ece340_lab4

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1 Objective

1.1 Diode as a current-controlled resistance

Small-signal analysis is a technique to understand how a circuit behaves with small variations around a static, or DC, operating point. This is especially useful when the circuit includes non-linear elements like diodes and transistors, where it is impossible to arrive at a closed-form solution to the circuit.

Including the *ideality factor* n, which is typically around 2 at low currents, the diode current is well approximated as:

$$I_D = I_s \exp\left(\frac{V_D}{nV_T}\right)$$

The slope of this function may be obtained by differentiating the diode current with respect to the applied voltage:

$$\begin{aligned}\frac{dI_D}{dV_D} &= \frac{I_s}{nV_T}\exp\left(\frac{V_D}{nV_T}\right)\\ &= \frac{I_D}{nV_T}\end{aligned}$$

This has units of $1/\Omega$. Alternatively, we may write the small-signal resistance (incremental slope of the V_D/I_D curve) as:

$$r_D = \frac{nV_T}{I_D}$$

We will use this relationship to predict and measure this small-signal resistance when used in a current-controlled voltage divider circuit. A slightly more sophisticated version of this type of circuit is used as the gain control element in several classic and modern dynamic range compressors used in audio recording and production. The attached schematic is for the Neve 2254/R showing the portion implementing the resistor-diode voltage divider stage.

In [2]:
```
from IPython.display import Image
Image('neve_2254r_front.jpg')
```

Out [2]:

1.2 Procedure

Construct the circuit shown in **Figure 1**. Note: the $33\mu F$ capacitor is an electrolytic type: it must be inserted with the indicated polarity.

- Use a standard x10 oscilloscope for Channel 1
- Use a BNC-to-alligator or BNC-to-minigrabber cable for Channel 2. Do not use a standard oscilloscope probe, we are measuring very small voltages.
- Channel 1 settings (V_{in}):
  - DC coupling
  - Bandwidth (BW) limit **on**
- Channel 2 settings (v_d AC) across the diode:
  - use plain BNC-grabber cable, not probe
  - AC coupling
  - Bandwidth (BW) limit **on**
  - in the channel's "Probe" sub-menu, ensure the probe is set to $1.00 : 1$
- Channel 3 settings (V_D DC) across the diode:
  - use oscilloscope probe
  - DC coupling
  - Bandwidth (BW) limit **on**
- Touch the **Acquire** button:
  - Mode -> High Resolution
- Signal generator settings:
  - Sine
  - 1.0 kHz
  - 200 mV peak-to-peak
  - 0 offset
- Use the 0-20V DC power supply for V_{DC}

Vary the DC power supply voltage to setup a DC current through the diode ranging from around $0.1mA$ through $10mA$. Measure the AC amplitude of the output sine wave with the oscilloscope's Measure functionality set on "AC RMS - N cycles" for at least 8 different currents. Use a logarithmic spacing of 0.1, 0.2, 0.5, 1, 2, 5 mA …

Make note of the display and settings for displaying the diode voltage. One is measuring the DC value of the diode voltage and the other is measuring the sinusoid's amplitude only.

1.3 Analysis

Using the equivalent small-signal AC circuit of Figure 2, calculate the gain of the circuit for small-amplitude input signals as a function of the circuit parameters and the equivalent small-signal diode resistance:

$$\frac{V_{out}}{V_{in}}(r_D) =$$

Assuming room temperature, $V_T = 26mV$ and an ideality factor of 2, plot this transfer characteristic as a function of diode bias current:

$$\frac{V_{out}}{V_{in}}(I_D) =$$

On the same graph, plot your measured V_{out}/V_{in}, also as a function of diode DC current.

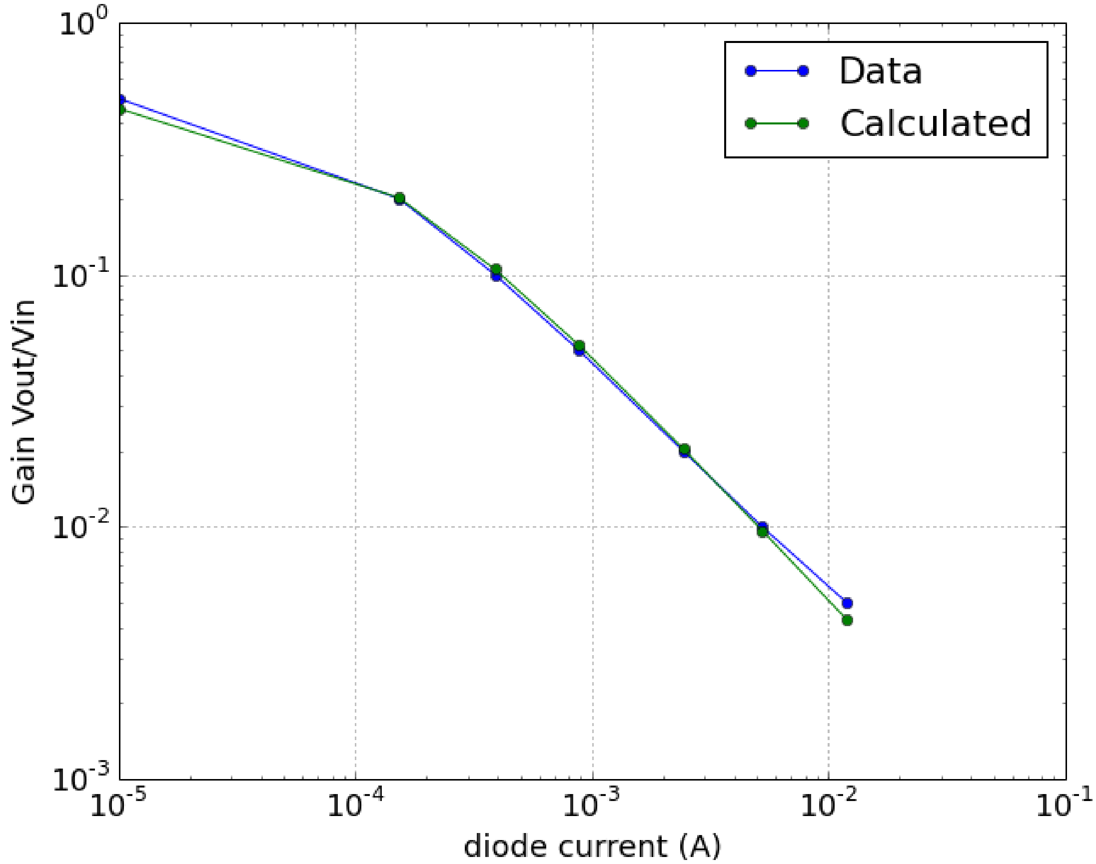
Discuss your observations about the output waveform shape as the bias current varied and ranges where your measurements matched the predicted values. Given your observations with the DC-coupled Channel 3, discuss the problems this circuit injects onto the output signal if the diode current is varied rapidly to dynamically change the attenuation ratio.

In [1]:

```
# sample measurements made in the lab
Rbias = 1e3
VT = 26e-3

amp3 = array([50, 20, 10, 5, 2, 1, 0.5]) # mVrms
vd3 = array([0.01, 0.154, 0.391, 0.888, 2.444, 5.28, 12.04])
idiode3 = vd3 / Rbias

Vin = 100.0 #mVrms
gain3 = amp3/Vin

#semilogx(idiode3, gain3, '-ob', label='Data')
loglog(idiode3, gain3, '-ob', label='Data')

#ideal small-signal resistance calculations
r_ideal = VT * 2.0 / idiode3
rp = r_ideal * 1e3 / (r_ideal + 1e3)
atten = rp / (rp + 1e3)

ax = loglog(idiode3, atten, '-og', label='Calculated')
tmp = legend()
tmp = grid('on')
xlabel('diode current (A)')
ylabel('Gain Vout/Vin')
```

Out [1]:

```
<matplotlib.text.Text at 0x47ffbd0>
```



Data
Calculated
Gain Vout/Vin
diode current (A)
10^0
10^-1
10^-2
10^-3
10^-5
10^-4
10^-3
10^-2
10^-1