POWER DRIVE CIRCUITS

Introduction

Power switching circuitry is required to complete the interface between electrical control signals provided by micro controllers and a system's loads. The real-world function of a load may be in the form of motion, light, or sound. Depending on the complexity of the control system, the interface circuit may be required to control a simple action to providing feedback signals and/or fault isolation.

To serve a wide range of requirements, Allegro offers a complete portfolio of interface circuitry. Using the ABCD3 process technology, the product line offers designers flexibility in architecture and power performance for a variety of solutions for specific applications.

This new family of power ICs are power DMOS devices that feature multiple integrated transistors in surface-mount and DIP packaging. The devices include on-chip control logic, ESD protection, and clamping circuitry.

Due to the high level of integration, Allegro's power ICs maintain significant cost advantage (such as reduced component count and board-space requirements, and minimized procurement and inventory expenses) over discretes on a per-transistor basis.

Power Applications

In a variety of end equipment:

EDP	Industrial	Automotive
- HDDs	- Automated test equipment	- Powertrain
- Tape back-ups	- Process control systems	- Body & chassis
- Printers	- Programmable machine tools	- Instrumentation
-Plotters	- Robotics	- Passive restraints
-Copiers	- Instrumentation panels	- ABS
-Scanners	- Personal appliances	- EFE
-Fax machines	- Telecom line cards	
	- Electronic games	

Allegro's Power Interface devices offer superior alternatives to discrete power MOSFETs and hybrids in many power switching applications including driving fractional horsepower motors, solenoids, valves, relays, and lamps. Applications Include:

- EDP: Hard-disk drives, tape back-ups, printers, plotters, copiers, scanners, fax machines, power distribution switching. With their low on-resistance and minimized power dissipation, these power devices operate reliably in confined spaces. Their surface-mount packaging is well suited for modules with limited headroom.

- Industrial: Automated test equipment, process control systems, programmable machine tools, robotics, instrumentation panels, personal appliances, telecom line cards, moving signs, electronic games. The ruggedness of these devices makes them very attractive for industrial environments. They offer power handling capabilities, extended temperature ranges, and avalanche energy absorption.

- Automotive: Powertrain (engine, transmission, and emission controls), body and chassis, instrumentation, passive restraints, anti-lock brake systems and electronic fuel injectors. For this cost-conscious segment and its extremely harsh operating environment, these devices offer wide operating ranges, a high level of integration, short cycle time to market, and cost-effectiveness. These are low-cost and low-risk catalog alternatives over custom solutions.

Inductive Loads

There are several types of loads such as resistive, capacitive, and inductive loads. Resistive loads are the simplest, since sizing is largely a question of examining the current and voltage specifications, estimating dissipation, making allowance for duty cycle, and then allowing margins for safety. Capacitive loads are comparatively rare; stray capacitance is the only capacitive element in an otherwise resistive load. Inductive loads can be complex to design because energy can be passed from the switch to the load and back again to the switch. This energy must be dissipated without damaging the load or switch. A well-specified avalanche energy value for the switch is helpful.

Inductive Load Switch Requirements

Motors, solenoids, lamps and other assorted loads are generally specified by operating voltage and current. The information provided is sufficient for operating at continuous duty. However, in most applications, the load is being switched on and off. When switching loads, the operating requirements as well as transient conditions must be considered. The power requirements are often further influenced by dynamic operating conditions.

The easiest way to look at load requirements is to consider the example above of a load operating from a battery and controlled by a low-side switch. The system power supply and load choice will determine:

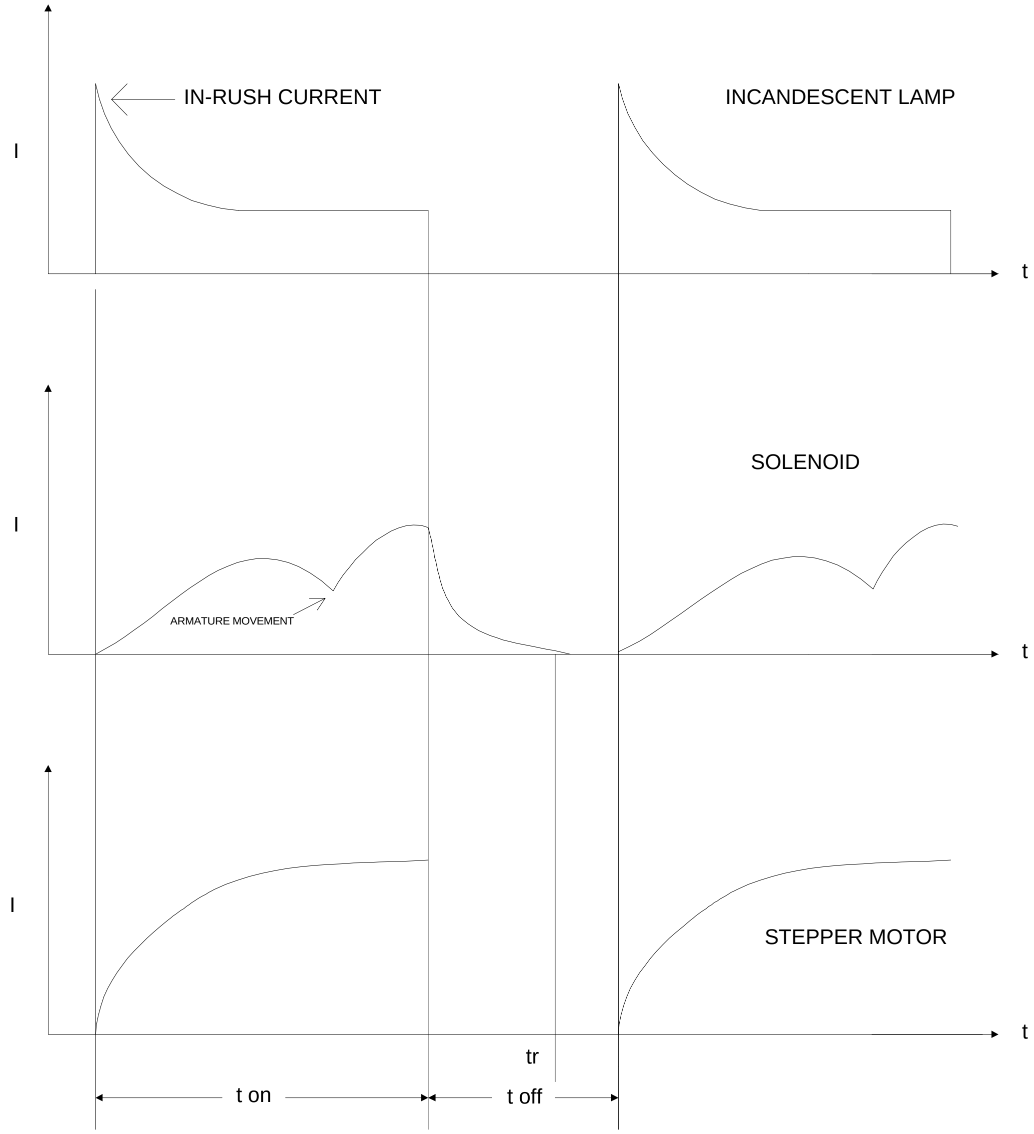
- Current drawn from the battery, including transients when the switch is turned on and off.
- Battery terminal voltage.
- Energy output from the load (motion, sound, etc.).
- Energy dissipated from the load in the form of heat (I^2R loss, magnetic loss, and friction).
- Energy returned to the system (inductive, regeneration, cross coupling).

These system load requirements must then be used to determine the switch requirements:

- Continuous drain-source current.
- Pulsed drain current.
- Continuous power dissipation @ T_A = 25°C.
- Single-pulse avalanche energy (energy returned to the switch from back EMF)
- Drain-source voltage (V_{DS}).
- Drain-source on-state resistance (R_{DS} on).

Selecting or designing a switch is a three-step process:

- Determine the total energy, current and voltage required.
- Select a switching device which will accommodate the energy.
- Evaluate the system power dissipation to determine any heat sinking requirements.



Switching Load Currents

Switching Load Currents

Determining the total energy begins with evaluating the load current during operation and during switching. The above diagram shows the current waveforms for an incandescent lamp, a solenoid and a stepper motor and depicts steady state and switching conditions that must be considered in controlling a load.

The incandescent lamp current shows a high inrush value at turn on (T_{ON}), due to the difference in filament resistance when cold and hot, decreasing to a steady current value until turn off, T_{OFF} and then a clean turn off with no current flowing after T_{OFF}. A lamp control switch will need to withstand high peak currents or limit the current until the lamp filament warms up. The latter approach is preferable, since it extends the life of the filament.

The solenoid current starts at T_{ON}, increases until T_{OFF}, and continues to flow until T_R. The change in current slope between T_{ON} and T_{OFF} is caused by the solenoid armature moving closer to the coil and increasing the coil inductance. The current flow between T_{OFF} and T_R is a result of the magnetic field in the solenoid collapsing and returning energy to the system. A solenoid switch must be capable of conducting the coil operating current and the system must provide a method for accommodating the energy returned to the system at turn off. Several methods are employed to deal with the returned energy, which when it is dissipated in the switch is referred to as avalanche energy.

The stepper motor exhibits an exponential current increase characteristic of an inductive load. Return energy is a factor in stepper motor control. Additionally, stepper motor windings can produce currents as a result of cross coupling from adjacent motor windings. This is particularly true for unipolar stepper motors. A control circuit for a stepper motor must accommodate the transient energy at turn on and the returned energy at turn off.

When considering a switch for a stepper motor application it should be noted that during normal commutation of a unipolar stepper motor, mutual coupling between the motor windings can force the outputs of the power switch below ground. This condition will cause forward biasing of the drain-to-substrate junction and source current from the output. For many L/R applications, this substrate current is high enough to adversely affect the logic circuitry and cause misstepping. External series diodes (Schottky are recommended for increased efficiency at low voltage operation) will prevent substrate current form being sourced through the outputs. Alternatively, external ground clamp diodes will provide a preferred current path from ground when the outputs are pulled below ground.

Once the load characteristics are determined, energy calculations can proceed.

Energy and Power Calculations for an Inductive Load

The energy calculations for an inductive load are presented above. The intent is to calculate the total power dissipated in the transistor switch.

Power dissipated during switch “on” time is calculated as follows:

During the power-on time, the inductor’s current approximates to a linear ramp, assuming the inductor’s L/R_L time constant is much greater than the turn on time (T_{on}). This results in a mean square drain current of $1/3\ I_p^2$ with I_P equal to the peak drain current. Therefore the average power dissipated in the output MOSFET, P_{ON}, is equal to:

$$P_{ON(AVE)} = 1/3\ (I_p^2) * R_{DS(ON)} * d$$

This assumption would be applicable to the stepper motor waveform shown earlier, but would not work for the solenoid. The solenoid time constant L/R_L is less than T_{ON}; therefore, P_{ON} will be greater than that calculated above.

Power dissipated during switch “off” time is calculated as follows:

When the output MOSFET is turned off, the back EMF generated by the inductor raises the drain voltage, which must be clamped either externally or internally. External clamping is normally accomplished with a snubber diode. Internal clamping is also accomplished with a Zener diode. The clamp voltage V_{CL} is also called the avalanche voltage.

The equation to define avalanche energy is:

$E_T = (3 * L_H * I_P^2 * V_{CL}) / \{6 * (V_{CL} - V_{ss}) + 4 * R_L * I_p\}$ *JEDEC Standard No. 10*

This equation assumes a linear decay of the current in the inductor. A more accurate calculation of E_T can be derived by integrating the inductor current and clamp voltage in the load from turn off until the inductor current decays to zero as follows:

$E_T=\int V_{CL}*I_L*dt$; Integrated from t to 0.

$I_L=\{I_P+(V_{CL}-V_{SS})/R_L\}e^{-(R_L/L)t-(V_{CL}-V_{SS})/R_L}$

$I_P=V_{SS}/R_L\{1-e^{-(R_{L/L_H}*d/f)}\}$

$t_1=L/R_L*\ln\{1+(I_P*R_L)/(V_{CL}-V_{SS})\}$

$E_T=V_{CL}*L_H/R_L*\{I_P-(V_{CL}-V_{SS})/R_L*\ln[1+(I_P*R_L)/V_{CL}-V_{SS})]\}$

The power dissipated during the turn-off period, P_{OFF}, can be equated to the product of E_T and the frequency of switching,

$P_{OFF} = E_T * f$

Hence, the total power, P_T, dissipated in an integrated switch with multiple output sections is:

$P_{T(AV)}=(P_{OFF}+P_{ON})*n+P_{(QUIES)}$

This is the average power dissipation for multiple sections whose duty cycles have a fixed time relationship to each other. For multiple outputs with variable duty cycles, the power calculation becomes more difficult.

Where,

E_T=Total turn-off transient energy absorbed

f=Switching frequency

d=Duty cycle

L=Load inductance

I_P= Peak output load current

n=Number of output switches operating

P_{OFF}=Turn-off power dissipation in each switch

P_{ON}= On-state power dissipation each switch

$P_{(QUIES)}$=Interface device bias power dissipation

$P_{T(AV)}$ =Average total power dissipation

R_L= Resistance of inductor

V_{CL}=Clamp voltage

V_{SS}=Load supply voltage

Thermal Consideration for Power Switches

With the device total power dissipation calculated, a thermal evaluation can proceed. The objective is to determine if external heat sinking will be required.

The requirement for external heat sinking is calculated based on the device's total average power dissipation, maximum junction temperature, and ambient operating temperature. The maximum power which can be dissipated in a device (P_d) can be determined as follows:

$$P_D = (T_J - T_A) / R_{\theta JA}$$

Where,

T_J=Maximum device junction operating temperature

T_A= Maximum ambient operating temperature

$R_{\theta JA}$=Junction to ambient thermal resistance, °C/W

T_J and $R_{\theta JA}$ are taken from the device specification and T_A is determined by the application environment.

If the total power dissipated in the device P_T exceeds the maximum power dissipation $P_{D,}$ then either a heat sink must be used or a different device must be selected.

A heat sink size can be determined by first calculating the required heat sink to ambient thermal resistance $R_{\theta SA}$ as follows:

$$R_{\theta SA}=[(T_J-T_A)/P_{T(AV)}]-(R_{\theta JC}+R_{\theta CS})$$

Where,

$R_{\theta JC}$=Device junction to case thermal impedance

$R_{\theta CS}$=Device case to sink thermal impedance

$P_{T(AV)}$=Total average power dissipation.

T_J=Junction operating temperature

T_A=Ambient temperature

The $R_{\theta SA}$ required can now be compared to heat sink design specifications to determine the design type and size required.

The preceding thermal calculations were based on the assumption that the device average power was duty cycle dependent. This is true if the pulse widths are short in relation to the device thermal time constant. An example would be a switch that is “on” for one hour in every twenty-four hours. The actual duty cycle is low but the system must be designed to accommodate 100% on time for the switch.