# On-Chip Thin Film Resistors Enable High-Performance Audio Circuitry

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TEXAS INSTRUMENTS

## Introduction

High-performance circuit design requires careful selection of both active and passive components in the signal path. It is common for designers to assume that using a high-performance integrated circuit ensures a high-performance system. However, selecting passive components solely for lowest cost can significantly degrade the performance of the system. In audio products requiring small size, low distortion, or excellent matching, on-chip thin-film resistors (TFRs) can provide superior performance compared to discrete resistors.

## Modern Amplifier Architecture

TFRs are formed by first depositing a thin layer of a resistive material, typically a metal alloy, onto a substrate such as a silicon wafer. Lithography is then used to pattern the resistive layer into regions of known resistance, often called links. In order to match two resistors closely, each may be broken into many links connected in parallel. The resistive links comprising each resistor are placed in an interdigitated fashion on the wafer, effectively allowing both resistors to occupy the same location of the wafer. This ensures that any variation in thin-film resistive material on the wafer affects both resistors equally. Figure 1 shows an example of the process.

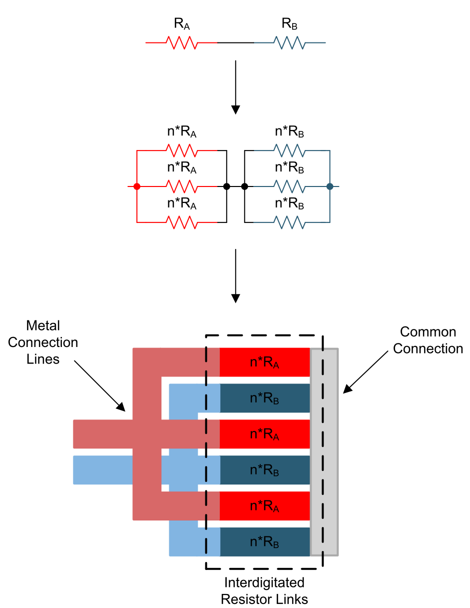


**Figure 1. TFR Network to Achieve Matched Values**

Modern semiconductor layout techniques, combined with simulations of extracted parasitics on the chip allow this process to produce resistor arrays with exceptional matching without laser trimming. For example, the INA1620 integrates a dual operational amplifier (op amp) with four arrays of thin-film resistors. Each array consists of two 1-kΩ resistors connected as a voltage divider. These resistors typically are matched to better than 0.005% error.

## Improving CMRR in a Difference Amplifier Circuit With Integrated Thin Film Resistors

The exceptional matching offered by TFRs is useful in many audio circuits. Line receivers, microphone preamplifiers, and audio digital-to-analog converter (DAC) output circuits all benefit from closely matched resistors. Improved common mode rejection ratio (CMRR) is one benefit of an integrated TFR pair. The CMRR of a typical audio DAC output circuit as seen in Figure 2 depends on how well the resistors are matched in the DAC output circuit.

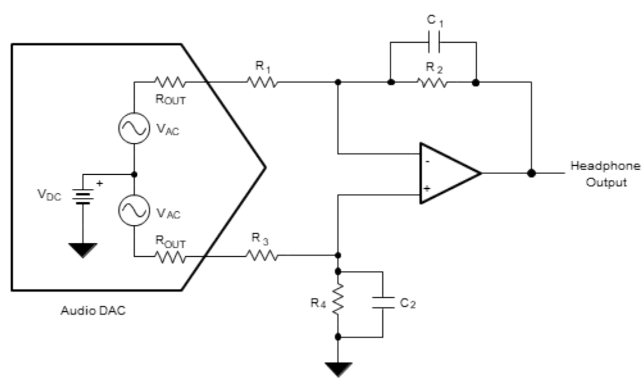


**Figure 2. Audio DAC Output Circuit**

CMRR was measured on this configuration using the INA1620 and OPA1622. The results can be seen in Figure 3.

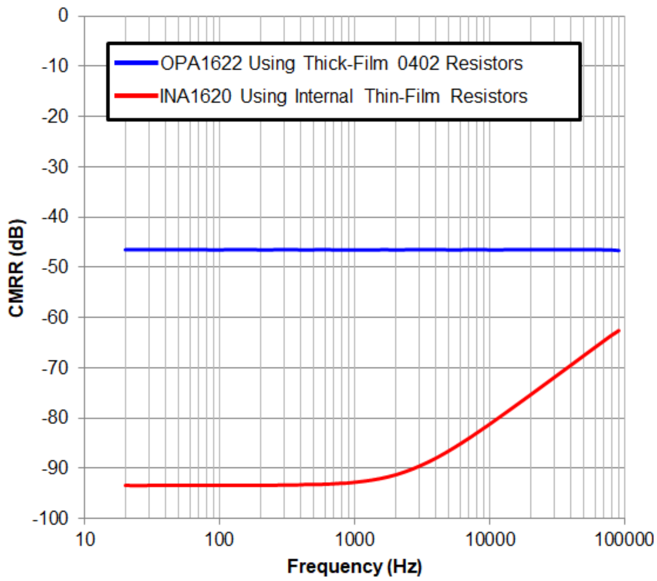


**Figure 3. CMRR vs Frequency**

The higher absolute value of the CMRR the better the amplifier rejects common-mode signals. Since the thin film process yields very high tolerance resistors, the CMRR can be significantly improved from standard resistor tolerance values. See Table 1 for how resistor tolerance affects CMRR. The INA1620 used in this test shows close to 93dB of CMRR which corresponds to 0.001% resistor matching. The worst case resistor matching for the INA1620 is 0.02% which corresponds to 74dB of CMRR. For more information on how CMRR affects a Difference Amplifier please see .

**Table 1. Worst Case CMRR based on Resistor Tolerance**

| RESISTOR TOLERANCE | WORST CASE CMRR (dB) |
|---|---|
| 10.000% | 14 |
| 5.000% | 20 |
| 1.000% | 34 |
| 0.010% | 74 |
| 0.001% | 94 |

## Improved Distortion Using Integrated TFRs

Harmonic distortion is the addition of unwanted frequencies that degrade the audio quality. It is easy to ignore the negative impact on distortion that is created by discrete components; most of an engineer's focus is typically on the amplifier. The discrete components surrounding an audio circuit are very important to consider when designing for good distortion characteristics.

Due to the difference in manufacturing process between thin film resistors and thick film resistors, they have very different properties. Thin film resistors are built using a vacuum deposition process that allows for much lower temperature coefficients and lower noise. Using the same devices and configuration from Figure 2, the THD+N was measured for the two devices. The results from the test can be seen in Figure 4. The thick film resistors show a 6-dB worse distortion than the thin film resistors. This shows that the resistors can make a significant impact on the THD+N in a circuit.

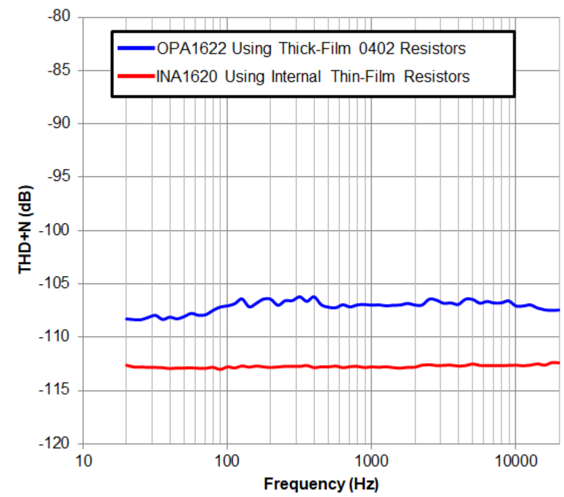


**Figure 4. THD+N vs Frequency**

## Additional Resources

**Table 2. TI Audio Amplifiers with Integrated Thin Film Resistors**

| DEVICE | Description |
|---|---|
| INA1620 | Headphone Amplifier: Bipolar input 2.8 nV/√Hz, –119 dB THD+N, 32 MHz GBW, Integrated resistor matching of 0.004% |
| INA1650 | Differential Line Receiver: -104.7dBu Noise Floor, -120dB THD+N, 91dB CMRR, 1 MΩ Differential Input Impedance |

**Table 3. Related Documentation**

| Literature Number | Name of Article |
|---|---|
| SBOT041 | EMI-Hardened Operational Amplifiers Reduce Inaccuracies |
| SBOA274 | Difference Amplifier (Subtractor) Circuit |

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