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APPLICATION NOTE 3996

Logging the Linear Digital Potentiometer

Abstract: Digital potentiometers (digital pots or digipots) are commonly used in volume-control applications. For audio applications, volume attenuation should closely mimic human hearing by applying a logarithmic scale. In some designs, a simple, low-cost linear potentiometer can be used in place of a logarithmic-taper potentiometer (log pot). This application note details how to implement a linear potentiometer in a log-taper application using a small, low-cost, higher resolution digipot.

Download: [GUI Software](#) (ZIP, 229kB)

Introduction

Because of their resiliency, small size, and ease of use, digital potentiometers have become widely accepted as replacements for mechanical potentiometers, particularly in volume-control applications. In this type of audio application, it is often preferable to use a log-taper pot instead of a linear-taper pot because the human ear perceives the logarithmic attenuation of sound as linear attenuation. However, as this application note demonstrates, a high-resolution linear potentiometer can also be used to implement volume control. The following analysis shows how to use a linear digital pot as a log pot (**Figure 1**).

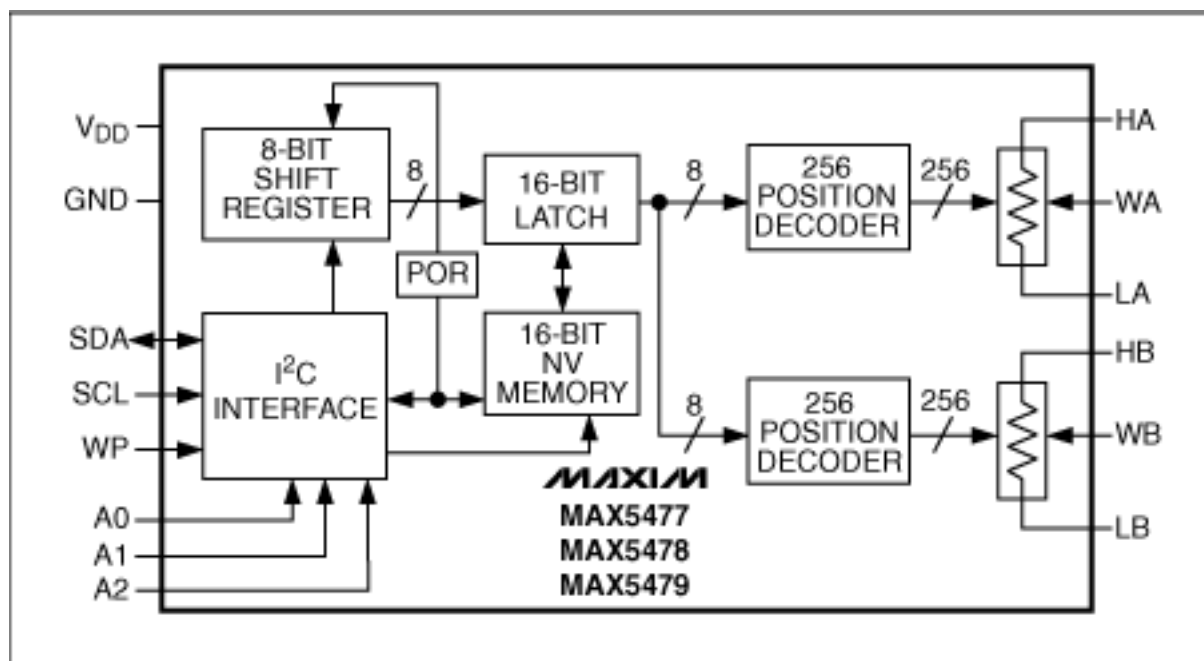


Figure 1. This family of digital pots is configured in a standard manner, as they include a connection to both the high end and the low end of the resistor string, as well as a wiper connection that moves among the resistor string's tap points.

Using a Linear Digipot as a Log Pot

Using simple math and a basic understanding of linear-taper digital potentiometers, it is possible to realize a

logarithmic taper from a linear-taper pot. Because a potentiometer is essentially a voltage-divider, its output voltage (V_{OUT}) can be written in terms of the voltage applied to its input V_{IN} , if V_{IN} is applied at R_H . The following equation can be used to express this relationship:

$$V_{OUT} = V_{IN}(R_{W-L} / R_{H-L}) \quad (\text{Eq. 1})$$

where R_{W-L} is the resistance between the wiper (W) and the low end of the resistor string (L) and R_{H-L} is the total end-to-end resistance of the resistor string.

The attenuation of a given signal in decibels can be found using the following equation:

$$\text{Attenuation (dB)} = 20 * \log(V_{OUT} / V_{IN}) \quad (\text{Eq. 2})$$

Substituting the V_{OUT} value from Equation 1 into Equation 2 yields the following equation:

$$\text{Attenuation (dB)} = 20 * \log[V_{IN}(R_{W-L} / R_{H-L}) / V_{IN}] = 20 * \log(R_{W-L} / R_{H-L}) \quad (\text{Eq. 3})$$

Figure 2 shows that these resistances can be represented by the tap position (R_{W-L}) and the total number of taps (R_{H-L}).

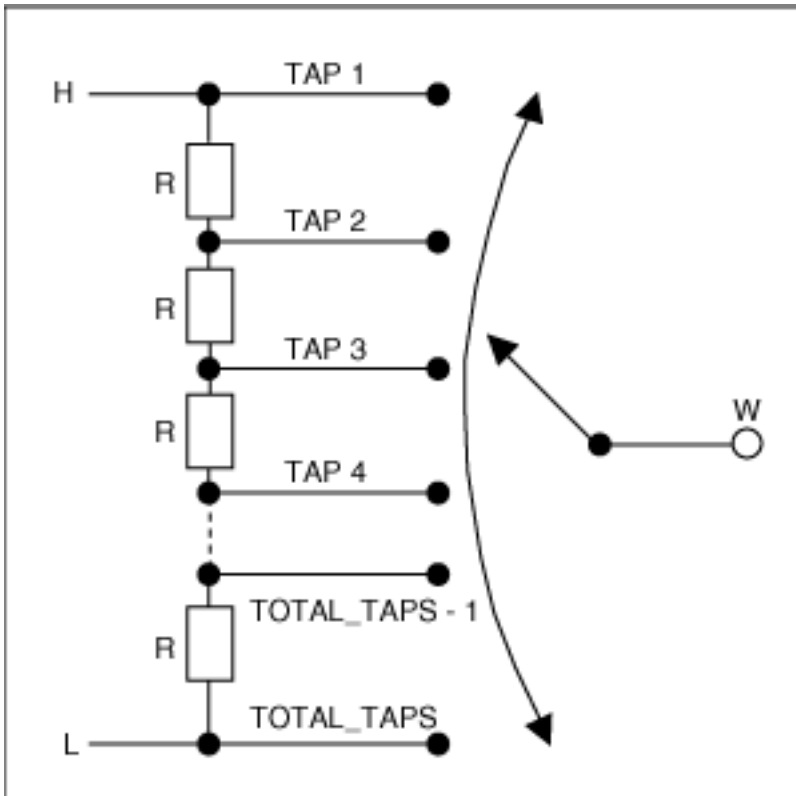


Figure 2. Linear-potentiometer tap points are located at equal resistor segments along the entire resistor string.

The tap position (R_{W-L}) can therefore be represented as:

$$R_{W-L} = (\text{Total_Taps} - x) * R \quad (\text{Eq. 4})$$

where $x = 1, 2, 3 \dots \text{Total_Taps}$.

Because the first tap point (minimum attenuation) contains no resistance from the resistor string, the total end-to-end resistance can be represented as $R_{H-L} = (\text{Total_Taps} - 1) * R$. Now, the attenuation equation takes the form of:

$$\text{Attenuation (dB)} = 20 * \log[(\text{Total_Taps} - x) / (\text{Total_Taps} - 1)] \quad (\text{Eq. 5})$$

where $x \neq \text{Total_Taps}$. If $x = \text{Total_Taps}$, then the attenuation approaches $-\infty$.

Conclusion

The above procedure details how to convert a linear-taper digital potentiometer into a logarithmic-taper potentiometer. This conversion works best with higher resolution linear pots (128 taps or greater) because logarithmic resolution is severely limited for linear pots with fewer than 128 tap points. Also, some inaccuracies may be encountered at the endpoints due to other internal structures, such as ESD protection or the nonlinear resistance of a pass transistor being used as a switch. The following source code converts desired attenuation to tap position (**Figure 3**), as well as desired tap position to the corresponding attenuation (**Figure 4**).

```
//-----  
  
// __int16 DB_to_Tap(double dB, __int16 TotalTaps);  
// input: dB -- double, db should be less than or equal to 0  
//        TotalTaps -- __int16, TotalTaps should bigger than 0  
// output: Function will returns the Tap number as __int16  
  
__int16 DB_to_Tap(double dB, __int16 TotalTaps)  
{  
    __int16 Closest_Tap;  
    double Raw_Value;  
  
    if(dB > 0) // Check the input  
    {  
        Closest_Tap = 1;  
    }  
    else  
    {  
        // Convert to the closest Tap number  
        Raw_Value = TotalTaps - (pow(10, (dB/20)) * (TotalTaps - 1));  
        Closest_Tap = (__int16)(Raw_Value + 0.5);  
    }  
  
    return(Closest_Tap);  
}  
//-----
```

Figure 3. This source code converts desired attenuation to tap position.

```

//-----

// double Tap_to_DB(__int16 Tap, __int16 TotalTaps);
// input: Tap -- __int16, Tap should be greater then 0 and less than TotalTaps.
//          If Tap equal to TotalTaps, the result should be negative infinity
//          TotalTaps -- __int16, TotalTaps should bigger than 0
// output: Function will returns the dB value as double

double Tap_to_DB(__int16 Tap, __int16 TotalTaps)
{
    __int16 tmp_a;
    double dB_Value, tmp_b;

    // Check input value
    tmp_a = Tap;
    if(Tap >= TotalTaps) tmp_a = TotalTaps - 1;
    if(Tap < 1)          tmp_a = 1;

    // Convert to dB value
    tmp_b = (double)(TotalTaps - tmp_a);
    tmp_b = tmp_b / (TotalTaps - 1);
    dB_Value = 20 * log10(tmp_b);

    return(dB_Value);
}
//-----

```

Figure 4. This source code converts desired tap position to the corresponding attenuation.

A similar article appeared in the April 4, 2005 edition of *EE Times*.

Application Note 3996: <http://www.maxim-ic.com/an3996>

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