Designing Transformer Coupled Gate Drive Circuits and Gate Drive Transformers

Metal oxide semiconductor field effect transistor (MOSFET) and Insulated gate bipolar transistor (IGBT) are amongst the most popular, efficient semiconductor devices for switching power supplies. For medium to high power switching applications, dedicated gate drivers are essential, because it would take too long to charge the gate capacitance for the gate of a power switch to be driven by the output of a logic IC. So, what are the circumstances under which gate drivers offer the best solution – and how can their design be optimised? **Bhuvana Madhaiyan & Sampath Palaniyappan, Design and Development Engineers, Talema Group, Ireland**

Isolated drivers are essential, for safety and other reasons. Most popular implementations of isolated gate drivers use either magnetic (Gate Drive Transformers, or GDTs) or optical (Opto Coupler) isolation techniques. Advantages of GDTs include a lack of propagation delay in carrying signals from the primary side to the secondary; no requirement for a separate isolated power supply; the provision of a step-up / step-down facility; and high efficiency. But there are some disadvantages too, including their unsuitability for DC, for low frequency AC, and for "normally on" devices.

Gate drivers

The MOSFET and IGBT are amongst the most popular, efficient semiconductor devices for medium to high power switching power supplies. Both are driven into conduction by making the gate terminal positive relative to the source/emitter (Figure 1).

Charging the gate capacitor turns the power device on, allowing current to flow between its drain and source terminals when the gate voltage reaches the threshold voltage (VTH). Discharging turns the device off. The device is operated as a switch by applying a voltage sufficiently larger than VTH between the gate and source/emitter terminal.

In high power applications, it would take too long to charge the gate capacitance for the gate of a power switch to be driven by the output of a logic IC (PWM controller). Instead, dedicated gate drivers are used to apply voltage which can be integrated within PWM controller ICs or implemented as dedicated ICs, discrete transistors, or transformers. Thus gate driver circuit design is critical to the achievement of the required DC/DC converter/SMPS output (Figure 2).

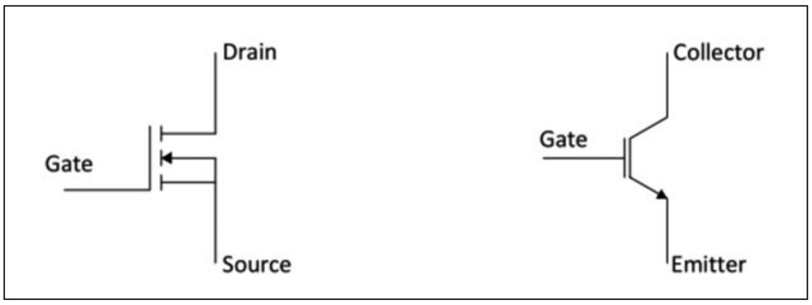


Figure 1: MOSFET (left) and IGBT symbols

Figure 3 shows the two alternative switch arrangements. "Low side drivers" drive ground referenced switches, whereas "high side–low side" drive a floating and a ground referenced switch using a bridge arrangement. Typical applications include solar inverters, converters for wind turbines, welding equipment, electric vehicles, and medical devices.

Isolated gate drivers

Isolation may be defined as the electrical separation between circuits in a system. Signals and power can pass between isolated circuits by inductive, capacitive or optical means. Isolation is mandated for safety for power inverter and converter gate drive circuits, where it also protects low voltage electronics from any damaging faults.

An isolated gate drive circuit is used for power converters where high power density and high efficiency are required. Such a circuit uses high and low switches such that the low side driver cannot directly drive an upper power device. That upper power device requires an isolated gate drive, because its source/emitter is at floating potential.

In Figure 4, the source terminal of switch 1 is allowed to float between

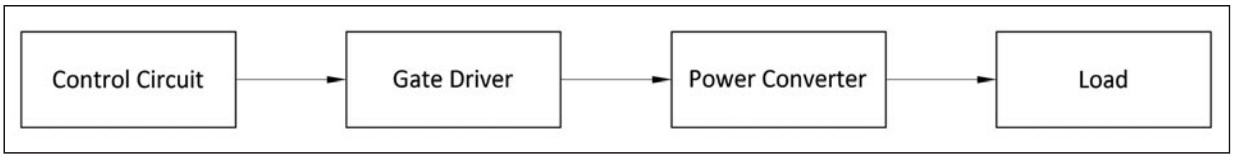


Figure 2: Schematic of typical power electronic system layout

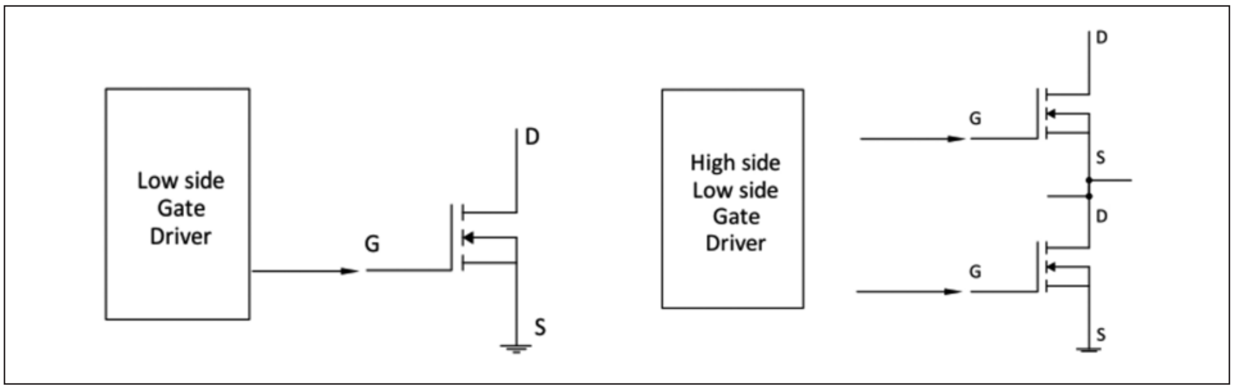


Figure 3: Alternative switch arrangements

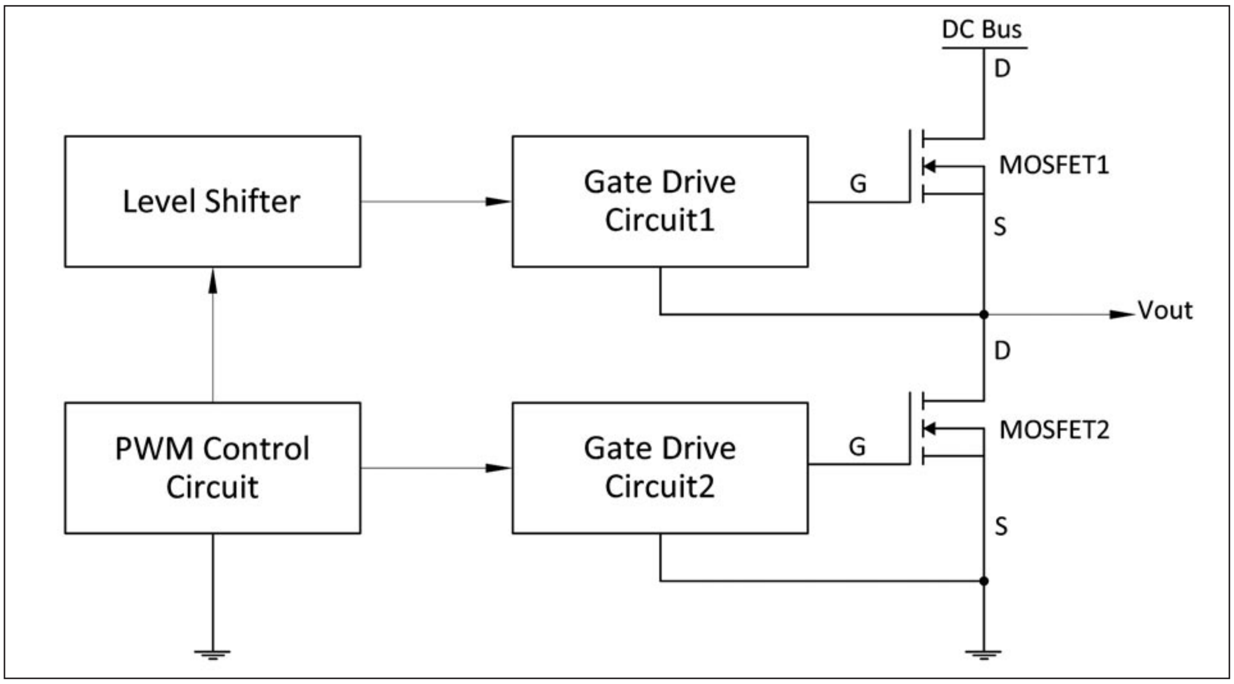


Figure 4: Isolated gate driver topology

ground and DC bus potential implying a requirement for both a floating supply, and a level shifter to transmit the PWM control signal to the floating driver circuitry. Most popular implementations of isolated gate drives use either magnetic (GDTs) or optical (Opto Coupler) techniques.

Gate drive transformers

A transformer coupled gate drive remains the best option for high power applications. Galvanically isolated output windings mean that a single transformer can drive all switches in the bridge and facilitate the driving of parallel switches (MOSFETs/IGBTs). A negative gate bias when the device is off also reduces dv/dt susceptibility to false switching, which can cause permanent damage. Transformer coupled solutions suffer negligible delays, and can operate across comparatively high potential differences.

GDTs are optimized to transmit rectangular electrical pulses with fast rise and fall times to activate or deactivate the switching device, handling low power but high peak currents to drive the gate of a power switch. Power ratings range from µW to several kW. They provide both the floating supply and the level shifting of the switching signal eliminating the need for a separate floating power supply.

MOSFET/IGBT gates can be driven directly, or an isolated control signal can be applied to a gate driver IC. Impedance matching is provided, and separate primary and secondary windings facilitate isolation and offer the option of voltage scaling.

When operating at switching frequencies above 100 kHz, designers of GDTs must guard against the adverse effects of leakage inductance and distributed capacitance.

GDTs are also known as pulse, trigger, wide band or signal transformers, mostly dependent on their application. The moniker “gate drive transformer” is used where the transformer directly drives a power device gate, whereas “pulse transformer” references a device used as a means to transmit rectangular voltage signals/pulses to a semiconductor gate. Generally, a pulse transformer transfers a pulse of current/voltage from the primary/generating side of the circuit to the secondary/load side, with shape and other properties maintained. A pulse transformer that initiates an action may be known as a trigger transformer.

Basic circuit

The basic circuit of a transformer-based isolated gate drive (Figure 5) includes reset components such as a blocking capacitor C, primary resistor R, gate resistor Rg, and a back to back Zener diode.

When a square pulse is applied at the primary terminals, it is transmitted by the secondary as a square wave or as a derivative of the input voltage. The blocking capacitor C is placed in series with the primary winding of the transformer to

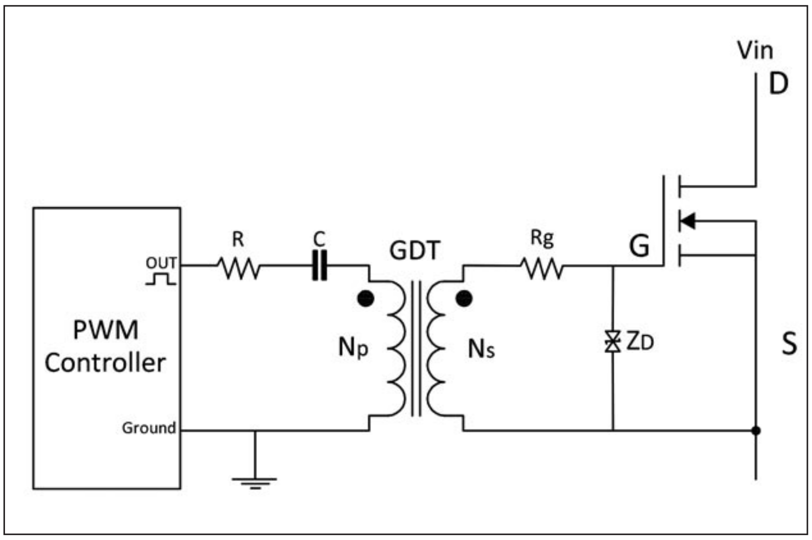


Figure 5: **Basic circuit of a transformer based isolated gate drive**

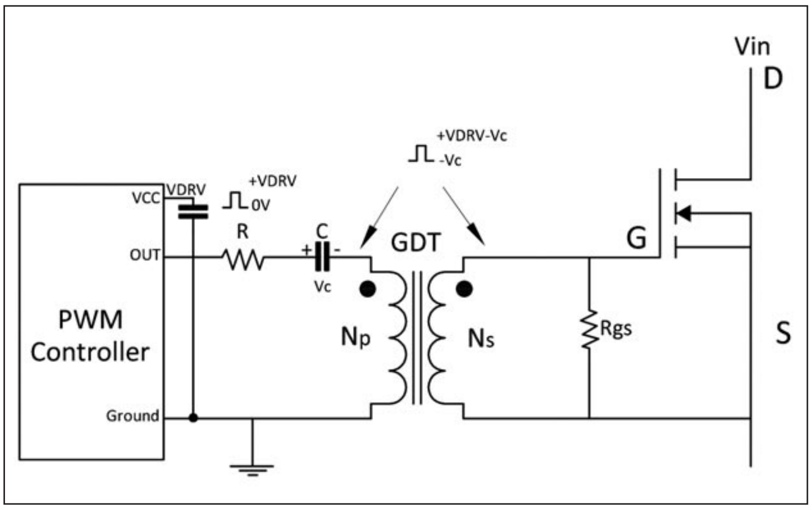


Figure 6: **Single ended transformer-coupled gate drive**

provide the reset voltage (negative bias) for the magnetizing inductance, preventing transformer saturation. The amplitude of output voltage reduces with the duty ratio increase, hence this circuit limits the duty cycle to less than 50 %. This approach works well in SMPS circuits, where the frequency is high and the duty cycle ratio is small.

Gate drive voltage, V_c, changes with duty ratio. Sudden changes in duty ratio will excite the L-C resonant tank formed by L_m & C, an effect that can be damped by the low value resistor (R). The gate is driven between $-V_c$ and V_{DRV}-V_c levels as opposed to original output voltage range of the driver, 0 V and V_{DRV}. A back to back Zener diode is used to clamp the device gate voltage, and gate resistor R_g is used to avoid gate transient surge current

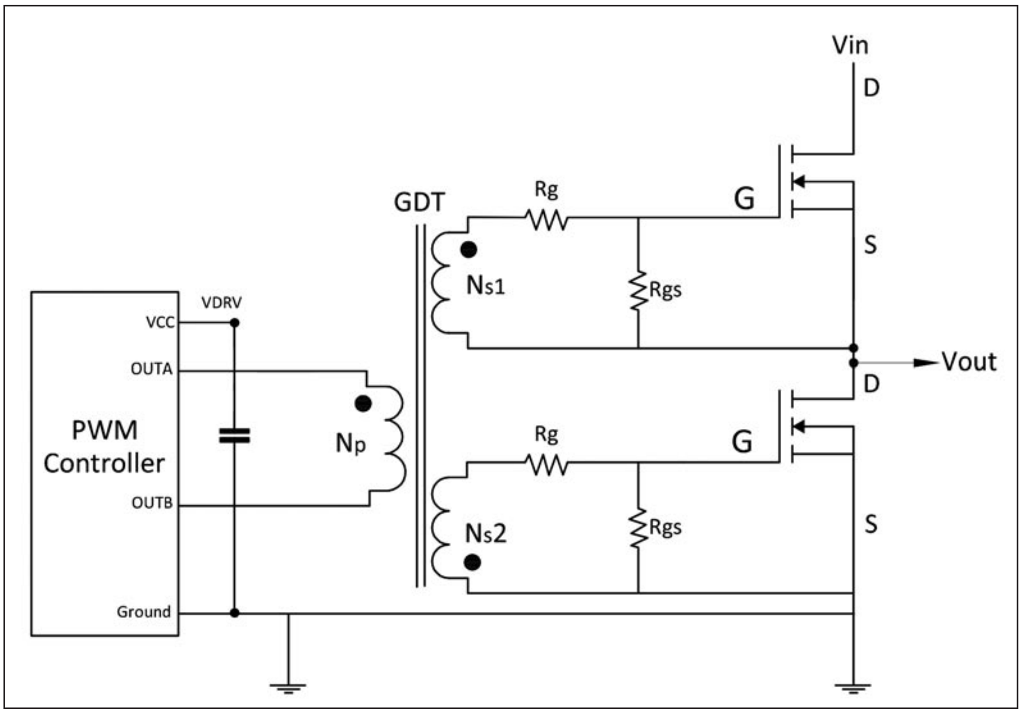
Core saturation limits the applied volt-time product across the windings, and the design must accommodate the maximum volt-time product.

The GDT is driven by a variable pulse width as a function of the PWM duty ratio. Amplitude may be constant or variable according to configuration.

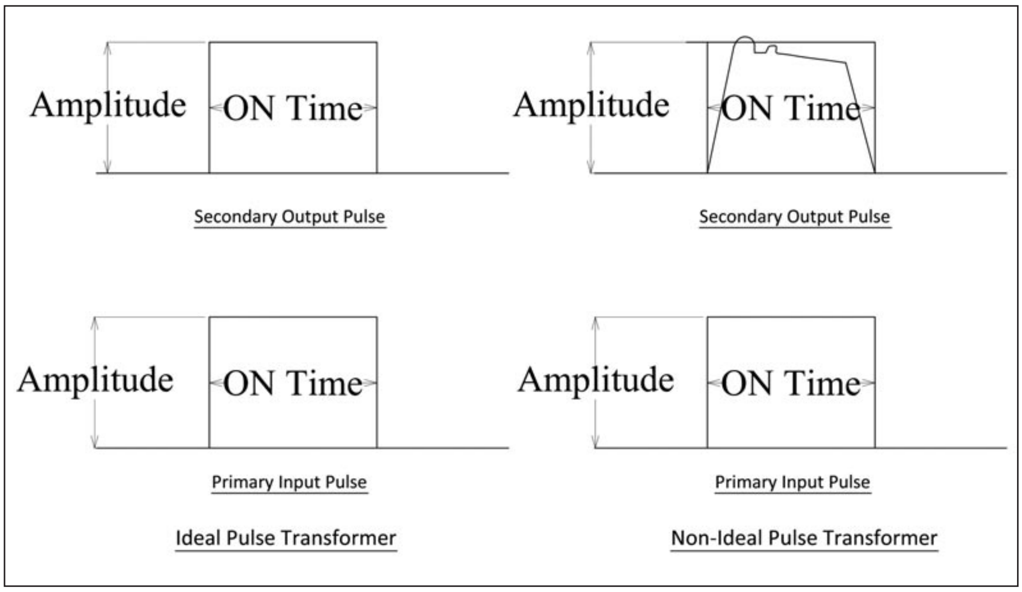
Single ended and double ended circuits

All GDTs operate in both the first and third quadrant of the B-H plane.

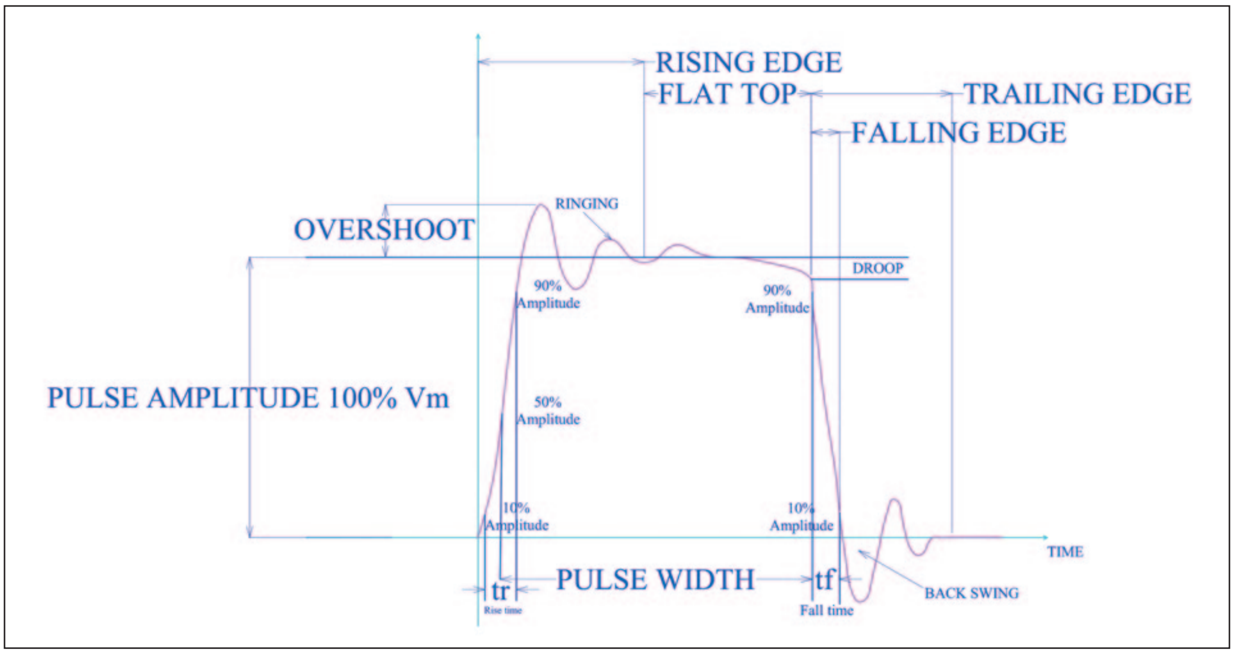
Single ended gate drive circuits are used with a single output PWM controller to drive a high side switch. The GDT is driven by a variable pulse width and variable amplitude (Figure 6). This circuit is limited to 50 % duty ratio. For wide duty cycle applications, a DC restoration circuit on the



LEFT Figure 7: **Double ended transformer-coupled gate drives**



LEFT Figure 8: Pulse response deviates from the ideal



BELOW Figure 9: Pulse response regions and parameters

secondary side of the transformer (capacitor & diode) ensures adequate gate drive voltage and restores the original gate drive amplitude on the secondary side of the transformer.

Double ended gate drive circuits are used with a double output PWM controller to drive 2 or 4 switches in high power applications (Figure 7). The GDT is driven by a variable pulse width and constant amplitude. OUTA and OUTB are opposite polarity and symmetrical. When OUTA is on, positive voltage is applied. The average voltage across the primary for any two consecutive switching periods is always zero, removing the need for any AC coupling.

Pulse response characteristics

It is important that a pulse transformer reproduces the shape of input pulse as accurately as possible at its secondary terminals. Performance is specified in terms of its ability to do so. In practice, output response is distorted. Current cannot change instantaneously resulting in finite rise and fall times, and the input voltage is of discontinuous nature (Figure 8).

The pulse width varies from less than 1 μs to about 25 μs, with parasitic elements causing overshoot, delay and ringing and non-ideal components (transients) causing deviations in the flat portion.

The aim of transformer design is therefore to minimize leakage inductance and distributed capacitance. As illustrated in Figure 9, a typical pulse wave has four regions, and permissible distortion is defined in terms of the illustrated parameters.

Conclusion

Most popular implementations of isolated gate drives use either magnetic (Gate Drive Transformers, or GDTs) or optical (Opto Coupler) techniques. Advantages of GDTs include a lack of propagation delay in carrying signals from the primary side to the secondary; no requirement for a separate isolated power supply; the provision of a step-up / step-down facility; and high efficiency. There are some disadvantages including their unsuitability for DC, for low frequency AC, for normally on devices, and for high power, high density synchronous rectification applications; the need for AC coupling capacitors and Zener diodes where high duty ratios are necessary, and a complexity and costliness resulting from the requirement for a transformer primary to be driven by a high speed buffer.However, where GDTs can be used, careful design can ensure a highly effective and efficient solution.