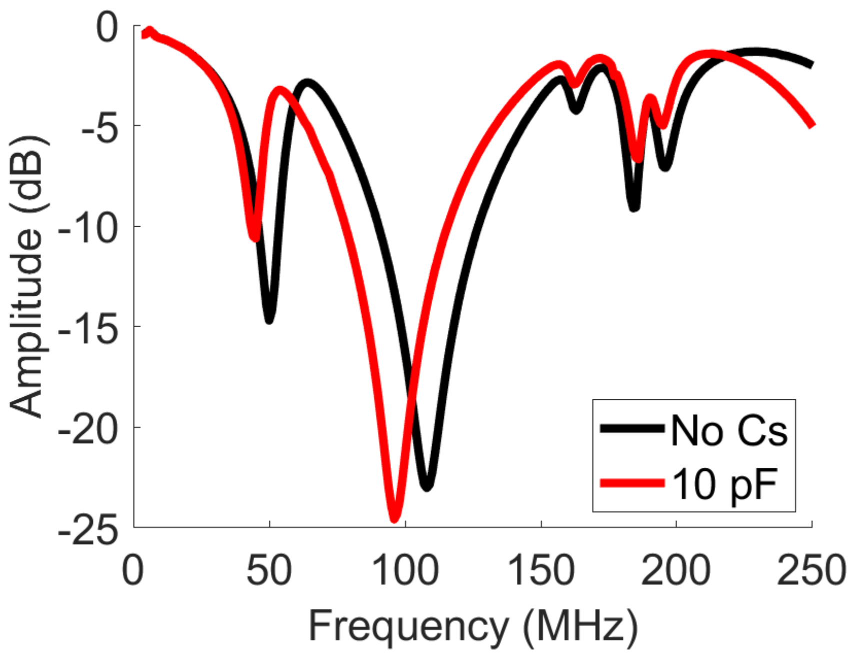

Figure 14: Resonance peaks with $C_s = 10\text{pF}$ and $C_s = 0$, holding $v_{DS} = -1\text{V}$, $v_{\text{gate}} = 0$.

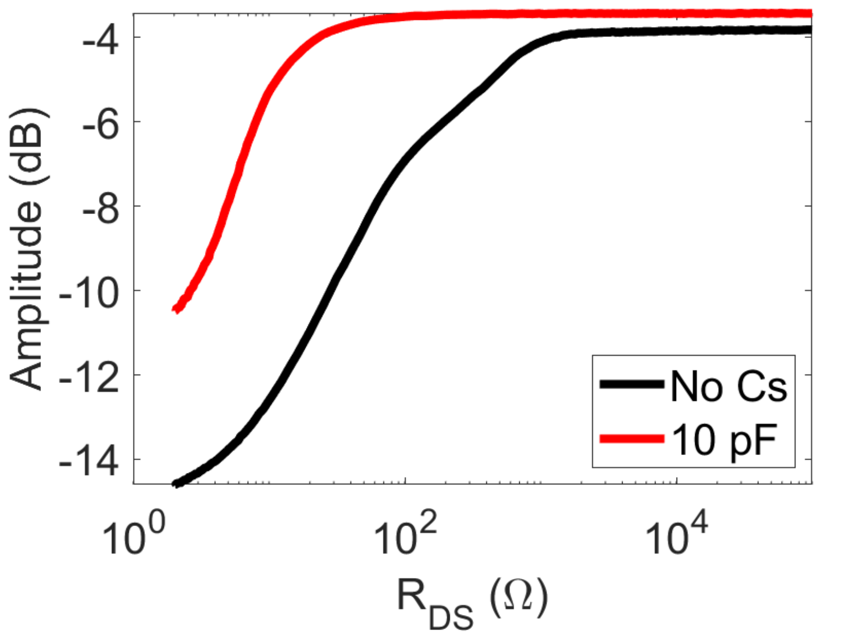

Figure 15: Transfer function at $f = 44\text{MHz}$ with $C_s = 10\text{pF}$ and at $f = 50\text{MHz}$ with $C_s = 0$.

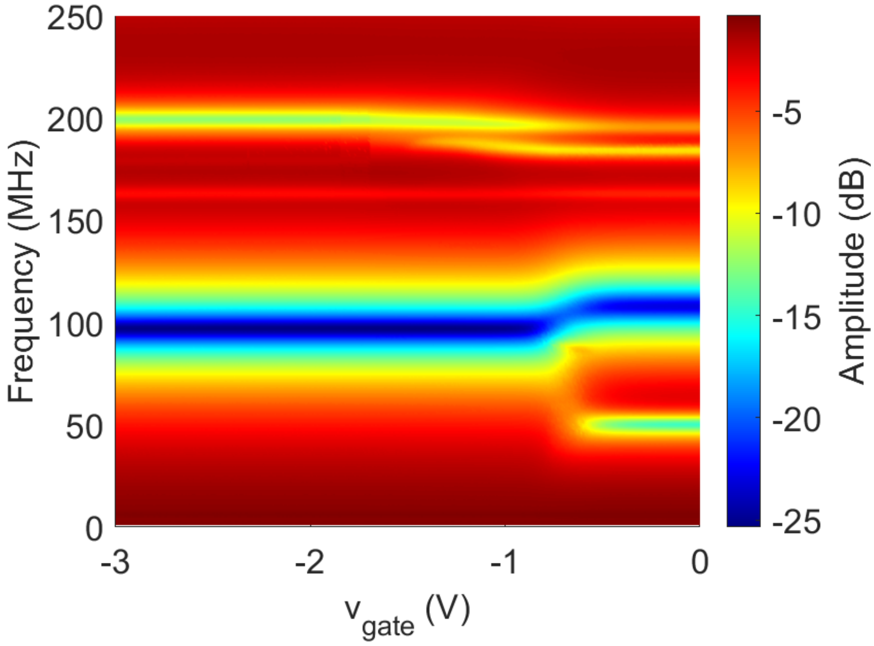

Figure 16: Resonance peaks at various v_{gate}, without a shunt capacitor.

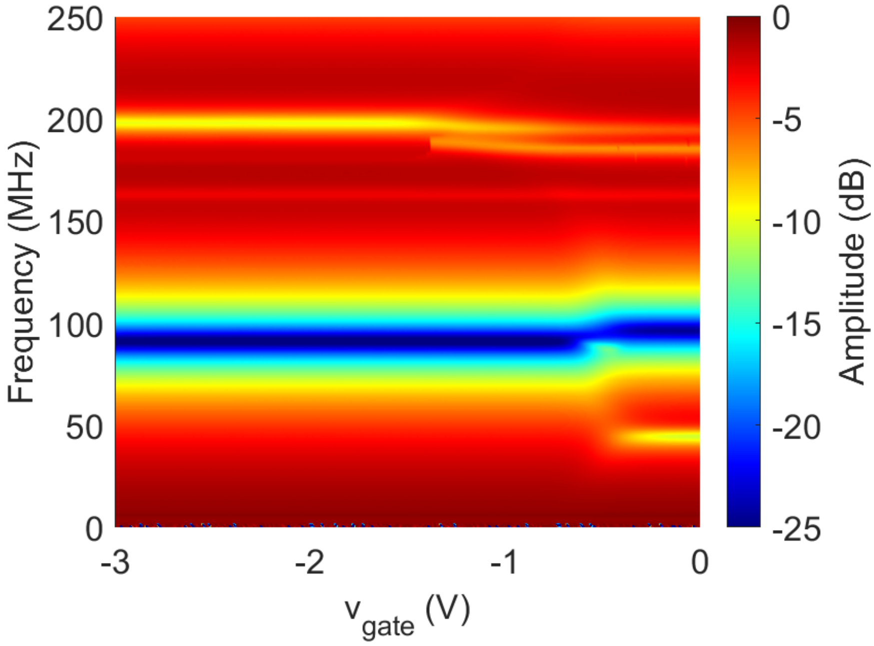

Figure 17: Resonance peaks at various v_{gate}, with $C_s = 10\text{pF}$.

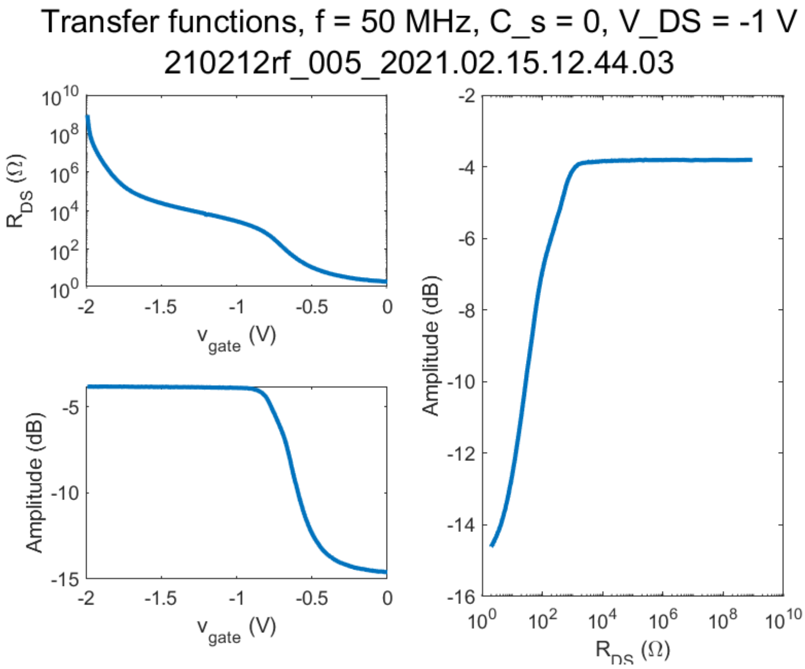

Figure 18: Transfer function at $f = 50\text{MHz}$ and $v_{DS} = -1\text{V}$, with no shunt capacitor

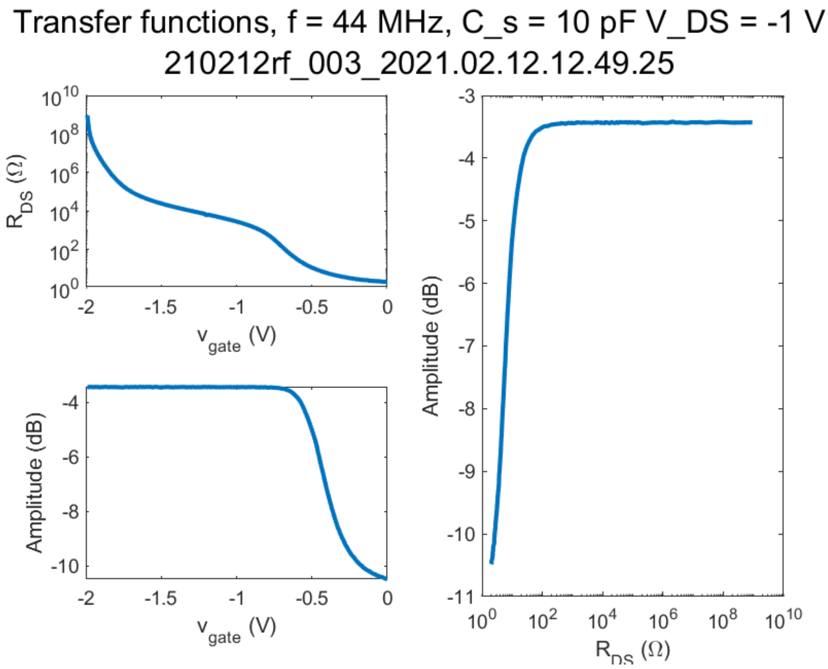

Figure 19: Transfer function at $f = 44\text{MHz}$, with $C_s = 10\text{pF}$.

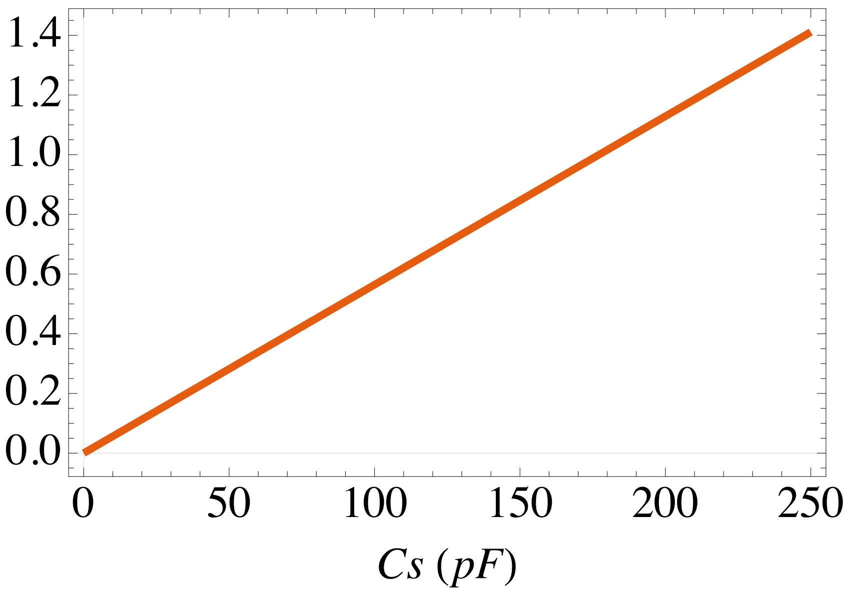

Figure 20: Ratio of RLC impedance to C_s impedance as a function of C_s, at $f = 50\text{MHz}$.