

Microphone Sensitivity Adjustments Using TPL1401



Smart DAC

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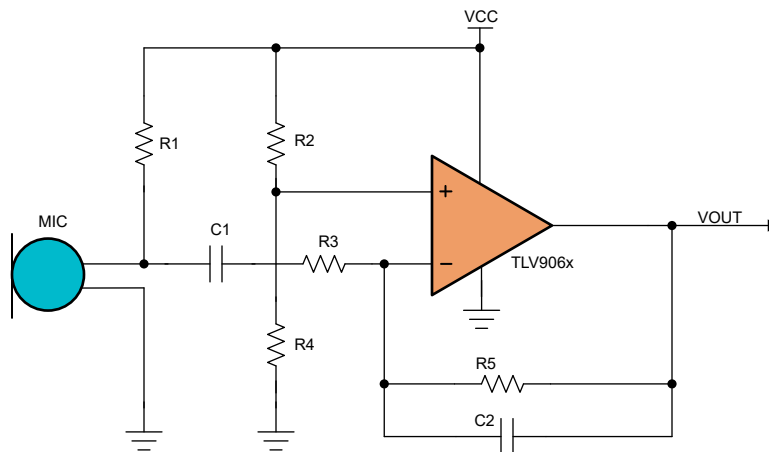
Design Objective

Key Input Parameter	Key Output Signal	Recommended Device
Input signal Level : 20mVrms Frequency of operation : 20Hz–20KHz Microphone sensitivity variation: ± 3 dB Supply voltage : 5 to 12V	1Vrms Output Voltage with code dependent gain calibration	TPL1401, TLV906x

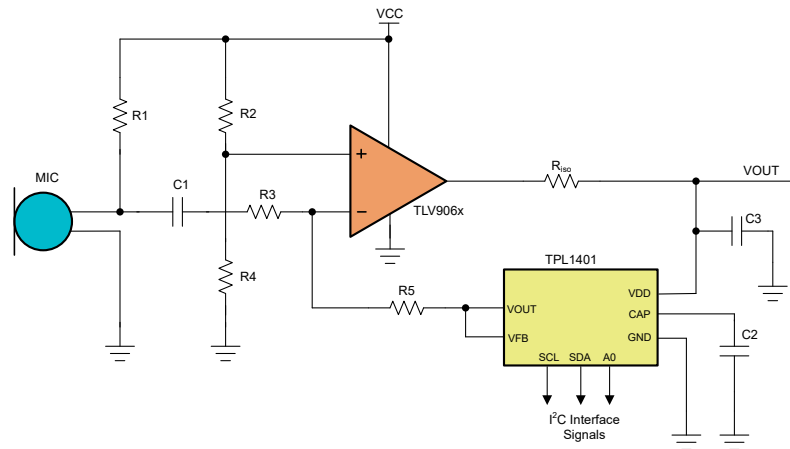
Objective: Calibration of microphone amplifier to adjust for the variation in sensitivity of the electret microphones.

Design Description

This application note describes how to adjust the gain and calibration of a microphone amplifier to adjust for the variation in sensitivity of electret microphones. Microphones are a primary component of any voice- or speech-based system and electret microphones are a common choice in applications for their small size, cost, and performance. The following figure shows a basic electret microphone amplifier circuit. Most electret microphones are internally buffered with a junction field-effect transistor (JFET), which is biased with the 3.3-k Ω (R1) pullup resistor. Sound waves move the microphone element, causing current flow into the JFET drain. The JFET drain current creates a voltage differential across R1 which is AC coupled and biased to mid-supply and connected to the inverting input of the op amp. The op amp can be configured as a simple inverting amplifier or configured as a band pass-filtered, non-inverting amplifier circuit. With the expected input signal levels and the desired output magnitude and response, the gain and frequency response can be calculated.



One of the main drawbacks of the previous circuit is the fixed gain. Most of the electret microphones have sensitivity variation in the order of ± 3 dB which will result in different output magnitude which can be a problem in production, leading to yield issues. This can be solved by adding a buffered digital potentiometer (digipot) like the TPL1401 in the feedback path of the op amp, which will enable programmability of the gain to adjust for sensitivity variation of the microphone in production. The following image shows the typical implementation diagram.



Design Notes

1. The [TPL1401 256-Tap, High-Accuracy, Digital Potentiometer With Buffered Wiper Data Sheet](#) recommends using a 100-nF decoupling capacitor for the VDD pin, and a 1.5μF or greater bypass capacitor for the CAP pin. The CAP pin is connected to the internal LDO. Place these capacitors close to the device pins.
2. When possible, use COG (NPO) ceramic capacitors (C1) for input filtering. The dielectric used in these capacitors provides the most stable electrical properties over voltage, frequency, and temperature changes.
3. Bias resistor, R1, will be decided based on the microphone (typical values range from 1kΩ to 10kΩ)
4. The resistance of R2 and R4 will be chosen in such a way that there is enough headroom requirements for the TPL1401 to operate. The voltage at the output of the operational amplifier is used as the supply for the TPL1401. At any point, this voltage cannot go less than 1.8V (including the AC signal that is modulated on the DC bias). For example, in this design, the target is 1V_{rms}, so a conservative commonmode voltage of 1.5V will be sufficient. With TPL1401 set to mid-code, the output of the operational amplifier will be 3V.
5. TPL1401 should be used in VDD as reference mode of operation and set the initial code to mid code. In this configuration gain is inversely proportional to the CODE set in the TPL1401.
6. Set the low frequency operation of the circuit.

$$F_{cutoff-lower} = 1 / (2 \times \pi \times R3 \times C1)$$

$$F_{cutoff-lower} = 20\text{Hz} \quad C1 = 1\mu\text{F}$$

$$R3 = 1 / (2 \times \pi \times 1e-6 \times 20) = 7.96\text{K}\Omega$$

7. Gain of the circuit is controlled by the following equation:

$$V_{out} = V_{in} \times (-1) \times (2^N / \text{CODE}) \times (R5 / R3)$$

$$V_{in} = 20\text{mV}_{rms} \quad V_{out} = 1\text{V}_{rms}$$

$$R3 = 7.96\text{K}\Omega \quad N = 128(\text{mid-code})$$

$$R5 = (1\text{V} \times 128 \times 7.96e3) / (2^8 \times 20e-3) = 199\text{K}\Omega$$

8. Gain can be adjusted with DAC code. For DAC codes greater than 128, gain will decrease and for DAC codes less than 128, gain will increase. This way we can adjust the gain for tuning the sensitivity of the microphone.
9. Higher cutoff frequency will be set by Riso and C3:

$$F_{cutoff-higher} = 1 / (2 \times \pi \times R_{iso} \times C3)$$

$$F_{cutoff-higher} = 20\text{KHz}$$

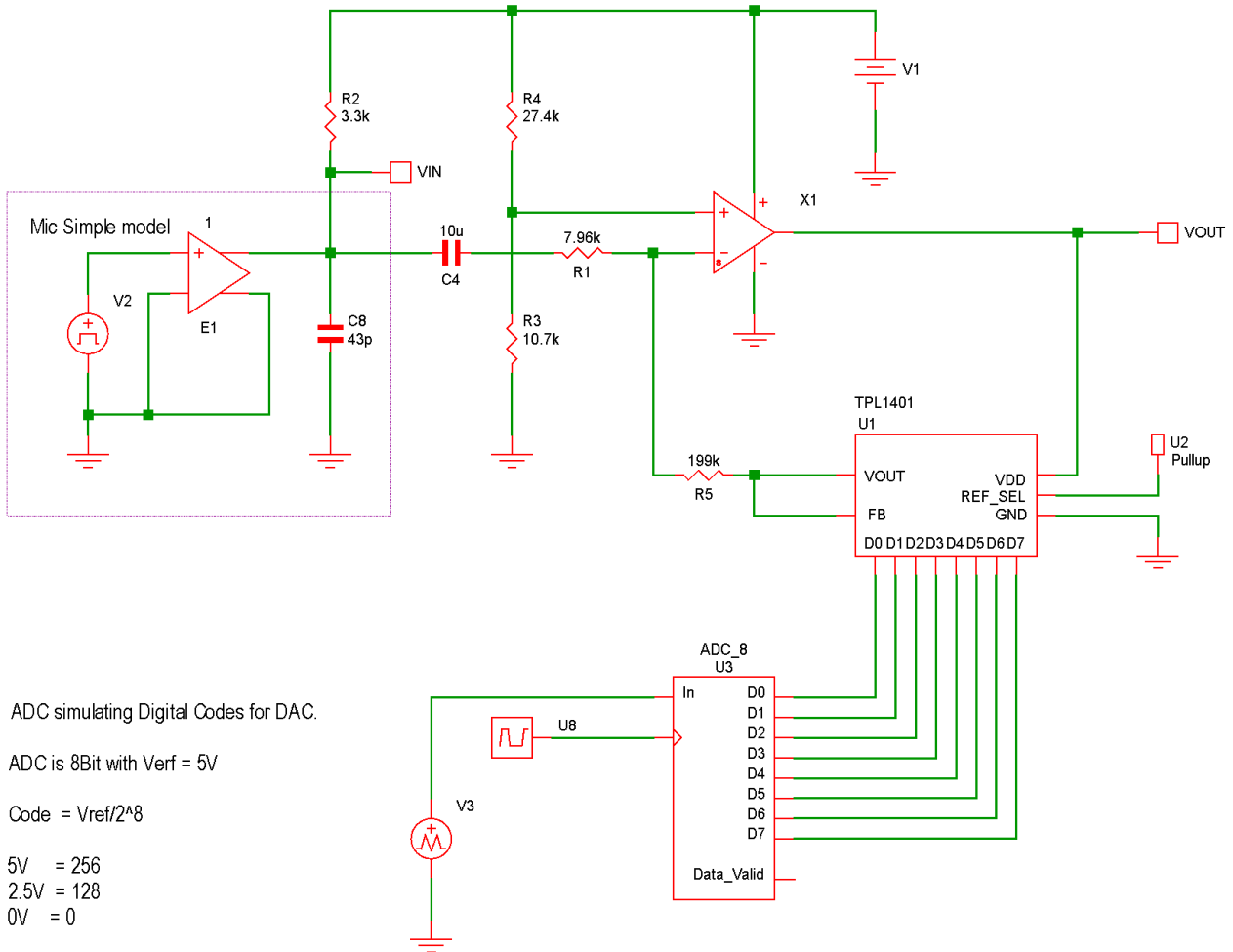
$$C3 = 100\text{nF}$$

$$R_{iso} = 1 / (2 \times \pi \times 20e3 \times 100e-9) = 79.6\Omega$$

10. The TPL1401 can be programmed with these initial register settings using I2C. The NVM of the device can be programmed using the PROTECT register to save all initial settings. After programming the NVM, the device will power load all registers with the values stored in the NVM.
11. Choose an op amp with lower noise, low bias current and support operation of single supply down to 1.8V. The TLV906x family of devices can be a good choice.

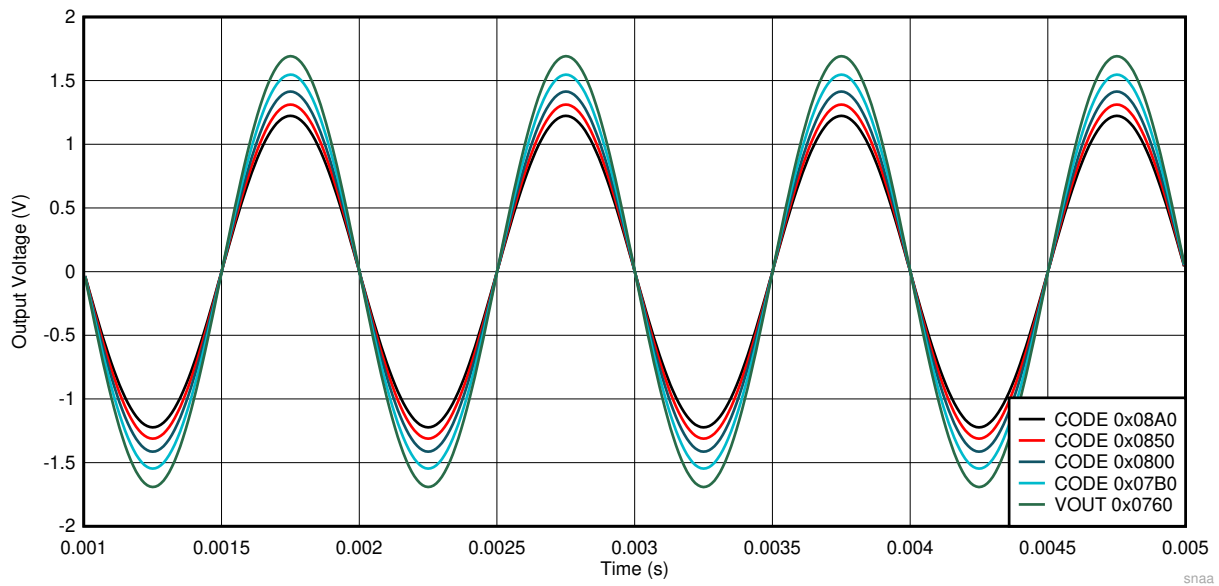
Design Simulations

Schematics used for simulation of TPL1401 used as sensitivity adjustments for microphone. In the following schematics, ADC is simulating the digital codes for the TPL1401. Simulation is done for DIGITPOT code changes from 118 to 138 (in decimal) which corresponds to ADC input voltage of 2.3V to 2.7V.



Transient Simulation Results

This simulation shows the output of the circuit changes with Digipot code with mid code corresponding to 1Vrms.



Output Voltage for Different Codes (Codes From 0x760 to 0x8A0)

ADC Input Voltage (Volts)	Digipot Data (DPOT_POSTION)	Output Voltage (Vrms)
2.3	0x0760	1.195
2.4	0x07B0	1.093
2.5	0x0800	0.999
2.6	0x0850	0.921
2.7	0x08A0	0.864

Register Settings

Register Configuration for the TPL1401 Programmable Comparator

Register Address	Register Name	Setting	Description
0xD1	GENERAL_CONFIG	0x01E0	[15:14] 0b00: Always write 0b00
			[13] 0b0: Write 0b1 to lock the device. Unlock by writing 0b0101 to DEVICE_UNLOCK_CODE field in the PROTECT register
			[12:5] 0x0F: Always write 0x0F
			[4:3] 0b00: Powers up the device output
			[2] 0b0: Disables the internal reference
			[1:0] 0b00: Sets the reference to VOUT gain 1.5×
0xD3	PROTECT	0x0010	[15:12] 0b0000: Write 0b0101 to unlock the device
			[11:10] 0b00: Don't care
			[9] 0b0: Write 0b1 to load all registers with factory reset values
			[8:6] 0b0000: Always write 0b0000
			[5] 0b0: Write 0b1 to reload applicable registers with existing NVM settings
			[4] 0b1: Write 0b1 to store applicable register settings to the NVM
			[3:0] 0b0000: Write 0b1010 to reset registers with existing NVM settings or default settings
0x21	DPOT_POSITION	0x0800	[15:12] 0b0000: Don't care
			[11:4] 0x80: 8-bit data updates the digipot output
			[3:0] 0b0000: Don't care

Pseudo Code Example

The following shows a pseudo code sequence to program the initial register values to the NVM of the TPL1401. The values given here are for the design choices made in the [Design Notes](#).

Pseudo Code Example for Microphone Sensitivity Tuning Using the TPL1401

```
//SYNTAX: WRITE <REGISTER NAME (Hex code)>, <MSB DATA>, <LSB DATA>
//Power-up the device, internal reference disabled
WRITE GENERAL_CONFIG(0xD1), 0x01, 0xE0
//Write digipot code 12-bit aligned
WRITE DPOT_POSITION(0x21), 0x08, 0x00
//Write settings to the NVM
WRITE PROTECT(0xD3), 0x00, 0x10
```

Design Featured Devices

Device	Key Features	Link
TPL1401	256-tap high-accuracy digital potentiometer (digipot) with buffered wiper	ti.com/product/TPL1401
TLV906x	10-MHz, RRIO, CMOS operational amplifiers for cost-sensitive systems	ti.com/product/TLV9062

Find other possible devices using the [Parametric search tool](#).

Design References

See [Analog Engineer's Circuit Cookbooks](#) for TI's comprehensive circuit library.

Additional Resources

- Texas Instruments, [TPL1401 Evaluation Module](#)
- Texas Instruments, [TPL1401 Evaluation Module User's Guide](#)
- Texas Instruments, [TPL1401 FAQ](#)
- Texas Instruments, [Precision Labs - DACs](#)
- Texas Instruments [New TI smart analog and smart DAC for adding intelligence to analog without software at low cost](#)

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