

SPEAKERS

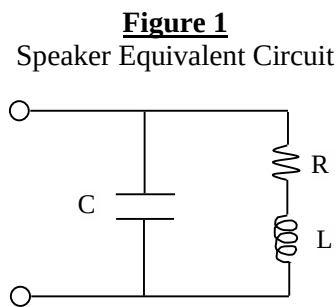
This application note describes the speakers manufactured by Projects Unlimited, Inc. and illustrates the techniques and hardware required to interface the devices to linear and digital electronic drive circuits.

Functional Description

The basic speaker model is a miniature paper cone, voice coil driven permanent magnet speaker assembly packaged in an enclosure. The enclosure is designed to optimize the speaker assembly frequency response and match the acoustic impedance of the speaker to the surrounding media to obtain maximum efficiency and sound pressure level output.

Special models are available with plastic cones and seals that will permit the speaker to operate in a moist environment. Consult the factory for detailed information and pricing.

The equivalent electric circuit for a speaker is shown in Figure 1. (Note the similar equivalent circuit for the electromechanical devices).



R = Resistance of voice coil and lead wires
L = Inductance of voice coil and lead wires
C = Distributed capacitance

The speaker resistance dominates the electrical characteristics in the normal operating range of 500 Hz to 4 kHz and the speaker appears to be a resistive load to the driving circuit.

Defining Operating Power Level

The Projects Unlimited, Inc. speaker assemblies have a maximum power rating of 100-120 mW. This simply means that the product of the applied RMS voltage and

RMS current PLUS any steady state DC voltage and current must not exceed 120 mW per the following equation:

Equation 1
Power Rating Calculation

$$\begin{aligned} \text{Total Power (P}_t\text{)} &\leq 120 \text{ mW} \\ &= (E_{\text{RMS}})(I_{\text{RMS}}) + (E_{\text{DC}})(I_{\text{DC}}) \end{aligned}$$

Exceeding this operational limit will cause heat build-up in the voice coil which will in time distort and rub the magnet or frame. Audio distortion will be noted and continued operation will destroy the voice coil.

The maximum continuous RMS current that may be applied to the 8Ω or 100Ω speaker assemblies may be calculated.

EXAMPLE 1

$$\text{Power} = (I_{\text{RMS}})^2 (R_{\text{SPEAKER}}) \leq 120 \text{ mW}$$

$$I_{\text{RMS Allowable}} = \left[\frac{P}{R} \right]^{1/2}$$

$$I_{\text{RMS}} (8\Omega) = \left[\frac{0.120}{8} \right]^{1/2} = 0.111 \text{ A or } 111 \text{ mA}$$

$$I_{\text{RMS}} (100\Omega) = \left[\frac{0.120}{100} \right]^{1/2} = 0.034 \text{ A or } 34 \text{ mA}$$

The minimum RMS voltage required to drive the speakers to maximum power output may be calculated.

EXAMPLE 2

$$P_{\text{RMS}} = (I_{\text{RMS}}) (V_{\text{RMS}})$$

$$V_{\text{RMS}} = \frac{P_{\text{RMS}}}{I_{\text{RMS}}}$$

$$V_{\text{RMS}} (8\Omega) = \frac{0.120}{0.111} = 1.081 V_{\text{RMS}}$$

$$V_{\text{RMS}} (100\Omega) = \frac{0.120}{0.034} = 3.529 V_{\text{RMS}}$$

The RMS voltage and current driving the speaker must be calculated from knowledge of the driving waveform.

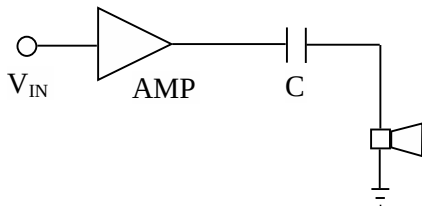
Please refer to the RMS calculation information in the Electromechanical Indicators and Transducers section of this Application Notes.

General Driving Considerations

The speaker assemblies may be directly driven from many circuits with DC coupling. However, any DC offset voltage or current must be continuously dissipated in the speaker.

It is usually more desirable to AC couple the output to the speaker using a capacitor in series with the speaker as shown in Figure 2.

Figure 2
AC Coupling To Speaker



The capacitor will block the DC component and couple the AC output from the driver. The capacitor must be sized so that the series reactance of the capacitor at about 500 Hz is approximately 10% of the resistance of the selected speaker to limit the power dissipation in the capacitor.

A polarized capacitor may be used if the AC coupled output is always referenced to ground as is the case with any driving circuit operating from a single supply. If a split or bipolar supply driving circuit such as a complementary output stage is used, a non-polarized capacitor is required. This type of capacitor is required because the voltage across it will reverse when the AC output waveform crosses the zero axis and the most polarized electrolytic capacitors can only withstand a 1 to 3 volt reverse polarity.

The AC RMS current should be computed or measured and compares to the capacitor manufacturer's permissible RMS ripple current specification to insure a long operating life for the capacitor. The ripple current will act with the Equivalent Series Resistance (ESR) rating of the capacitor to generate heat that aluminum electrolytic capacitor will meet most requirements while providing a ripple current specification that is greater

than the 110 mA required to drive the 8Ω speaker at full power.

The optimum capacitor size should always be used to realize maximum economy. If the application only requires the generation of a single tone or frequency audio signal, then the capacitor should be sized at the operating frequency per the following equation.

Equation 2

Calculation of Capacitor Required

$$C_{\text{REQUIRED}} = \frac{1.6 \times 10^5}{(f) (C_X)}$$

Where: C_{REQUIRED} = Minimum capacitance required in microfarad (μF)

f = Operating frequency in Hz

C_X = Allowable reactance of the capacitor at the operating frequency.

Note: Set C_X = 1 for 8Ω speaker and 10 for 100Ω speaker.

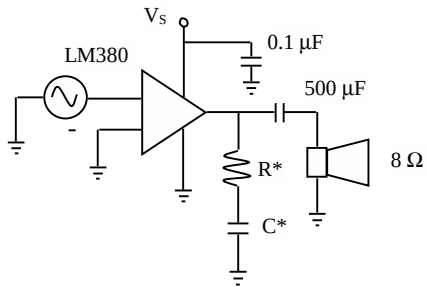
Linear Drive Applications

Linear drive circuits are those in which the speaker must produce a sound output. The sound output is proportional to the instantaneous variable amplitude of an applied signal as opposed to a digital drive where the input signal is a square wave that switches between a high and low level and the frequency of the waveform is varied to produce different tones or sounds.

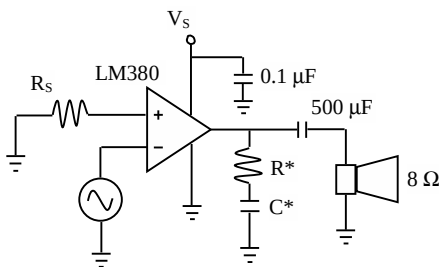
A typical linear drive requirement is sinusoidal tone or voice synthesis application or one in which the rate of change (attach/decay) of the waveform must be varied.

The most cost effective means of driving a speaker type audio transducer in the linear mode is to utilize one of the many inexpensive monolithic power audio amplifiers that are currently available from several domestic and foreign sources. Typical complete circuits for inverting and non-inverting configurations are shown in figure 3.

Figure 3
Power Audio Amplifier Circuits



Non-inverting: $V_{OUT}/V_{IN} = 50$



* $R = 2.7 \Omega$ and $C = 0.1 \mu F$ may be needed to suppress zero crossing, transient oscillations. R_S is selected equal to the source resistance.

Minimum Current Drive Applications

The previous Power Audio Amplifiers can be used to drive the 100Ω speakers. The trade-off is that the minimum supply voltage must be increased to approximately $12 V_{DC}$ to obtain the $3.5 V_{RMS}$ minimum drive signal required for the 100Ω speaker.

EXAMPLE 3

$$3.5 V_{RMS} = \frac{3.5}{0.707} \text{ or } 4.95 V_P \text{ or } 9.9 V_{P-P}$$

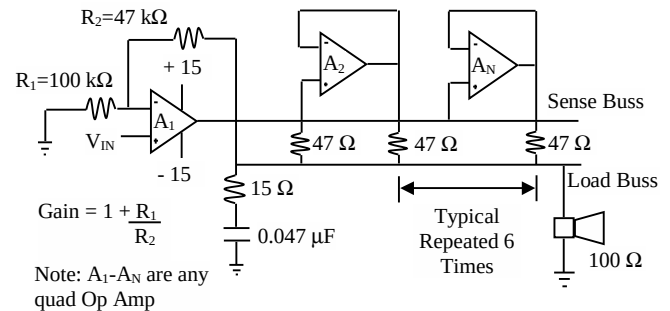
A 12 to $15 V_{DC}$ supply voltage prevents clipping or saturation of the transistors and precludes abnormal distortion in the output. The minimum current required to obtain full power output will now drop to $34 mA_{RMS}$. Some additional economy can be realized because the capacitance in series with the speaker can be reduced to about 1/10 of what is used with the 8Ω speaker.

Operational Amplifier Drive Circuitry

Operational amplifiers are not well suited to driving the speaker type audio transducers in the linear mode because they are designed to operate into a relatively high resistance load which is typically greater than 2000Ω . The maximum current output is usually limited to 10 mA.

The newer series of power operational amplifiers will provide the current output, but their cost is many times that of the simple monolithic power audio amplifier. The very low cost of the many medium performance quad operational amplifiers doesn't permit an economical drive circuit to be constructed for 100Ω speakers by paralleling the outputs of two quad amplifier packages as shown in the circuit of figure 4.

Figure 4
Load Sharing Operational Amplifier Drive Circuit
Using Two Quad Op Amp Packages

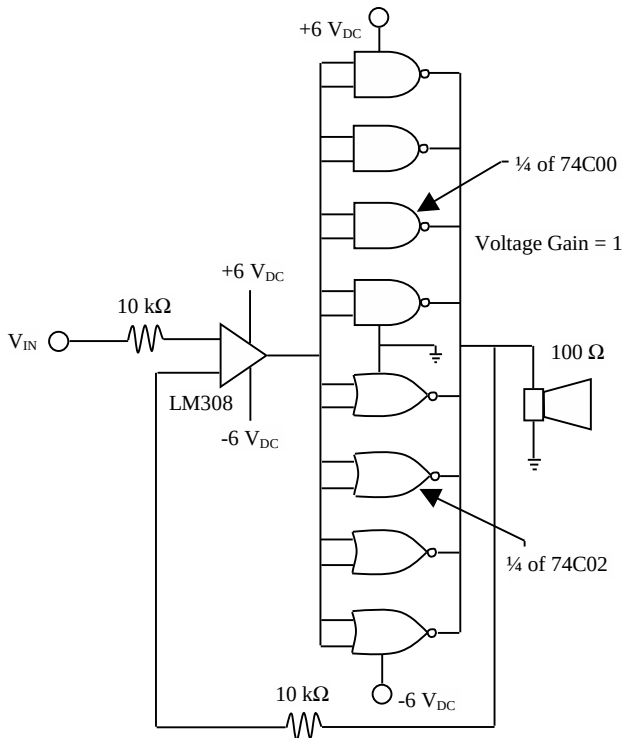


Each 47Ω load balancing resistor will dissipate about $\frac{1}{4}$ of a watt of power when the speaker is driven at rated power output.

CMOS Linear Drive Circuits

The 74C00 NAND gate and the 74C02 OR gate can be utilized in a complimentary, linear mode to provide a post amplifier to a low power operational amplifier as shown in figure 5.

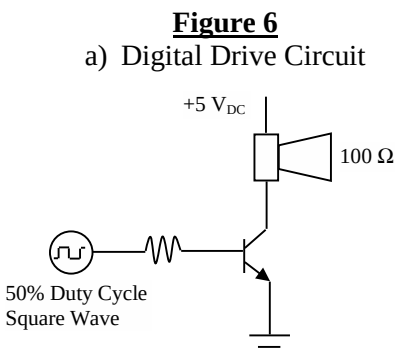
Figure 5
CMOS Post Amplifier for
Low Power Operational Amplifiers



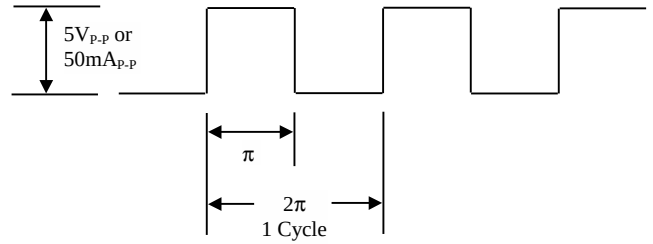
Digital Drive Circuits

Digital drive circuits are usually the best choice when a square waveform can be used to drive the speakers. It is significantly easier and thus more cost effective to switch a current on and off thru a speaker than it is to pass the equivalent waveform thru a linear audio power amplifier without distortion or instability.

The 8 Ω and 100 Ω speakers can both be driven with digital switching techniques. The 100 Ω speaker is usually the best choice unless the supply voltage is less than 5 V_{DC} because this is the minimum peak voltage required to force an RMS current of 35 mA thru a 100 Ω speaker per the following analysis.



b) Resulting Waveform Across
The Speaker



$$V_{\text{RMS}} = \left[\frac{(V_{\text{PEAK}})^2 (\pi)}{2\pi} \right]^{1/2} = \left[\frac{5^2 \pi}{2\pi} \right]^{1/2} = 3.5 V_{\text{RMS}}$$

$$I_{\text{RMS}} = \frac{V_{\text{RMS}}}{R_{\text{SPEAKER}}} = \frac{3.53}{100} = 35.3 \text{ mA}$$

$$\begin{aligned} \text{Audio Power Output} &= V_{\text{RMS}} I_{\text{RMS}} = (3.53)(0.0353) \\ &= 120 \text{ mW} \end{aligned}$$

The switching device must have a low “on” resistance to limit the voltage drop across the switch to a reasonably low level. This is not usually any problem with the 100 Ω speaker because a 1/4 volt drop across the switch when flowing 50 mA of current will reduce the peak power input by only 5%.

The 8 Ω speaker requires a lower “on” resistance or saturated voltage drop to keep the power loss in the switching device to a reasonable level.

Working backward thru the previous analysis will show that the 8 Ω speaker requires a minimum RMS current of 110 mA to develop full rated power and will need a supply voltage of approximately 1.5 V for a digital drive, assuming no voltage drop across the switch.

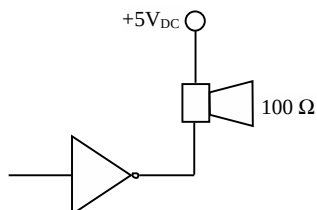
If a 1/4 drop is allowed across the switch, the voltage to the speaker will be reduced to about 1.25 V, resulting in a 17% reduction in input power.

The supply voltage can always be increased to offset the voltage drop of the switching device, but the switching device must dissipate the product of the RMS voltage drop across the switch multiplied by the RMS current at a duty cycle equal to that of the signal activating the switch.

Bipolar switching transistors, Power FET transistors, open collector TTL buffer/drivers and CMOS buffer/drivers may be used to create digital drive circuits for the speakers and type electromechanical audio transducers as shown in the following examples in figure 7.

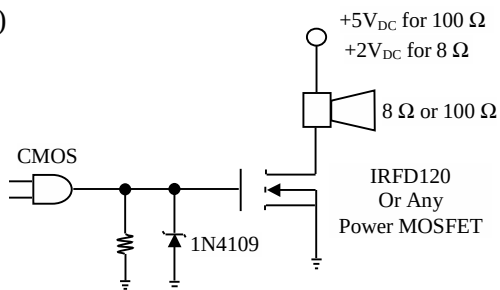
Figure 7
Typical TTL and CMOS Digital Drive Circuits

A)

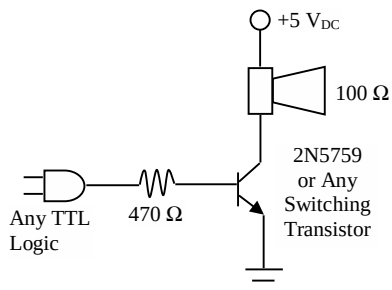


Any Open Collector, 40 mA Sink,
TTL/CMOS Buffer Drive

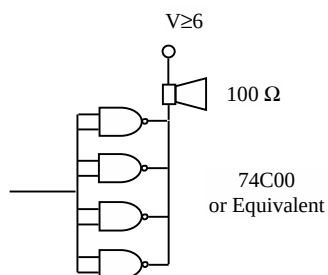
B)



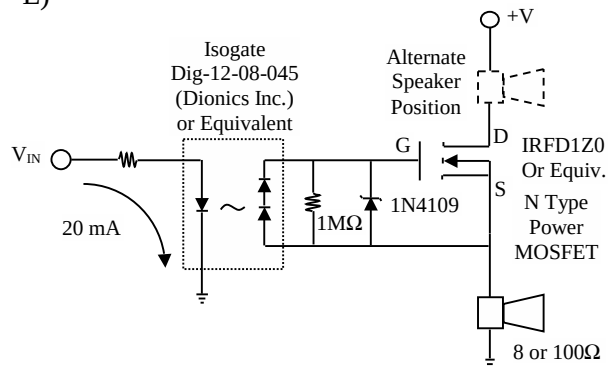
C)



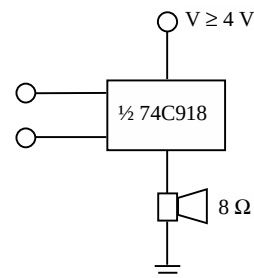
D)



E)



F)



G)

