TI TechNotes

Current Sense Amplifiers in Class-D Audio Subsystems

Arjun Prakash, Current Sensing Products

TEXAS INSTRUMENTS

CLASS-D audio amplifiers provide output power with an efficiency of over 90% as compared to CLASS-AB amplifiers that can provide an output efficiency of <50%. CLASS-D amplifiers are implemented in portable personal audio systems that provide quality sound output enabling longer battery life. A widely used CLASS-D amplifier in automotive systems are for E-call systems that provide critical audio feedback to the driver in case of a driver emergency. In E-call systems discrete current sensing is often implemented for continuous diagnostics to ensure speaker is operational at all times.

Current sensing in audio subsystems are widely used in conjunction with CLASS-D amplifiers for diagnostics or to provide speaker current feedback to the DSP for speaker enhancement to emulate smartamp. The most expensive component in the audio subsystem is the speaker. The impedance of the speakers ranges from 2Ω for subwoofer to a 8Ω for stereo speakers. Exceeding the current flowing through the speakers has a potential to create excessive heat in the voice coil which can lead to permanent damage of the speakers.

CLASS-D amplifier subsystem is as show in Figure 1. High power, high voltage class-d systems are often built discretely as integrated class-d amplifiers with silicon FETs do have limitations in terms of thermal limitations. High voltage class-d systems with GaN FETs are widely being accepted due to its advantages in efficiency and ability to switch at higher frequency. As integrated class-d amplifiers do have integrated over current protection that protects the class-d and speaker from exceeding currents however with discrete class-d implementation discrete current sensors is needed for implementing over current protection to provide diagnostics for speaker protection.

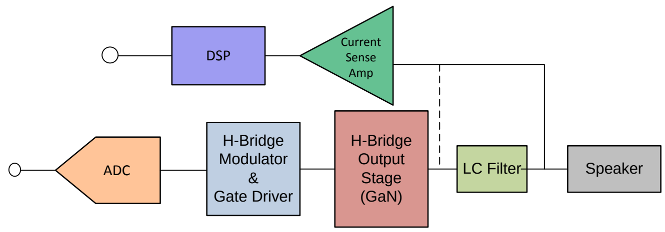

Figure 1. Discrete CLASS-D System Block Diagram

Current sensing in a CLASS-D could be realized with either a shunt based or a magnetic based system. Shunt based current sensing are best suited for audio applications due to its linearity, lower noise and higher dynamic range. However magnetic hall sensors on the other hand are lower cost to implement with drawbacks to lower dynamic range, higher noise and increased output sensitivity to external magnetic fields. Table 1 describes a summary of pros and cons to using shunt based solution to a magnetic solution in audio.

Table 1. CLASS-D current sensing summary

Current Sensing Application	Shunt based current sense solution		Magnetic based current sense solution	
	Pros	Cons	Pros	Cons
Over Current Protection	Accurate over current protection <1%	Series shunt power loss, High series inductance of the shunt	No shunt power loss, No parasitics	Output accuracy is unpredictable due to external magnetic and environmental fields
Analog feedback control	High linearity feedback (<0.01%), High dynamic range, Lower noise	Cost of solution	Cost of solution	Lower linearity (>5%), Higher output noise, Lower output range control
Smartamp control	High linearity feedback (<0.01%), High dynamic range, Lower noise, Faster loop control, faster DSP processing	Cost of solution	Cost of solution	Lower linearity (>5%), slower control loop response, longer DSP processing

Discrete CLASS-D Protection and Diagnostics

For diagnostics, the shunt and the discrete current sense amplifier is preferred to be connected pre-filter as shown in Figure 2. The challenge with the pre-filter current measurement is the amplifier is subjected to fast switching transients. Amplifiers with high bandwidth and fast output settling is required to measure accurate currents. As the switching frequency increases beyond 150 kHz the need for unity gain bandwidth of current sense amplifier significantly increases to the order of 15 MHz. Such high bandwidth amplifiers has disadvantages of higher Iq, higher offset and limited output slew rate. However, pre-filter current measurements offers fast response to over current detection with ability to provide diagnostics of external LC filter to detect abnormalities in the passive.

To overcome the challenges of current sensing in pre-filter measurements, a possible solution to provide complete diagnostics with a cost effective solution would be to measure currents post LC filter. Post LC filter the common mode signal is a slow moving signal limited to <30 kHz. For post filter current sensing, the current sense amplifier can detect shorted speaker connections and provide information back to the control loop for shutdown.

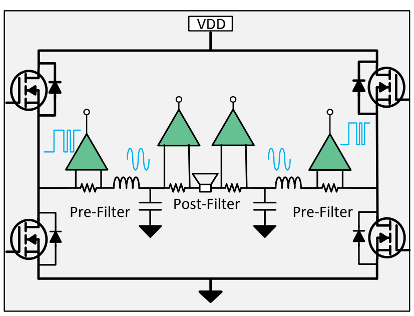

Figure 2. Current sensing in CLASS-D amplifier

Speaker parameters extraction for smartamp implementation

As the advancements are being made in the digital signal processing technology, higher processing power, smaller DSP with lower power consumption are available today. Real time speaker parameters such as current, voltage, impedance and temperature are increasingly being measured to create a real time closed loop speaker system which can adapt to the changes in the environment the speaker system is subjected to. One of the key components to realize a closed loop smart amp system is a precision current sense amplifier with high dynamic range, lower noise and higher bandwidth (>200 kHz). Speaker parameters are measured in the DSP subsystem by measuring current in the feedback system as shown in Figure 3.

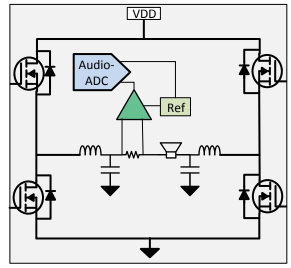

Figure 3. Closed loop CLASS-D system with current sensing

INA240 is a high voltage (V_{CM} -4 V to 80 V), high precision, bi-directional current sense amplifier with low input offset and gain drift across temperature range making it an ideal device for measuring currents in a CLASS-D subsystem. The INA240 is specifically designed to work in switched node environments where the common mode transients will have large dv/dt signals. The ability to reject high dv/dt signals enables accurate current measurements with high precision and linearity. With a large dynamic range of 80dB and the THD+N of <0.04% the INA240 ensures that the feedback system can correct for nonlinearities to as low as 0.04%. The signal throughput bandwidth of INA240 is 400kHz at the gain 20. The high bandwidth of the amplifier enables accurate current measurements with a flat response band up to 200 kHz and benefits in faster signal throughput for over current detection. The INA240 has low maximum input offset voltage of 25µV and a maximum gain error of 0.2% allowing for smaller shunt resistance values to be used without sacrificing measurement accuracy. The offset drift and gain error drift is as low as 0.25µV/°C and 2.5ppm/°C respectively enabling accurate and stable current measurements across temperature.

Table 2. Alternate Device Recommendations

Device	Optimized Parameter	Performance Trade-Off
INA168	Bandwidth : 800kHz, Package: SOT-23	Adjustable gain, external components
LMP8601	V_{CM} -22 V to 60 V	Offset voltage: 1mV, bandwidth: 60kHz
INA253	V_{CM} -4 V to 80 V, Integrated low-inductive 2mΩ, 3nH shunt	± 15A

Table 3. Related TI TechNotes

SBOA174	Current Sensing in an H-Bridge
SBOA176	Switching Power Supply Current Measurements
SBOA166	High-Side Drive, High-Side Solenoid Monitor With PWM Rejection

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265