PIN Diode Drivers

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 1.

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<th>TABLE 1. DH0035 Characteristics</th>
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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.

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

\[
i = \frac{dQ}{dt} + \frac{Q}{\tau}
\]

Equation (1) implies a circuit model shown in Figure 2. Under steady conditions, hence:

\[
Q = \frac{I_{\text{DC}}}{\tau} \text{ or } Q = I_{\text{DC}} \cdot \tau
\]

where: \( I = \) steady state “ON” current.

The conductance is proportional to the current, \( I \); hence, in order to minimize modulation due to the RF signal, \( I_{\text{DC}} \gg I_{\text{RF}} \). Typical values for \( I_{\text{DC}} \) 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 \( Q \):

\[
Q(s) = \frac{r(s)}{1 + s\tau}
\]

Solving Equation (3) for \( Q(t) \) yields:

\[
Q(t) = L^{-1}[Q(s)] = I(t)(1 - e^{-t/\tau})
\]

The time response of \( Q \) is shown in Figure 3. As can be seen, several carrier lifetimes are required to achieve the steady state “ON” condition (\( Q = I_{\text{DC}} \cdot \tau \)).
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, IDC, as shown in Figure 4. The optimum response would be dictated by:

\[ (Ipk)(t) = \tau \cdot IDC \]  

(5)

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, IDC. A charge, IDC \cdot \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:

\[ -Ipk > \frac{Q}{\tau} \]  

(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 \( \tau \), then the diode would acquire an excess charge equal to Ipk \cdot \tau. This same charge must be removed at turn off, instead of a charge IDC \cdot \tau, resulting in a considerably slower turn off. Accordingly, control of the width of turn on current 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 5. 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 6, 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 Q1 and in turn to the base of Q5. Q5 has an hfe = 20, and the collector current is hfe \cdot 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 C2 is nearly charged. This time is given by:

\[ t = \frac{C2 \Delta V}{Ipk} \]  

(7)

where: \( \Delta V \) = the change in voltage across C2.

Prior to Q5’s turn on, C2 was charged to the minus supply voltage of −10V. C2’s voltage will rise to within two diode drops plus a Vsat of ground:

\[ V = |V^-| - Vf(PIN \ Diode) - VfCR1 - VsatQ5 \]  

(8)

for \( V^- = -10V, \Delta V = 8V \). Once C2 is charged, the current will drop to the steady state value, IDC, which is given by:

\[ IDC = \frac{V}{R1} - \frac{V^+}{R3} - \frac{VCC}{R1} \]  

(9)

where: \( V_{CC} = 5.0V \)

\[ R1 = 250\Omega \]

\[ R3 = 500\Omega \]

\[ R_M = \frac{(R3 (\Delta V) (R1))}{R1V^+ + IDC R3 R1 + VCC R3} \]  

(10)
FIGURE 5. DH003S Schematic Diagram

FIGURE 6. Cathode Grounded Design
For the driver of Figure 6, and $I_{DC} = 100 \text{ mA}$, $R_M$ is 56 Ω (nearest standard value).

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

$$t = \frac{\tau I_{DC}}{I_{PK}} = \frac{C_2 V}{I_{PK}}$$

(11)

Solving Equation (11) for $C_2$ gives:

$$C_2 = \frac{I_{PK} \tau V}{I_{DC}}$$

(12)

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

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:

$$P_{\text{diss}} = I_{DC} (V^- - \Delta V) + \frac{(V^+ - V^-)^2}{R_3} \times (\text{D.C.}) \leq P_{\text{max}}$$

(13)

where: D.C. = Duty Cycle =

$$\frac{\text{“ON” time}}{\text{“ON” time + “OFF” time}}$$

$P_{\text{max}} = 1.5W$

In terms of $I_{DC}$:

$$I_{DC} \leq \frac{(P_{\text{max}}) (V^+ - V^-)^2}{(\text{D.C.}) 500}$$

(14)

For the circuit of Figure 6 and a 50% duty cycle, $P_{\text{diss}} = 0.5W$.

Turn-off of the PIN diode begins when the $Q$ output of the DM8830 returns to logic “0” and the $Q$ 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 $Q_3$. $Q_3$ absorbs the stored base charge of $Q_5$ facilitating its rapid turn-off. As $Q_3$’s collector begins to rise, $Q_5$ turns “ON”. At this instant, the PIN diode is still in conduction and the emitter of $Q_2$ is held at approximately −0.7V. The instantaneous current available to clear stored charge out of the PIN diode is:

$$I_{pk} = \frac{V^+ - V_{BE\ Q4} + V_{(PIN)}}{R_3} \frac{h_{fe} + 1}{R_3} = \frac{(h_{fe} + 1)(V^+)}{R_3}$$

(15)

where:

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

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

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

For typical values given, $I_{pk} = 400 \text{ mA}$. 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 7 shows the DH0035 driving a cathode grounded PIN diode switch. The peak turn-on current is given by:

$$I_{pk} = \frac{(V^+ - V^-)(h_{fe} + 1)}{R_3}$$

(16)

= 800 mA for the values shown.

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

$$I_{DC} = \frac{(V^+ - 2V_{BE})}{R_3} \frac{h_{fe} + 1}{R_p}$$

(17)

where: $2V_{BE}$ = forward drop of $Q_4$ base emitter junction plus $V_1$ of the PIN diode = 1.4V.
In terms of $R_p$, Equation (17) becomes:

$$R_p = \frac{(h_{re} + 1) (V_+ - 2V_{BE}) - I_{DC} R_3}{(h_{re} + 1) I_{DC}}$$  \hspace{1cm} (18)$$

For the circuit of Figure 7, and $I_{DC} = 100$ mA, $R_p$ 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 $C_1$, $V_c$, is given by:

$$V_c = \frac{V^+ R_3 + R_p(h_{re} + 1) (2V_{BE})}{R_3 + (h_{re} + 1) R_p}$$  \hspace{1cm} (19)$$

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

In the “OFF” state, $V_c$ is given by:

$$V_c = \frac{V^+ R_3 - |V^-| R_p}{R_3 + R_p}$$  \hspace{1cm} (20)$$

$V = 8.0V$ for the circuit of Figure 7.

Hence, the change in voltage across $C_1$ is:

$$V = (V_c)_{OFF} - (V_c)_{ON} = 8.0 - 3.8 = 4.2V$$  \hspace{1cm} (21)$$

The value of $C_4$ is given, as before, by Equation (12):

$$C_4 = \frac{l_{DC} \tau}{V^-}$$  \hspace{1cm} (22)$$

For a diode with $\tau = 10$ 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:

$$P_{OFF} = \frac{(V^+ - V^-)^2}{R_3}$$  \hspace{1cm} (D.C.)  \hspace{1cm} (23)$$

where: D.C. = duty cycle =

$$\frac{“O F F” \text{ time}}{“O F F” \text{ time} + “O N” \text{ time}}$$

The “ON” power dissipation is given by:

$$P_{ON} = \frac{(V_c)_{ON}^2 + I_{DC} \times (V_c)_{ON}}{R_3} (1 - \text{D.C.})$$  \hspace{1cm} (24)$$

where: $(V_c)_{ON}$ is defined by Equation (19).

Total power dissipated by the DH0035 is simply $P_{ON} + P_{OFF}$.

For a 50% duty cycle and the circuit of Figure 7, $P_{diss} = 616$ mW.

The peak turn-off current is, as indicated earlier, equal to $50$ mA $\times h_{re}$ 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 is $V^- - V_{sat} = -10V$ for the circuit of Figure 7.
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 $C_1$, $R_p$. The capacitors must recharge completely during the diode “OFF” time. In short:

\[
\begin{align*}
4R_M C_2 & \leq t_{OFF} & (25) \\
4R_p C_1 & \leq t_{OFF} & (26)
\end{align*}
\]

CONCLUSION

The circuit of Figure 7 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 DM9830 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 Figure "NO TARGET FOR fig NS0292" and Figure "NO TARGET FOR fig NS0292". 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.

REFERENCES


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