Using the AD5206 digital potentiometer with AC signals

- The AD5206 behaves like six mechanical potentiometers.
- Each potentiometer has three terminals (A,B, and W), just like a mechanical.
- These potentiometers are (to the best of my knowledge) completely isolated—I did not observe any leakage between them.
- There are two power terminals on the chip: V_{SS} and V_{DD}.
- These terminals are subject to the constraints that

  $$V_{\mathrm{SS}} \leq 0 \leq V_{\mathrm{DD}}$$

  and

  $$|V_{\mathrm{DD}}| + |V_{\mathrm{SS}}| \leq 5.5V$$

- The potentials of all three wiper terminals MUST be between V_{SS} and V_{DD}:

  $$V_{\mathrm{SS}} \leq \{A, B, W\} \leq V_{\mathrm{DD}}$$

- If this condition is not met, the response is nonlinear, and signals are distorted.

Monopolar Mode

These potentiometers are usually used in (and most online resources assume) monopolar mode

- In this mode, $V_{\mathrm{SS}} = 0V = \mathrm{GND}$, and $V_{\mathrm{DD}} = 5V$.
- This is very convenient, since the logic output of most microcontrollers (e.g. Arduino) is $5V$, so no step-down is needed.
- However, because of the voltage bounds mentioned above, this means we can't send zero-offset AC signals (like we're working with here) through the digipot
- We could add an offset using an opamp, but that makes scaling very difficult, and adds unnecessary noise.

Bipolar Mode

Instead, we can operate in bipolar mode, where $V_{\mathrm{SS}} < 0$. Some considerations in this mode:

- The potential bounds still apply. If we power the digipot with $\pm 2.5V$, the signal must fall within those bounds as well. This should not be a problem, since our signal should be within the $\pm 1V$ envelope.
- The logic voltage must be within $0.3V$ of V_{DD} (or specifically, when $V_{\mathrm{DD}} = 3V$, the logic must be between $2.6V$ and $3.3V$, as per the datasheet).
- Logic low is still ground.
- There are $3.3V$ logic Arduinos, which could directly drive the chip in this mode. I am looking to acquire one of these, to eliminate the three voltage dividers needed with a $5V$ arduino.

Communication

- We communicate with the potentiometer using SPI (serial peripheral interface).
- To set a resistance:
  - Drive the CS (chip select) pin low
  - Write the address as a single byte, MSB first. Because valid addresses are $0-5$ (zero-indexed), the word will look like `0b00000101` (for address 5).
  - In Arduino, this can be done with `SPI.transfer(channel)`, where channel is in the range $0-5$.
  - Then write the desired potentiometer value as a single byte, ranging from 0 (minimum resistance) to 255 (maximum resistance). In theory, the output resistance at step n will be

    $$R_{\text{out}} = (n/255) \cdot 50\,\text{k}\Omega$$

    Experimental response curves are detailed below.
  - Drive the CS pin high.
  - The code used on the Arduino is in the associated Github repository.

Odds and ends

- During testing, I used an external power supply tuned to $\pm 2.5V$. However, to simplify the circuit (the less wires running on and off the board, the better), I am using voltage dividers off the $\pm 15V$ opamp bus.
- Because of gaps in our resistor set, I was not able to power the chip at $\pm 2.5V$. Instead, it is powered at $-2V/+3V$. This should not present a problem, since it still gives us the $\pm 2V$ envelope, which should be sufficient.
- IMPORTANT!!! The AD5206 comes in three varieties—10 kΩ, 50 kΩ, and 100 kΩ. The 10 and 100 varieties DO NOT respond properly in bipolar mode. This was not documented anywhere, but only the 50 kΩ works for our purposes.
- The only possible explanation I was able to find is that the 50 kΩ is listed as RoHS compliant on DigiKey, while the others are not. The 50 kΩ could therefore be a newer make. This stymied me for about 5 days, since I was using a 100 kΩ.

Response curves

Potentiometer	Base resistance (Ω)	Response (Ω/tick)
Ideal	50[1]	196.1
R1	30.3	202.6
R2	39.5	202.3
R3	39.9	202.1
R4	42.0	202.1
R5	10.9	202.6
R6	27.4	202.4

These resistors have a small (near-negligible) wiper resistance, and a slightly higher maximum resistance than advertised. The typical maximum resistance was about 51.5 kΩ. No statistically significant nonlinearity was observed.

[1] "Typical" wiper resistance from datasheet