PIN Diode Drivers

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INTRODUCTION

The DH0035/DH0035C is a TTL/DTL compatible, DC coupled, high speed PIN diode driver. It is capable of delivering peak currents in excess of one ampere at speeds up to 10 MHz. This article demonstrates how the DH0035 may be applied to driving PIN diodes and comparable loads which require high peak currents at high repetition rates. The salient characteristics of the device are summarized in Table I.

TABLE I. DH0035 Characteristics

Parameter	Conditions	Value
Differential Supply Voltage ($V^+ - V^-$)		30V Max.
Output Current		1000 mA
Maximum Power		1.5W
t_{delay}	PRF = 5.0 MHz	10 ns
t_{rise}	$V^+ - V^- = 20V$ 10% to 90%	15 ns
t_{fall}	$V^+ - V^- = 20V$ 90% to 10%	10 ns

PIN DIODE SWITCHING REQUIREMENTS

Figure 1 shows a simplified schematic of a PIN diode switch. Typically, the PIN diode is used in RF through microwave frequency modulators and switches. Since the diode is in shunt with the RF path, the RF signal is attenuated when the diode is forward biased (“ON”), and is passed unattenuated when the diode is reversed biased (“OFF”). There are essentially two considerations of interest in the “ON” condition. First, the amount of “ON” control current must be sufficient such that RF signal current will not significantly modulate the “ON” impedance of the diode. Secondly, the time required to achieve the “ON” condition must be minimized.

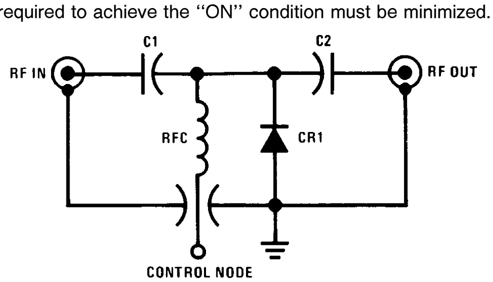

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FIGURE 1. Simplified PIN Diode Switch

The charge control model of a diode[1,2] leads to the charge continuity equation given in equation (1).

$$i = \frac{dQ}{dt} + \frac{Q}{\tau} \quad (1)$$

where: Q = charge due excess minority carriers

τ = mean lifetime of the minority carriers

Equation (1) implies a circuit model shown in *Figure 2.* Under steady conditions $\frac{dQ}{dt} = 0$, hence:

$$I_{DC} = \frac{Q}{\tau} \text{ or } Q = I_{DC} \bullet \tau \quad (2)$$

where: I = steady state “ON” current.

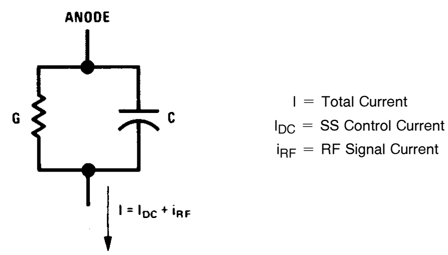

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FIGURE 2. Circuit Model for PIN Switch

The conductance is proportional to the current, I; hence, in order to minimize modulation due to the RF signal, $I_{DC} \gg i_{RF}$. Typical values for I_{DC} range from 50 mA to 200 mA depending on PIN diode type, and the amount of modulation that can be tolerated.

The time response of the excess charge, Q, may be evaluated by taking the Laplace transform of equation (1) and solving for Q:

$$Q(s) = \frac{\tau I(s)}{1 + s\tau} \quad (3)$$

Solving equation (3) for Q(t) yields:

$$Q(t) = L^{-1}[Q(s)] = I\tau(1 - \epsilon^{-t/\tau}) \quad (4)$$

The time response of Q is shown in *Figure 3a*. As can be seen, several carrier lifetimes are required to achieve the steady state “ON” condition ($Q = I_{DC} \bullet \tau$).

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The time response of the charge, hence the time for the diode to achieve the "ON" state could be shortened by applying a current spike, Ipk, to the diode and then dropping the current to the steady state value, I_{DC}, as shown in *Figure 3b*. The optimum response would be dictated by:

$$(Ipk)\ (t) = \tau \bullet I_{DC} \qquad (5)$$

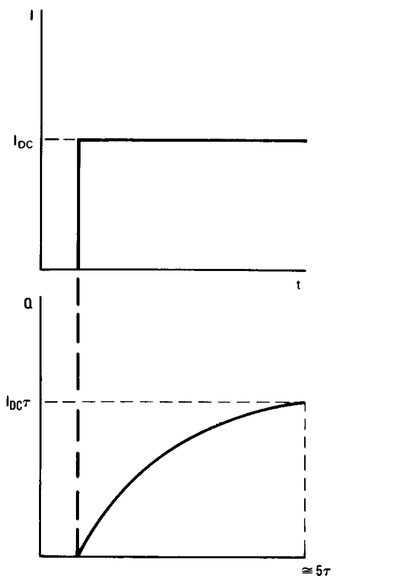

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FIGURE 3a

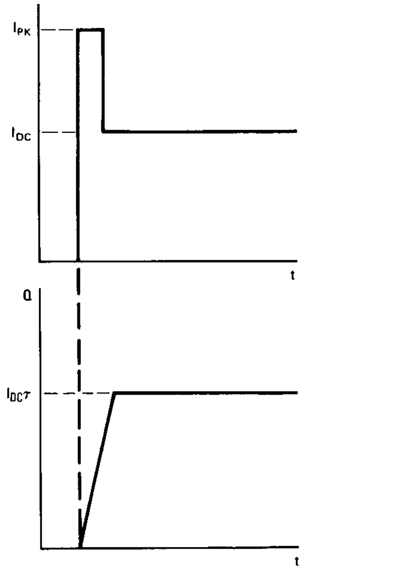

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FIGURE 3b

The turn off requirements for the PIN diode are quite similar to the turn on, except that in the "OFF" condition, the steady current drops to the diode's reverse leakage current.

A charge, $I_{DC} \bullet \tau$, was stored in the diode in the "ON" condition and in order to achieve the "OFF" state this charge must be removed. Again, in order to remove the charge rapidly, a large peak current (in the opposite direction) must be applied to the PIN diode:

$$-Ipk \gg \frac{Q}{\tau} \qquad (6)$$

It is interesting to note an implication of equation (5). If the peak turn on current were maintained for a period of time, say equal to τ, then the diode would acquire an excess charge equal to Ipk • T. This same charge must be removed at turn off, instead of a charge $I_{DC} \bullet \tau$, resulting in a considerably slower turn off. Accordingly, control of the width of turn on current peak is critical in achieving rapid turn off.

APPLICATION OF THE DH0035 AS A PIN DIODE DRIVER

The DH0035 is specifically designed to provide both the current levels and timing intervals required to optimally drive PIN diode switches. Its schematic is shown in *Figure 4*. The device utilizes a complementary TTL input buffer such as the DM7830/DM8830 or DM5440/DM7440 for its input signals.

Two configurations of PIN diode switch are possible: cathode grounded and anode grounded. The design procedures for the two configurations will be considered separately.

ANODE GROUND DESIGN

Selection of power supply voltages is the first consideration. Table I reveals that the DH0035 can withstand a total of 30V differentially. The supply voltage may be divided symmetrically at ±15V, for example. Or asymmetrically at +20V and −10V. The PIN diode driver shown in *Figure 5,* uses ±10V supplies.

When the Q output of the DM8830 goes high a transient current of approximately 50 mA is applied to the emitter of Q_1 and in turn to the base of Q_5.

Q_5 has an $h_{fe} = 20$, and the collector current is $h_{fe} \times 50$ or 1000 mA. This peak current, for the most part, is delivered to the PIN diode turning it "ON" (RF is "OFF").

Ipk flows until C_2 is nearly charged. This time is given by:

$$t = \frac{C2\Delta V}{Ipk} \qquad (7)$$

where: ΔV = the change in voltage across C_2.

Prior to Q_5's turn on, C_2 was charged to the minus supply voltage of −10V. C_2's voltage will rise to within two diode drops plus a V_{sat} of ground:

$$V = |V^-| - Vf(\text{PIN Diode}) - Vf_{CR1} - V_{satQ5} \qquad (8)$$

for $V^- = -10V$, $\Delta V = 8V$.

Once C_2 is charged, the current will drop to the steady state value, I_{DC}, which is given by:

$$I_{DC} = \frac{V}{R_M} - \frac{V^+}{R_3} - \frac{V_{CC}}{R_1} \qquad (9)$$

where: $V_{CC} = 5.0V$

$R_1 = 250\Omega$

$R_3 = 500\Omega$

$$\therefore R_M = \frac{(R_3\ (\Delta V)\ (R_1)}{R_1V^+ + I_{DC}R_3R_1 + V_{CC}R_3} \qquad (9a)$$

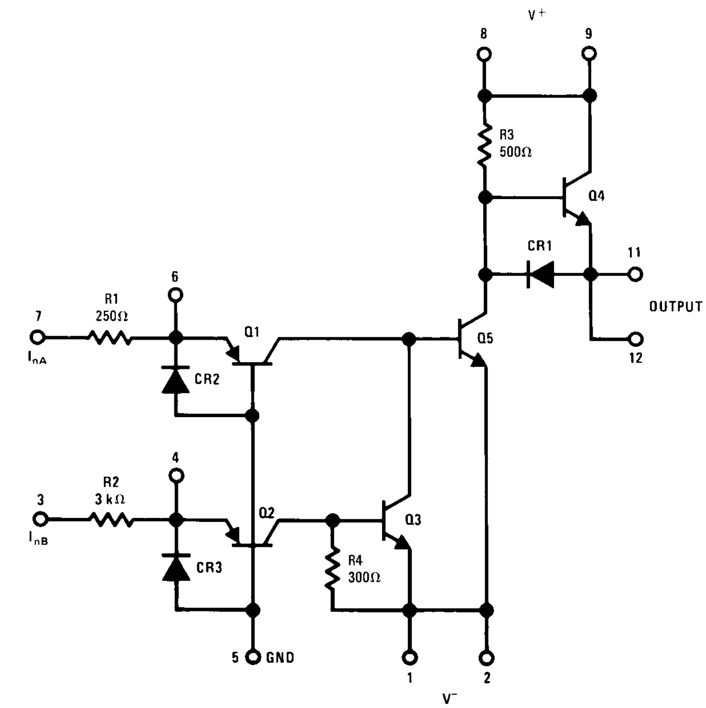

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FIGURE 4. DH0035 Schematic Diagram

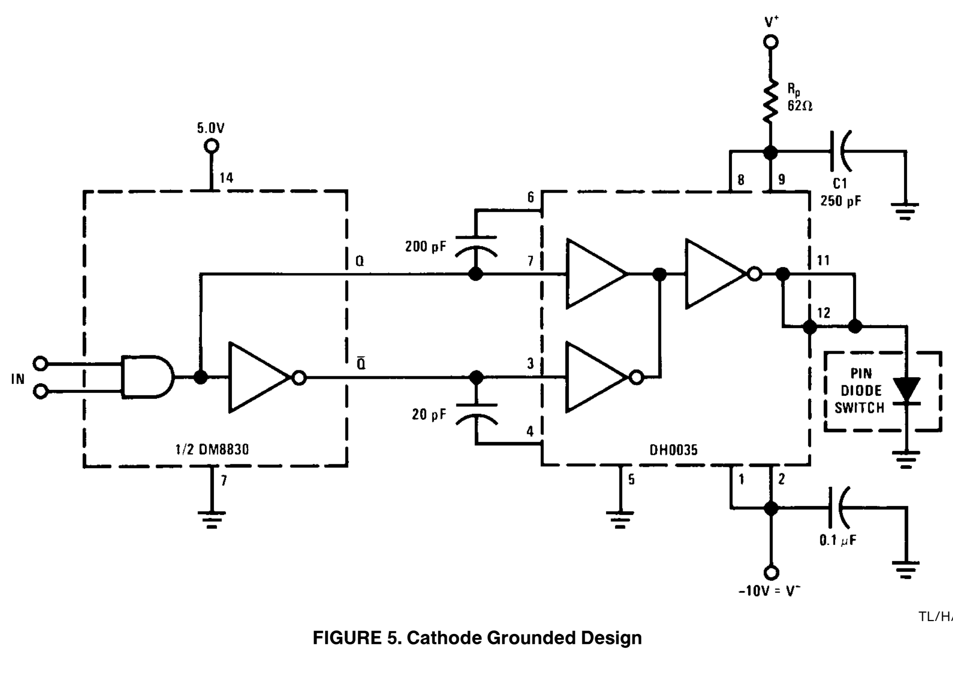

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FIGURE 5. Cathode Grounded Design

For the driver of *Figure 5,* and $I_{DC} = 100$ mA, R_M is 56Ω (nearest standard value).

Returning to equation (7) and combining it with equation (5) we obtain:

$$t = \frac{\tau I_{DC}}{Ipk} = \frac{C_2 V}{Ipk} \quad (10)$$

Solving equation (10) for C_2 gives:

$$C_2 = \frac{I_{DC}\tau}{V} \quad (11)$$

For $\tau = 10$ ns, $C_2 = 120$ pF.

One last consideration should be made with the diode in the "ON" state. The power dissipated by the DH0035 is limited to 1.5W (see Table I). The DH0035 dissipates the maximum power with Q_5 "ON". With Q_5 "OFF", negligible power is dissipated by the device. Power dissipation is given by:

$$P\ diss \cong \left[I_{DC} \left(|V^-| - \Delta V \right) + \frac{(V^+ - V^-)^2}{R3} \right] \times (D.C.) \leq P_{max} \quad (12)$$

where: D.C. = Duty Cycle =

$$\frac{(\text{"ON" time})}{(\text{"ON" time} + \text{"OFF" time})}$$

$$Pmax = 1.5W$$

In terms of I_{DC}:

$$I_{DC} \leq \frac{\left[\frac{(Pmax)}{(D.C.)} - \frac{(V^+ - V^-)^2}{500} \right]}{|V^-| - \Delta V} \quad (12a)$$

For the circuit of *Figure 5* and a 50% duty cycle, P diss = 0.5W.

Turn-off of the PIN diode begins when the Q output of the DM8830 returns to logic "0" and the $\overline{Q}$ output goes to logic "1". Q_2 turns "ON", and in turn, causes Q_3 to saturate. Simultaneously, Q_1 is turned "OFF" stopping the base drive to Q_5. Q_3 absorbs the stored base charge of Q_5 facilitating its rapid turn-off. As Q_5's collector begins to rise, Q_4 turns "ON". At this instant, the PIN diode is still in conduction and the emitter of Q_4 is held at approximately −0.7V. The instantaneous current available to clear stored charge out of the PIN diode is:

$$Ipk = \frac{V^+ - V_{BE\,Q4} + V_{f(PIN)}}{\frac{R3}{h_{fe} + 1}} \cong \frac{(h_{fe} + 1)(V^+)}{R_3} \quad (13)$$

where:

$h_{fe} + 1$ = current gain of $Q_4 = 20$

$V_{BE\,Q4}$ = base-emitter drop of $Q_4 = 0.7V$

$V_{f(PIN)}$ = forward drop of the PIN diode = 0.7V

For typical values given, Ipk = 400 mA. Increasing V^+ above 10V will improve turn-off time of the diode, but at the expense of power dissipation in the DH0035. Once turn-off of the diode has been achieved, the DH0035 output current drops to the reverse leakage of the PIN diode. The attendant power dissipation is reduced to about 35 mW.

CATHODE GROUND DESIGN

Figure 6 shows the DH0035 driving a cathode grounded PIN diode switch. The peak turn-on current is given by:

$$Ipk \cong \frac{(V^+ - V^-)(h_{fe} + 1)}{R3} \quad (14)$$

= 800 mA for the values shown.

The steady state current, I_{DC}, is set by Rp and is given by:

$$I_{DC} = \frac{(V^+ - 2V_{BE}}{\frac{R3}{h_{fe} + 1} + R_P} \quad (15)$$

where: $2V_{BE}$ = forward drop of Q_4 base emitter junction plus V_f of the PIN diode = 1.4V.

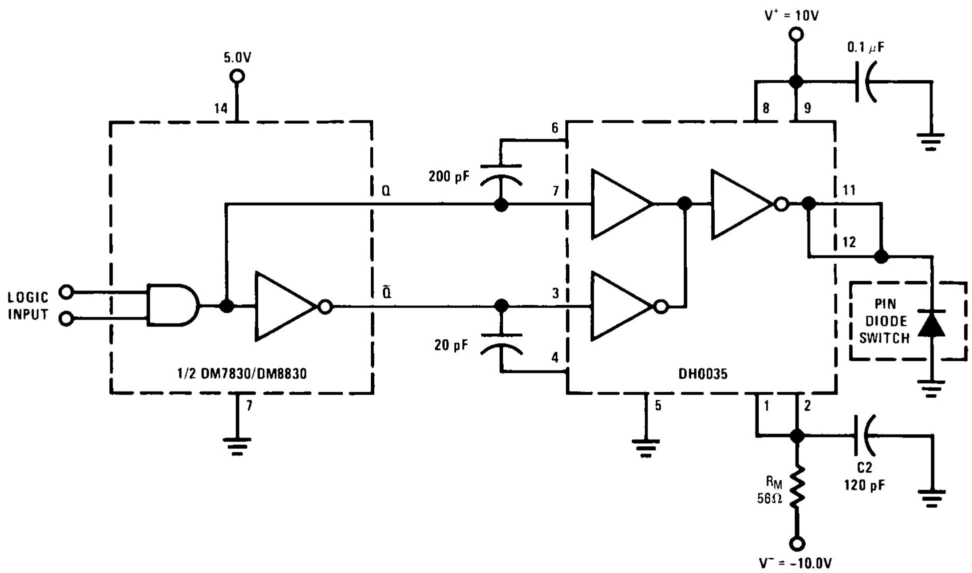

FIGURE 6. Anode Grounded Driver

In terms of Rp, equation (15) becomes:

$$Rp = \frac{(h_{fe} + 1)\,(V^{+} - 2V_{BE}) - I_{DC}R_9}{(h_{fe} + 1)\,I_{DC}} \qquad (15a)$$

For the circuit of *Figure 6,* and I_{DC} = 100 mA, Rp is 62Ω (nearest standard value).

It now remains to select the value of C_1. To do this, the change in voltage across C_1 must be evaluated. In the "ON" state, the voltage across C_1, Vc, is given by:

$$(Vc)_{ON} = \frac{V^{+}R_3 + Rp(h_{fe} + 1)\,(2V_{BE})}{R_3 + (h_{fe} + 1)\,Rp} \qquad (16)$$

For the values indicated above, $(Vc)_{ON}$ = 3.8V.

In the "OFF" state, Vc is given by:

$$(Vc)_{OFF} = \frac{V^{+}R_3 - |V^{-}|Rp}{Rp + R_3} \qquad (17)$$

= 8.0V for the circuit of *Figure 6.*

Hence, the change in voltage across C_1 is:

$$V = (Vc)_{OFF} - (Vc)_{ON} \qquad (18)$$
$$= 8.0 - 3.8$$
$$= 4.2V$$

The value of C_4 is given, as before, by equation (11):

$$C_1 = \frac{I_{DC}\tau}{V^{-}} \qquad (19)$$

For a diode with τ = 10 ns and I_{DC} = 100 mA, C_1 = 250 pF.

Again the power dissipated by the DH0035 must be considered. In the "OFF" state, the power dissipation is given by:

$$P_{OFF} = \left[\frac{V^{+} - V^{-})^2}{R_3}\right] (D.C.) \qquad (20)$$

where: D.C. = duty cycle =

$$\frac{\text{"OFF" time}}{\text{"OFF" time} + \text{"ON" time}}$$

The "ON" power dissipation is given by:

$$P_{ON} = \left[\frac{(Vc)_{ON}^2}{R_3} + I_{DC} \times (Vc)_{ON}\right] (1 - D.C.) \qquad (21)$$

where: $(Vc)_{ON}$ is defined by equation (16).

Total power dissipated by the DH0035 is simply P_{ON} + P_{OFF}. For a 50% duty cycle and the circuit of *Figure 6,* P diss = 616 mW.

The peak turn-off current is, as indicated earlier, equal to 50 mA × h_{fe} which is about 1000 mA. Once the excess stored charge is removed, the current through Q_5 drops to the diodes leakage current. Reverse bias across the diode = $V^{-} - V_{sat} \cong -10V$ for the circuit of *Figure 6.*

REPETITION RATE CONSIDERATIONS

Although ignored until now, the PRF, in particular, the "OFF" time of the PIN diode is important in selection of C_2, R_M, and C_1, Rp. The capacitors must recharge completely during the diode "OFF" time. In short:

$$4\,R_MC_2 \le t_{OFF} \qquad (22a)$$
$$4\,RpC_1 \le t_{OFF} \qquad (22b)$$

CONCLUSION

The circuit of *Figure 6* was breadboarded and tested in conjunction with a Hewlett-Packard 33622A PIN diode.

I_{DC} was set at 100 mA, $V^{+} = 10V$, $V^{-} = 10V$. Input signal to the DM8830 was a 5V peak, 100 kHz, 5 μs wide pulse train. RF turn-on was accomplished in 10–12 ns while turn-off took approximately 5 ns, as shown in *Figures 7* and *8*.

In practice, adjustment C_2 (C_1) may be required to accommodate the particular PIN diode minority carrier lifetime.

SUMMARY

A unique circuit utilized in the driving of PIN diodes has been presented. Further a technique has been demonstrated which enables the designer to tailor the DH0035 driver to the PIN diode application.

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