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Speeding Up Horizontal Outputs

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There are at least two ways to speed up a horizontal output stage. One is to design the transistor specifically for the application. That has been done with the SCANSWITCH series of horizontal output transistors. Another is to optimize the base drive. A very effective technique is to design the base drive backwards, i.e., start with the output transistor's device physics and work back to the horizontal oscillator. The base drive circuit described here takes this approach, and produces some rather interesting results.

TRANSISTOR SELECTION

In horizontal outputs, it turns out that most of the dissipation occurs as collector-emitter voltage rises during storage time. In other words, there is a tendency for the voltage rise waveform to be soft and rounded as opposed to abrupt and square. The parameter that describes this behavior is called dynamic desaturation. SCANSWITCH transistors are specifically designed to minimize dynamic desaturation, and simultaneously avoid collector current tailing.

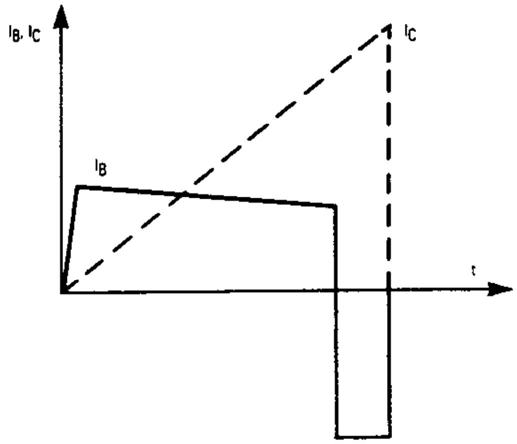
Minimizing dynamic-desaturation requires a relatively wide base width. Monitor specific transistors, therefore, have wider bases than is normal for high voltage bipolars, and a somewhat unique set of characteristics. A drive strategy that optimizes the performance of the SCANSWITCH structure is outlined as follows.

DRIVE STRATEGY

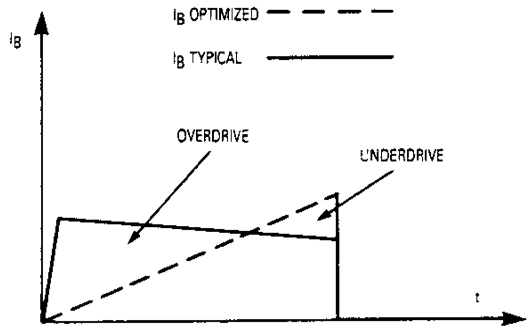
Optimum drive strategy is driven by transistor physics. The conditions are:

1. Provide adequate drive just prior to turn-off to minimize dynamic desaturation.
2. Avoid overdrive during any portion of the turn-on time to avoid tailing.
3. Provide reverse base current that is independent of forward base current so that transistor performance can be optimized.
4. Provide for a controlled rate of transition from forward to reverse drive to avoid tailing.
5. Avalanche the base-emitter junction during fall time. This is especially important for wide base SCANSWITCH transistors.

Typical techniques for driving horizontal outputs rely on a pulse transformer to supply forward base current, and a turn-off network that includes a series base inductor to limit the rate of transition from forward to reverse drive. The resulting base current waveform is shown in Figure 1A. If this waveform is compared to the representation of collector current that is shown in dashed lines, it can readily be seen that condition number 2 is violated. As is evident from Figure 1B, heavy overdrive is present at the beginning of the collector current ramp. In addition, condition number 1 is violated since heavy overdrive at the beginning is compensated by underdrive just prior to turn-off.



a.) Base and Collector Current Waveforms



b.) Base Drive — Typical and Optimized

Figure 1. Typical Base Drive

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Heavy overdrive at the beginning of the collector current ramp is particularly significant since, bipolar transistors have a memory effect. In other words, the transistor will remember that it has been previously overdriven, for some period of time. For the 1000 volt to 1500 volt transistors that are used in horizontal outputs, there is a first order memory effect for roughly 5 μs, a second order effect for approximately 10 μs, and virtually no memory after 25 μs. As horizontal scan frequencies go up the memory effect becomes more and more important, since the time from which the worst overdrive occurs until the time that turn-off occurs gets shorter. At 64 kHz the memory effect is a first order design constraint. To comply with this constraint and satisfy condition number 1, it is necessary to ramp the base current, such that forced gain is approximately held constant.

A circuit that produces the required ramp and also meets all of the other conditions is shown schematically in Figure 2. In this circuit, a ramped forward current is produced when high side switch Q_2 applies B^+ to the primary of T_1. While Q_2 is conducting, D_1 is reverse biased and no current flows in the secondary. Forward base current, therefore, is a ramp that is determined by B^+ and the primary inductance of T_1. When Q_2 is turned off, virtually all of the energy that was stored in T_1 is available to produce reverse base current through the secondary winding, forward biased diode D_1, and L_B. With this arrangement, the amount of reverse base current is determined by the turns ratio and can be optimized for the type of device that is being driven. In addition, at turn-off the secondary of T_1 is a true current source, with a compliance voltage high enough to avalanche the output transistor's base-emitter junction. As is common in horizontal output circuits, L_B controls the rate of transition from forward to reverse drive.

At the front end, high side drive for T_1 is produced when an open collector horizontal input switches to ground, thereby turning on Q_1. With this arrangement, Q_1 is configured as a current source. The values of R_1, R_2, & R_3 are specific to a 24 volt power supply and are designed to generate 20 milliamps at the collector of Q_1. When present, this 20 milliamps flows through a forward biased diode in the MPSG1000 to turn on the gate of Q_2. Gate voltage is limited by an 11 volt zener in the MPSG1000, which is the reason for current source drive. In the absence of an input current, the MPSG1000 switches R_3 to Q_2's source, turning off the high side switch when the horizontal oscillator input goes high. A schematic of the MPSG1000 is included in the appendix.

In addition to meeting all of the conditions that are necessary for a high performance base drive, this approach has two important advantages. First, the configuration of T_1 allows L_B to be placed outside the path of forward base current. Therefore, at turn-off it is not necessary to expend energy to reverse current flow in a series base inductor. For a given L_B more negative drive is obtained, and with it faster switching. The second advantage is also an important design constraint. Note that there is no resistor to limit forward base current, and therefore no power loss associated with setting the value of forward base current. The process of generating a ramp stores rather than dissipates energy. If the stored energy is used rather than wasted, forward base drive can be essentially "lossless." This will happen if the amount of energy stored in T_1 to produce the ramp is equal to the amount of energy ($E_{B(off)}$) that is required to turn off the output transistor. In other words, if B^+ and the primary inductance of T_1 (L_P) are chosen such that $1/2 L_P I_B{}^2 = E_{B(off)}$, then the forward drive is essentially lossless. $E_{B(off)}$ is a new specification that is

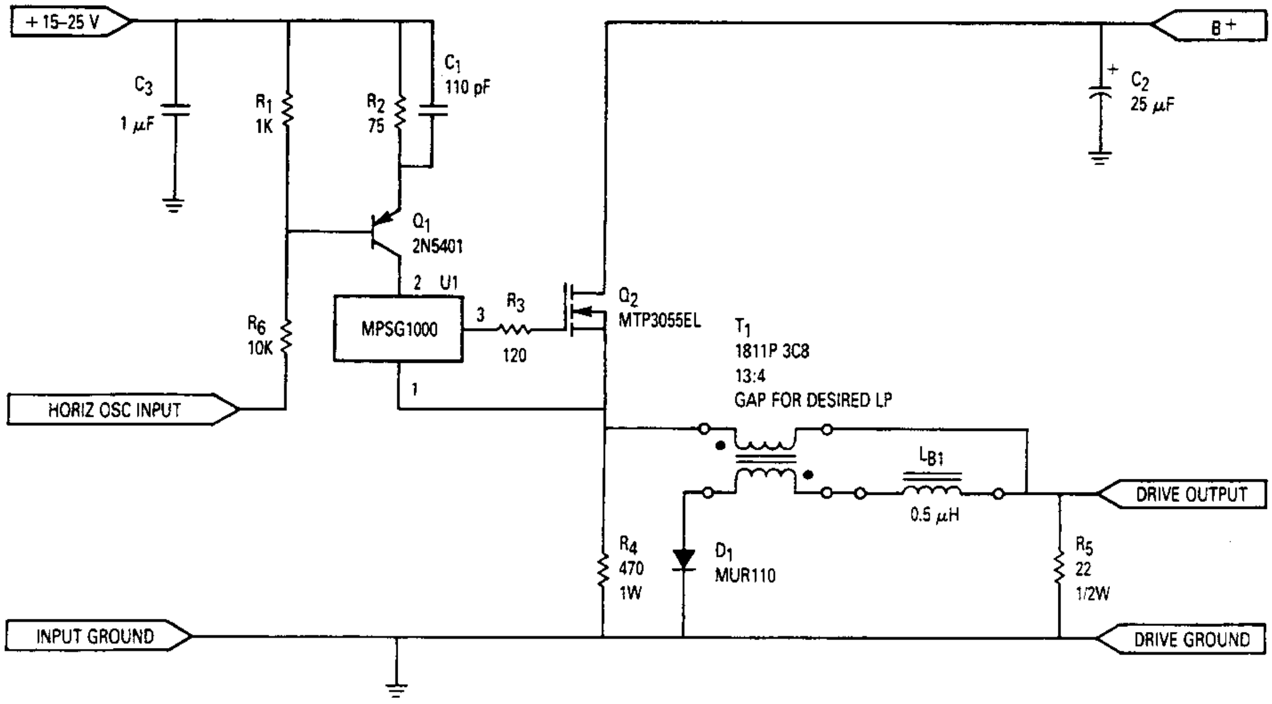


Figure 2. Base Drive Schematic

included in the SCANSWITCH data sheets. It assumes an R_{BE} of 22 ohms and targets a base-emitter avalanche time of 500 ns. If B+ and Lp are not chosen in this way, either enough energy to adequately avalanche the output transistor's base-emitter junction will not be provided, or excess energy will show up in the output transistor as dissipation due to excess base-emitter avalanche time.

DESIGN EXAMPLE

A few simple steps are all that is required to compute nominal design values. As an example, let's assume a 64 kHz application with peak collector current of 6 amps and on-time (t_{on}) of 6.25 µs. To start, base current is computed from data sheet test conditions for switching time. For the MJH16206 switching times are measured at 6.5 amps with a base drive of 1.5 amps, which implies a forced gain of 6.5/1.5 = 4.33. Applying the same forced gain to operation at 6 amps gives a base current of 1.4 amps. For this transistor $E_{B(off)}$ is specified at 30 µjoules. Using this value, Lp and B+ are selected to give 1.4 amps of base current in a 6.25 µs on-time and produce $1/2 L_p I_B^2 = E_{B(off)} = 30\ \mu J$. These values are computed in two steps given by equations 1 & 2.

(1) $L_p = 2 \cdot E_{B(off)}/I_B^2 = 2 \cdot 30 \cdot 10^{-6}/(1.4)^2 = 31\ \mu H$

(2) $B+ = L_p \cdot I_B/t_{(on)} + 1 = 31 \cdot 10^{-6} \cdot 1.4/6.25 \cdot 10^{-6} + 1 = 8$ Volts

In this example the turns ratio for T_1 (n) is chosen as 13:4 and L_B is specified as 0.5 µH. These values are found on the SCANSWITCH data sheet. When this information is not available, a good place to start for 1000 volt to 1500 volt horizontal output transistors is $E_{B(off)} = 30\ \mu J$, n = 12:4, and $L_B = 1\ \mu H$.

Data sheet values take into account the gain variation that is normally expected in a production environment. When using these values, performance of the distribution, as opposed to performance of individual units is optimized. The average part will look better with less forward base drive (lower B+), and all parts will perform better with a lower value of L_B if B+ has been adjusted for gain. Therefore, at very high frequencies, it is possible to further optimize performance by adjusting B+ to accommodate individual transistor characteristics.

RESULTS

The resulting base drive waveform is shown in Figure 3. It produces the output waveforms that are plotted in Figure 4, and a storage time of only 1 µs. Both crossover losses and storage time are roughly half of what more common base drive techniques produce. Base-emitter voltage is plotted versus time along with collector current in Figure 5. Note that the base-emitter junction is avalanched for somewhat less than 1 µs, which minimizes fall time. In very high frequency monitors, the avalanche time can also be used to provide immunity to dV/dt produced by the flyback pulse.

CONCLUSION

In order to get optimum performance from SCANSWITCH horizontal output transistors, there are 5 conditions which the base drive circuit must meet. When these conditions are all met, it is possible to significantly speed up horizontal outputs.

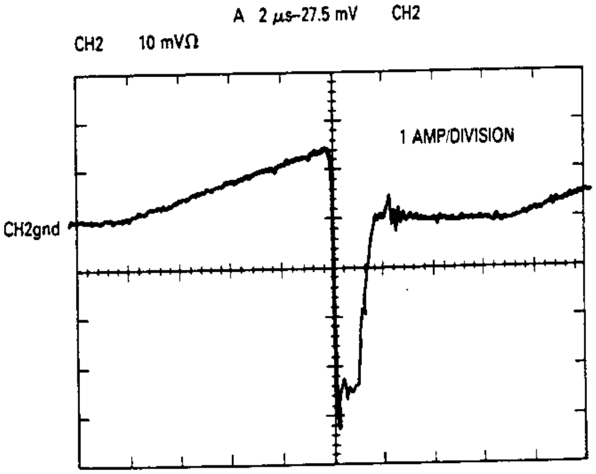


Figure 3. Optimized Base Drive Waveform

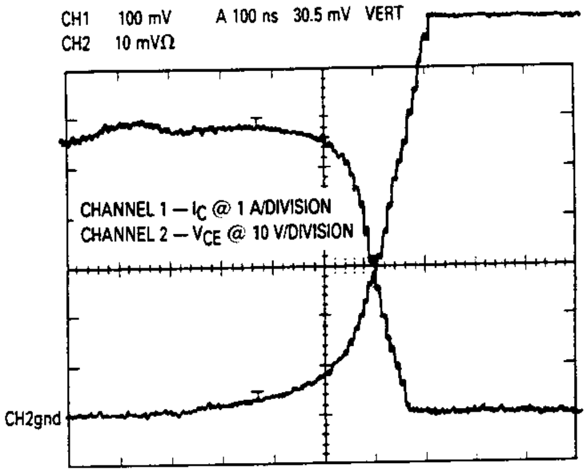


Figure 4. Crossover Performance

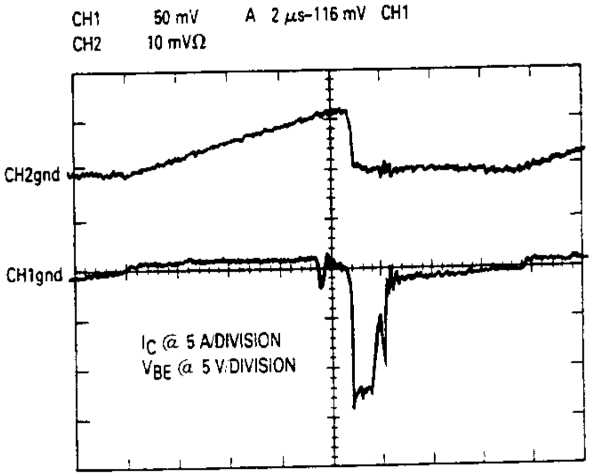
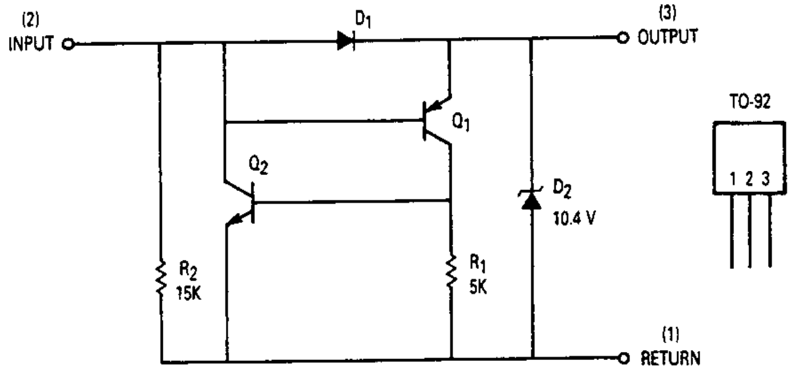


Figure 5. Avalanched V_{BE}

APPENDIX

Davies' Driver
Simplified Schematic



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