Automotive Applications

This chapter discusses the application of semiconductor power devices to automotive systems. Automotive systems are broadly defined to include all surface vehicles employing internal combustion engines. Power devices perform a wide variety of functions in such systems, and many more functions are being considered.

Table XXIX is a listing of systems showing the function performed by the power device, the voltage and current requirements imposed on the device, and typical devices employed.

GENERAL DEVICE REQUIREMENTS

The performance requirements of power devices in automotive systems are almost always dictated by worst-case conditions. Although they occur infrequently, these conditions must be accommodated in order to permit the vehicle to function adequately under all reasonably encountered circumstances. Some requirements are imposed so that minimum system performance levels are achieved, others are imposed to assure survival of the power device under transient and fault conditions to which the device may be exposed.

The following are the most common worst-case or extreme conditions which must be considered individually and to varying degrees in combination:

1. **Ambient temperature range.**
   -40° C (-30° C for selected systems); +85° C (passenger compartment systems); +100° C (engine compartment systems)—for some specialized engine compartment systems this may reach +125° C.
2. **Continuous high system voltage.**
   For the nominal 14-volt automotive system an extreme voltage of 24 volts is usually the maximum voltage which occurs during "jump" or booster starting of a vehicle with a dead battery. The jump start source is from two 12-volt batteries in series, or from a 24-volt service vehicle electrical system. The power device must survive the conditions imposed when the system voltage goes to 24 volts for short periods. With the nominal 14-volt system, the power device must function properly at 17 to 18 volts for extended periods, in the event the voltage regulator fails in the full-field or over-charge mode.
3. **Reverse battery.**
   The power device must also survive conditions experienced when the battery is inadvertently connected to the system with reverse polarity for short periods.
4. **Low system voltage.**
   Minimum performance levels are usually required at voltages as low as 5 to 10 volts, depending on the system.
5. **Transient voltage (forward polarity).**
   Forward voltage transients of 75 to 150 V with exponentially time-decaying waveforms having time constants of many 10's of milliseconds are experienced in automotive electrical systems if the battery is disconnected while the engine is running. This condition is referred to as "load dump" because it occurs when the stabilizing effect of the battery (the load) is removed. When load dump occurs, it is important that the power device have the voltage- and/or energy-handling capability to survive the transient voltage conditions imposed by the particular system.
6. **Transient voltage (reverse polarity).**
   A transient voltage of reverse polarity, also referred to as a negative transient, is generated in an automotive system when a circuit in series with an inductor is opened under load (see Figs. 353 and 354), while current is flowing, thus interrupting the current. This voltage is also called a field decay transient which is normally limited to the specific circuit being opened, and will not generate a transient on the system bus to which the

Table XXIX

System	Function	Device Requirements (Approx.)		RCA Device			
		Voltage V	Current A	Type	Polarity	Class	Package
Automotive Voltage Regulator	Controls Current to Alternator Field Winding	40-150	5	2N6107	p-n-p	Transistor	TO-220
				2N6668	p-n-p	Darlington	TO-220
				2N6669	n-p-n	Transistor	TO-220
				2N6533	n-p-n	Darlington	TO-220
				RCA8766	n-p-n	Darlington	TO-3
Automotive Engine Ignition (Inductive-Discharge)	Output Device: Switches Current in Ignition Spark Coil	400	5	2N6513	n-p-n	Transistor	TO-3
				RCA8766B	n-p-n	Darlington	TO-3
	Driver: Supplies Base Drive to Output Device	80	1	2N6385	n-p-n	Darlington	TO-3
				2N6292	n-p-n	Transistor	TO-220
Automotive Engine Ignition (Capacitive-Discharge)	Inverter: Charges Capacitor	60	5	2N3055	n-p-n	Transistor	TO-3
Automotive Radio	Class A Audio Amplifier	35	1	2N3054	n-p-n	Transistor	TO-66
	Class B True-Comp. Audio Amplifier	40	1.5	2N6288	n-p-n	Transistor	TO-220
				2N6111	p-n-p	Transistor	TO-220
Automotive Tape Player	Motor Drive	40	1	2N5296	n-p-n	Transistor	TO-220
				2N6288	n-p-n	Transistor	TO-220
Anti-Skid Adaptive Braking	Solenoid Driver	80	3-5	2N5496	n-p-n	Transistor	TO-220
				2N6388	n-p-n	Darlington	TO-220
				2N3055	n-p-n	Transistor	TO-3
Air Conditioner Blower	Motor Control	80	20	2N6365	n-p-n	Darlington	TO-3
				2N3772	n-p-n	Transistor	TO-3
				2N5303	n-p-n	Transistor	TO-3
Instrument Cluster	Series Regulator Lamp Driver	60-60	1-3	2N6688	p-n-p	Darlington	TO-220
				2N6292	n-p-n	Transistor	TO-220
				2N6478	n-p-n	Transistor	TO-220
				2N6388	n-p-n	Darlington	TO-220
Engine Governor	Solenoid Driver	80	1	2N6386	n-p-n	Darlington	TO-220
Feedback Carburetor	Solenoid Driver or Stepped Motor Drive	80	1	2N6388	n-p-n	Darlington	TO-220
				2N6668	p-n-p	Darlington	TO-220
				2N6292	n-p-n	Transistor	TO-220
Fuel Injection	Solenoid Driver	80	5	2N6101	n-p-n	Transistor	TO-220
				2N6368	n-p-n	Darlington	TO-220
				2N5866	n-p-n	Transistor	TO-3
Electronic Engine Controls Fuel Pump	Motor Drive	80	15	2N6286	p-n-p	Darlington	TO-3
Fuel Metering	Servo Motor Drive or Solenoid Driver	80	10	2N6383	n-p-n	Darlington	TO-3
				2N6366	p-n-p	Darlington	TO-3
Exhaust Gas Recirculation	Servo Motor Drive or Solenoid Driver	80	10	2N6388	n-p-n	Darlington	TO-3
				2N6668	p-n-p	Darlington	TO-3
Cold-Start Control	Solenoid Driver	80	5	2N6388	n-p-n	Darlington	TO-220
				2N6668	p-n-p	Darlington	TO-220
Transmission Control	Solenoid Driver	80	5	2N6368	n-p-n	Darlington	TO-220
				2N6668	p-n-p	Darlington	TO-220

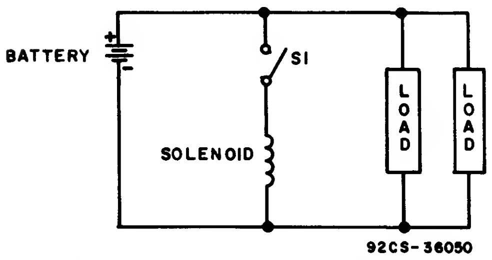


Fig. 353 - Negative transient condition.

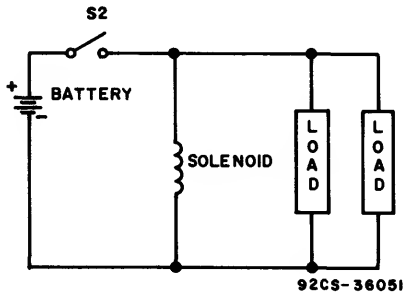


Fig. 354 - Negative transient condition.

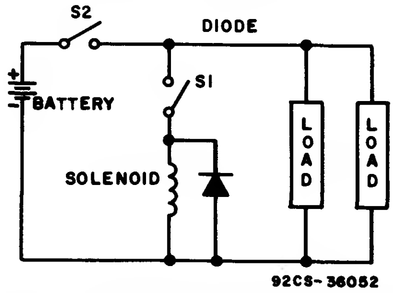


Fig. 355 - Diode suppression of negative transient.

battery is still connected. However, if the current interruption is caused by disconnecting the battery from the system bus, the resulting transient will appear on the entire system, unless provision is made to limit the voltage as the inductor is discharged.

The negative transient is typically an exponentially decaying waveform having a voltage of 75 to 100 volts peak, and a time constant of several milliseconds. Loads which can generate the negative transient are solenoids, the field winding of the alternator, and motors. In systems where negative transients can be generated, the power device must be capable of surviving the conditions generated by these transients.

In most circuits when a solid-state power device is employed to switch the current to the inductive load, a diode is connected across the inductive load (Fig. 355) in such a way that the diode is not disconnected from the load during switching. This diode limits the voltage appearing across the inductor to the diode voltage drop while the inductor is being discharged. Under these conditions negative transients will not be impressed on the system bus.

It is recommended that all inductive loads including solenoids and motors be provided with a shunting diode of sufficient current rating to absorb all negative transients.

7. **Mechanical.**
   The mechanical shock and vibration conditions experienced do not significantly affect device performance. However, the method used to mount the devices in the system can introduce conditions detrimental to that performance. If excessive forces are employed in securing the devices to the mounting structure, permanent deformation can occur, with resultant internal damage to the devices. On the other hand, if device headers are only loosely secured to mounting structures that also serve as heat-removal elements, excessive heating of the device can occur.
8. **Thermal cycling.**
   The device must be of such a design that it will continue to function in a suitable manner after repeated thermal cycles to the extreme temperatures typically experienced in service. The number of cycles to be imposed should be consistent with the service life of the system.

Transistor Requirements

The type of transistor selected for use in automotive electrical systems is dictated by the following considerations:

A. The **collector-to-emitter saturation voltage**, $V_{CE}(sat)$, at given I_C and I_b, and the **base-to-emitter voltage**, V_{BE}, at given I_C and V_{CE}. These specifications, which the transistor must meet in terms of the indicated conditions and limits are determined by on-state performance requirements imposed by the system at the lowest battery voltage and at the lowest ambient temperatures. In some instances, the

$V_{CE}(sat)$ conditions and limits must also be specified at the highest junction temperatures consistent with acceptable performance. Production testing is usually performed at room temperature, with test conditions and/or limits appropriately guardbanded to assure that performance at the temperature extremes is maintained within the specification limits. Tests at the temperature extremes are usually performed on a sampling basis.

B. The **leakage specification** for the transistor is determined from the maximum permissible off-state current at the highest junction temperature, at a high collector-to-emitter voltage, and with a specific base-to-emitter termination. A typical base-to-emitter configuration, shown in Fig. 356, includes:

  1. Base-to-emitter resistor, R_{BE}.
  2. Current sinking transistor, with the collector of Q_1 connected to the base of Q_0, and emitter of Q_1 connected to emitter of Q_0. See Fig. 356 which may be used with or without series resistor R_1.

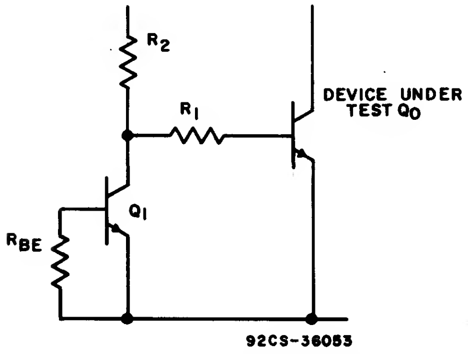


Fig. 356 - Typical transistor circuit configuration.

In this circuit the device under test experiences a small forward bias which is the $V_{CE}(sat)$ voltage of device Q_1.

To verify performance at the required elevated temperature the test may be set up as follows:

1. **As a leakage test**: For a maximum limit of I_C leakage at a specified collector-to-emitter voltage (V_{CE}) and forward-bias voltage (V_{BE}) or,
2. **As a forward-bias voltage (V_{BE}) test**: For a minimum V_{BE} at specified I_C (corresponding to maximum permissible leakage) and V_{CE}. If a device exhibits a V_{BE} value below the minimum limit, the device is rejected.

C. The **sustaining voltage and breakdown voltage** requirements of a transistor are usually governed by the voltage the device will experience in the system under load-dump conditions. For output transistors in ignition service these voltages are dependent on the clamp circuit which limits the peak collector voltage during turn-off.

D. The **energy-handling (safe-operating-area or SOA)** capability of the device may be dictated by conditions experienced under high battery operation and conditions experienced during load dump. In the case of output transistors for ignition service, the worst-case condition occurs under high battery operation with an open-circuit ignition-coil secondary (disconnected spark plug). In testing these transistors, a "use test" inductive discharge circuit simulating the above worst-case system condition is specified to insure SOA capability.

AUTOMOTIVE IGNITION SYSTEMS

Under worst-case conditions, about 22 kilovolts are required to ignite the combustible mixture in the cylinder of an automobile engine. In addition, a minimum energy of about 20 millijoules must be available in the spark to assure propagation of a stable flame front originating at the spark. The exact values of voltage and energy required under all operating conditions depend on many factors, including those described in the following paragraphs.

Condition of spark plugs—Fouled plugs reduce both the voltage and the energy available for ignition. The plug gap also affects both the voltage and the energy required. As the plug gap is increased, the required voltage increases, but the required energy decreases.

Cylinder pressure—The cylinder pressure depends on both the compression at the point of ignition and the air-fuel mixture. The minimum breakover voltage in any gas is a function of the product of gas pressure and electrode spacing (Paschen's Law). In automobile engines, the minimum voltage increases as this product increases. Therefore, higher pressures also require higher voltages. However, the energy required decreases as the pressure increases, and increases as the fuel-air mixture deviates from the optimum ratio. Worst-case conditions occur when the engine is started, at idle speeds, and during acceleration from a low speed because carburetion is poor and the fuel-air mixture is lean. The combination of a lower cylinder pressure and a dilute fuel-air mixture under these conditions results in a high energy requirement.

Spark plug polarity—The center electrode of the spark plug is hotter than the outside electrode because of the thermal resistance of the ceramic sleeve that supports it. If the center electrode is made negative, the effect of thermionic emission from this electrode can reduce the required ignition voltage by 20 to 50 per cent.

Spark plug voltage waveshape—The spark plug voltage waveshape is shown qualitatively in Fig. 357. The voltage starts to rise at point A and reaches ignition at point B. The region from B′ to C represents the sustaining voltage for ionization across the spark plug. When there is insufficient energy left to maintain the discharge (at point C), current flow ceases and the remaining energy is dissipated by ringing. The final small spike at point D occurs when the ignition coil again starts to pass current.

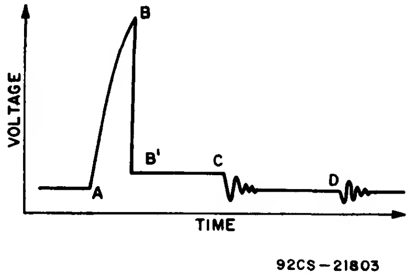


Fig. 357 - Ignition-voltage waveshape.

The two most important characteristics of the voltage waveshape are its rise time (from A to B) and the spark duration (from B′ to C). A rise time that is too long results in excessive energy dissipation with fouled plugs; a rise time that is too short can lead to loss by radiation through the ignition harness of the high-frequency components of the voltage. The minimum rise time should be about 10 microseconds; a 50-microsecond rise time is acceptable. Conventional systems have a typical rise time of about 100 microseconds. It should be noted that, at an engine speed of 5000 revolutions per minute, one revolution takes 12 milliseconds. Engine timing accuracy is usually no better than 2 degrees, which corresponds to 67 microseconds. The error caused by the rise time is therefore comparable to normal timing errors. At normal cruising speeds (about 2000 revolutions per minute), the 2-degree timing error corresponds to about 165 microseconds, and rise-time effects are negligible.

Energy storage—The energy delivered to the spark plug can be stored in either an inductor or a capacitor. Although the inductive storage method is the more common approach, both are used. Both are discussed below. One requirement common to both methods is that, after the storage element is discharged by ignition, it must be recharged before the next spark plug is fired. For an eight-cylinder engine that has a dwell angle of 30 degrees, the time τ between ignition pulses (in milliseconds) is equal to 15,000 divided by the engine r/min., and the time t_{on} during which the points are closed is equal to 10,000/r/min. When the engine r/min. is 5000, t_{on} is 2 milliseconds. Therefore, the charging time constant for either an inductive or a capacitive storage system should be small compared to 2 milliseconds.

Inductive-Discharge Automotive Systems

Fig. 358 shows the basic circuit for an inductive-discharge system. The total primary-circuit resistance (ballast plus coil) is represented by R_p; the primary inductance of the coil is represented by L_p. Switch S respresents the points in a conventional system. The step-up turns ratio of the transformer is N. When the points close, current increases exponentially with a time constant t_L equal to L_p/R_p.

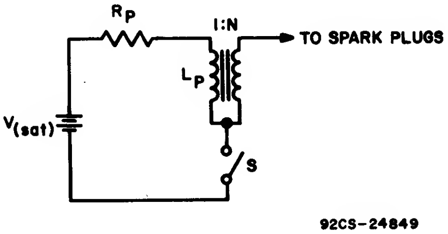


Fig. 358 - Basic inductive-discharge ignition circuit (Kettering system).

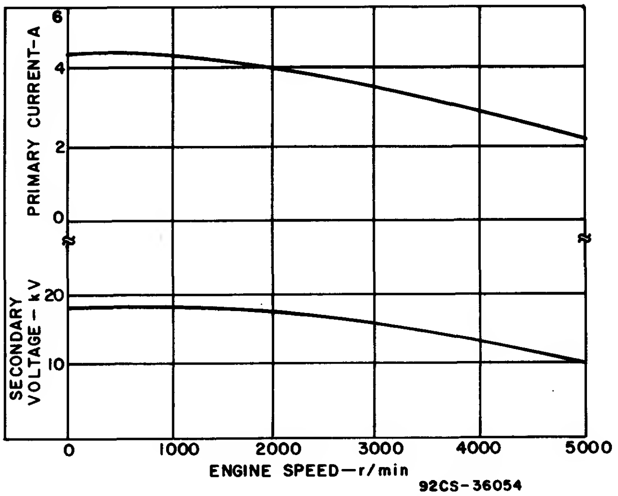


Fig. 359 - Performance of conventional inductive-discharge ignition system.

The maximum primary current I_p is equal to V_{BAT}/R_p, and the energy e_L stored in the coil is equal to $L_pI_p^2/2$. When the points open, a voltage V_p is generated across the primary terminals; this voltage is equal to $-L_p(dI_p/dt)$, where I_p is the primary current as a function of time t. The secondary voltage V_S, which is delivered to the spark plugs through the distributor, is equal to NV_p.

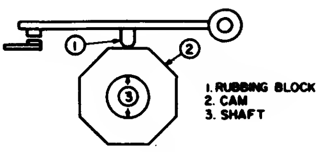
The maximum current is limited to about 4 amperes by possible burnout of the points. The total energy stored in the coil must be about 50 millijoules to provide for energy losses by radiation, fouled plugs, and the like. For a battery voltage of 12 volts and a primary-circuit resistance of 3 ohms, L_p must have a value of about 6 millihenries. The time constant t_L is then about 2 milliseconds; the coil current does not reach its maximum value at high engine speeds. Fig. 359 shows primary current and secondary voltage as a function of engine speed for a typical non-transistorized ignition circuit. The degradation in secondary voltage follows the primary current. The available energy decreases even more rapidly because it is proportional to the square of the current. This problem can be even more severe than indicated because some conventional ignition coils have inductances as high as 12 millihenries, and the time constant is correspondingly longer.

Capacitive-Discharge Systems

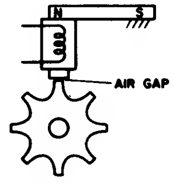
Capacitive-discharge (CD) ignition systems have been in use since the introduction of silicon controlled rectifiers (SCR's). The early recognition and application of the benefits of the SCR CD ignition in limited areas of the small-engine market (one-cylinder, two- and four-cycle engines, and marine engines) has since expanded to nearly 100 per cent penetration of that market. Typical applications are chain saws, lawn mowers, snowmobiles, motorcycles, mini-bikes, fence chargers and auxiliary power sources relying on the maintenance-free, high performance CD ignition system. For further discussion of CD systems refer to the **RCA Solid-State Devices Manual**, SC-16.

The emission standards and service restrictions imposed on the automotive industry have made electronic ignition systems all but mandatory. An improvement in nearly any part of the engine will help to meet the emission requirements, and even if the contribution of the electronic ignition to the total improvement of the performance of the automobile is considered small, it is significant. Those areas in which the present system is deficient and in which the electronic system is superior are explained below.

The points (contacts) in the standard ignition system produce ignition timing errors in three ways, as shown in Fig. 360: 1) wear of the rubbing block, 2) variations in the cam profile, and 3) shaft eccentricity. Cam and shaft eccentricity change the timing of each cylinder relative to the others. The elimination of these



(a) POINTS



(b) MAGNETIC PICKUP

Fig. 360 - (a) Standard ignition timing system, (b) magnetic pickup timing system.

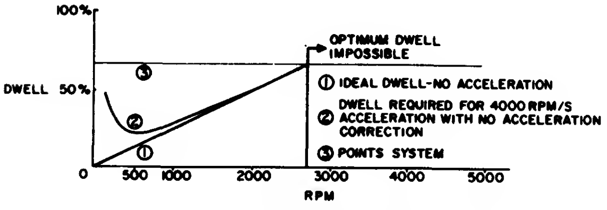
points of wear in the ignition-point system is also helpful in meeting the emissions tests for 50,000 miles without engine service. These three problems are solved by using a magnetic pickup, Fig. 360, instead of points. But a magnetic pickup produces only a small signal, which necessitates amplification and, hence, an electronic system.

In summary, the automotive industry is using electronic ignition to obtain performance not previously required—more accurate spark timing and the elimination of the need for periodic adjustment of the timing.

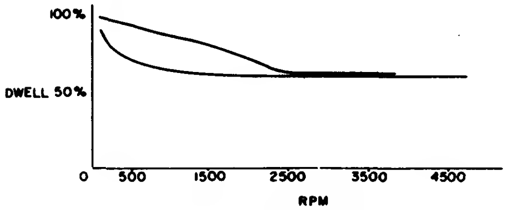
Legal restrictions prohibit the description of circuits in use by particular manufacturers; however, a general discussion of the four principal characteristics of inductive ignition systems is appropriate. These characteristics include dwell, battery-voltage compensation, high-voltage limiting, and obtaining output-transistor base drive.

Dwell—Dwell is the portion of the operating cycle in which the ignition coil is being charged, and is expressed in either per cent (as in this discussion), in degrees of crankshaft rotation (100% dwell=90° for 8 cylinders; 100% dwell=120° for 6 cylinders, etc.), or in milliseconds (the amount varies with r/min.). Breaker points produce constantpercentage dwells independent of r/min., as shown in curve 3 of Fig. 361(a). This is not the optimum dwell; it is excessive at low r/min. and wastes current as shown in Fig. 361(b). At high r/min., Fig. 361(c), the dwell is more correct. Fig. 361(d) shows spark energy as a function of r/min. for a constant-per cent dwell system. The minimum dwell is shown in curve 1 of Fig. 361(a). This dwell would minimize the battery current consumption. A magnetic pickup does not allow the use of a simple circuit to compensate for acceleration. One solution adds extra dwell; this approach produces curve 2 of Fig. 361(a).

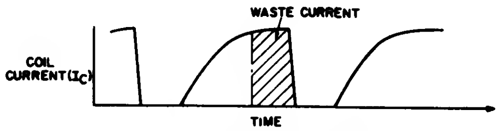
These functions are important because a magnetic pickup can only produce a 50%



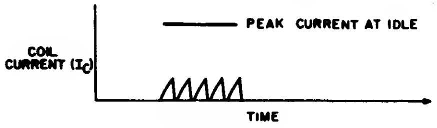
(a) comparison of dwell percentages vs. r/min.



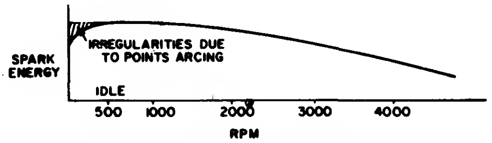
(e) two practical dwell curves.



(b) engine idling at 500 r/min.

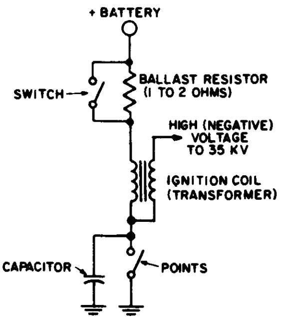


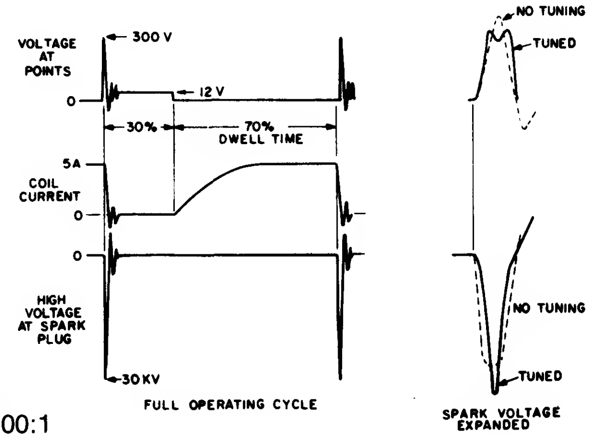
(c) engine at 5000 r/min (same scale as Fig. 2b).



(d) spark energy as a function of r/min for a constant-percent dwell system.

Fig. 361 - Ignition system dwell waveforms.





Typical Ignition-Coil Parameters

Turns Ratio	100:1
Secondary	25,000 turns #41
Primary	250 turns #22
Primary Inductance	6 to 10 mH
Primary Resistance	about 1.5 ohms
Secondary Inductance	40 H
Secondary Resistance	10 kilohms

Fig. 362 - Operation of a basic ignition circuit. A low engine speed and a disconnected spark plug are assumed for clarity. The high voltage is generated when the points located in the distributor open. The capacitor reduces arcing by decreasing the rate of voltage rise at the points. It also "third-harmonic" tunes the coil and raises the peak output voltage. The switch shown may be built into the ignition switch, the starter, or the starter relay.

dwell unless electronic circuits are added. The resultant dwell function will be a compromise with circuit economics. Two simple, practical, dwell curves are shown in Fig. 361(e).

Battery-voltage compensation—Some method must be used to compensate for battery-voltage variation. Just when the best spark is needed—during starting—a low battery voltage exists. When starting, the plugs and the air are cold, the cylinder pressure is up, and the fuel mixture is poorly controlled, so a good spark is needed. The battery voltage drops as much as 60% because of the high current drain in the starter motor. Conventionally, this loss in battery voltage is compensated for by shorting a ballast resistor in the ignition, as shown in Fig. 362. However, when used with an electronic ignition, this method causes excessive transistor currents when the battery is fully charged, or worse if a booster battery (24 V) is applied by a service truck. The latter is a worst-case condition for the transistor; the collector currents can approach 20 A.

An electronic ignition system can be made to compensate for battery-voltage variations if the output transistor is made to operate as a current limiter. However, not only is it difficult to cool a transistor operating in the active-region in the hostile environment under the engine hood, but such operation limits the number of suitable mounting locations. Also important is the fact that a system so operated produces less spark energy than the point system when the battery is fresh, and this might adversely affect starting capability when the engine is hot.

High-voltage limiting—High-voltage limiting is concerned with the method used to protect the output transistor from excessively high voltages. All of the systems being used or considered by the automotive manufacturers use the standard 100-to-1 turns-ratio coil, and require the transistor to operate at approximately 300 V. Either a disconnected spark plug or a cold start with a good battery can raise the transistor's voltage to 800 or 1,000 V. There are four ways to eliminate the need for a 1,000-V transistor. The coil current can be limited by the output transistor, as described

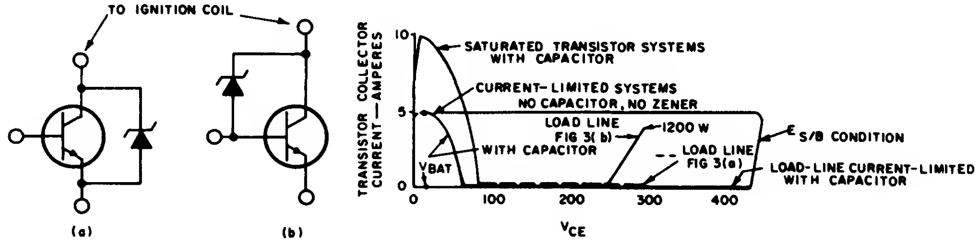


Fig. 363 - Methods of eliminating the need for a 1,000-V transistor in the transistor ignition system.

above, in which case a 400- or 500-V transistor would be adequate. The second way is to use a zener clamp from the transistor's collector to its emitter to absorb the energy, as shown in Fig. 363(a), however, the required 10-W zener is expensive. The third way to protect the transistor is to use the transistor to amplify the zener output. The zener is a 0.5-W unit placed across the transistor's collector and base, as shown in Fig. 363(b). The transistor must dissipate high peak powers (900 W) in short pulses. The fourth way is to use a 300-V transistor that can absorb the energy in a voltage-breakdown mode. This approach would be the most expensive with the present state of the art.

An example of the worst-case load lines are shown in Fig. 363(c). Current limiting requires high power-dissipation capability, particularly when the engine stalls. When no capacitor is used, a severe second-breakdown condition exists. In saturated transistor-switch systems with collector-emitter zeners, the transistor requirements are minimized. Despite the high pulse-power loads needed for the collector-base zener approach, this system is the least expensive.

Each of the methods discussed requires different output transistor capabilities.

Obtaining base drive—The final difference among inductive, electronic-ignition systems is the source of base drive for the power transistor. Cost-effective, high-voltage power transistors require more than one ampere of base drive for the starting condition (a battery voltage of 6 V and a collector current of 3 to 5 A); two methods exist for obtaining this current. In the first, a Darlington transistor is used, as shown in Fig. 364(a), which means that the base drive of the output transistor passes through the coil. This arrangement minimizes the current requirement but increases V_{CE}(sat), and a lower resistance, more expensive coil is needed. In the second approach, as shown in Fig. 364(b), the base drive comes from the battery through a separate power resistor. This yields a better V_{CE}(sat), but requires up to 3 A more battery current, a 50-W resistor, and extra wiring.

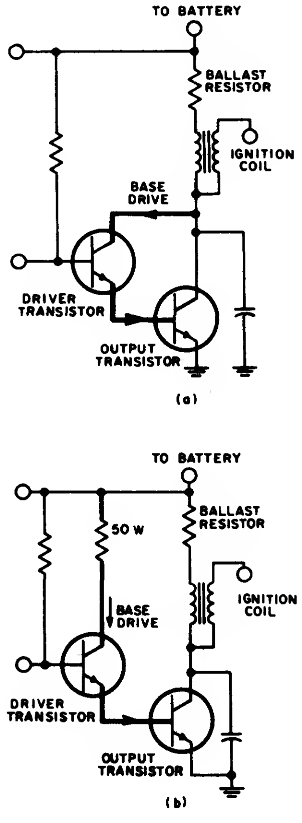
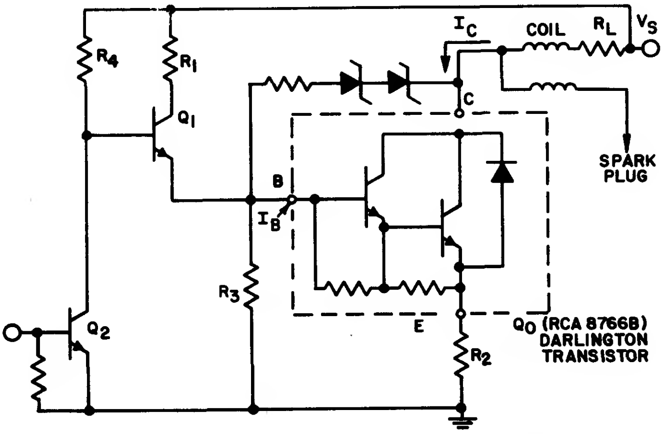


Fig. 364 - Methods of obtaining base-drive.

A typical circuit for the power stage of an automotive ignition system is shown in Fig. 365. The saturation voltage V_{CE}(sat) of the



92CS-36055

Fig. 365 - Typical automotive ignition circuit.

output device Q_O is governed by the relationship: $V_{CE}(sat) \leq V_S$ low — $I_C(R_L + R_2)$ at specified I_C and $T_{ambient}$. (This relation assumes I_b has negligible effect on the voltage drop across R_2) where

V_S = supply voltage

V_S low = lowest value of system voltage at which performance is expected (starting or cranking mode)

I_C = minimum allowable coil current which provides adequate energy for the ignition spark

R_2 = low-value sensing resistor often used to monitor and control coil current

R_L = internal resistance of the primary winding of the ignition coil. The value of R_L depends on the ambient temperature because most coil windings are of copper. Therefore, the appropriate value of R_L should be used corresponding to the specified ambient temperature.

T_A = Typically -30° C for the low-temperature extreme, +100° C to 125° C for the high-temperature extreme

I_b = base current to Q_O

It is usually necessary to specify the $V_{CE}(sat)$ requirements at the two temperature extremes.

The relationship for the base driving current (I_b) required, and the related components and device parameters are derived from the following expression:

$$V_S = V_{CE}(sat)(Q_1) + V_{BE}(Q_O) + R_2\,(I_c + I_b) + R_1\left(I_b + \frac{V_{BE}(Q_O) + R_2(I_c + I_b)}{R_3}\right)$$

This expression assumes that the contribution of the driving current to Q_1 through R_4 can be neglected for purposes of determining the voltage distribution in the main Q_O drive circuit. The expression can be solved to determine a value for R_1 based on the other parameters under worst-case, low-system voltage and worst-case low ambient temperature conditions as follows:

$$R_1 = \frac{V_S\,\text{low} - V_{CE}(sat)(Q_1) - V_{BE}(Q_O) - R_2(I_c + I_b)}{I_b + \dfrac{R_2}{R_3}\,(I_c + I_b) + \dfrac{V_{BE}(Q_O)}{R_3}}$$

or it may be solved to determine the I_b drive to Q_O available or supplied under similar worst-case conditions, as follows:

$$I_b = \frac{V_S\,\text{low} - V_{CE}(sat)(Q_1) - I_c\left(R_2 + \dfrac{R_1\,R_2}{R_3}\right)}{R_1 + R_2 + \dfrac{R_1\,R_2}{R_3}} - \frac{V_{BE}(Q_O)\left(1 + \dfrac{R_1}{R_3}\right)}{R_1 + R_2 + \dfrac{R_1 \times R_2}{R_3}}$$

Where,

$V_{CE}(sat)(Q_1)$ = maximum voltage drop across the driver transistor at low ambient temperature extremes

and,

$V_{BE}(Q_O)$ = base-to-emitter voltage drop across Q_O with Q_O current equal to I_c

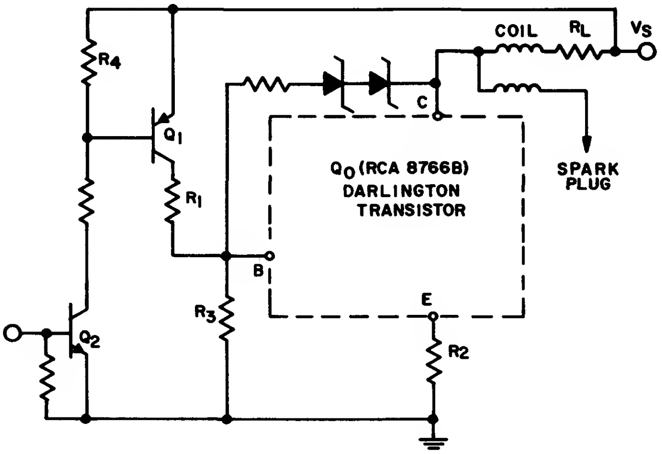


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Fig. 366 - Alternate ignition circuit.

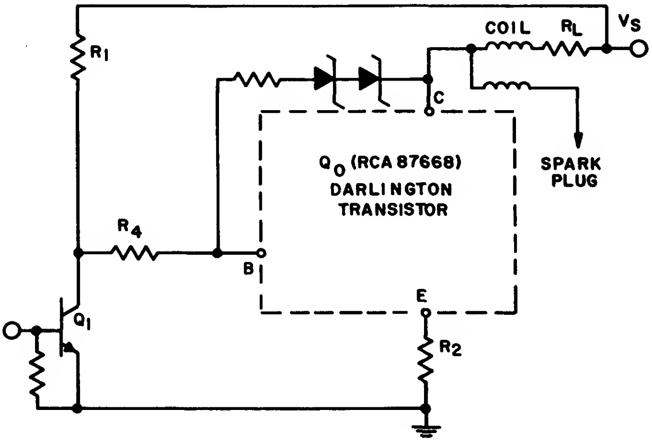

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Fig. 367 - Ignition circuit with collector-coupled drive transistor.

with,

V_{CE}=V_{CE}(sat)(Q_O) and T_A=low ambient-temperature extreme.

The equation for I_b shows the tradeoff between I_b and V_{BE} such that any combination of values of V_{BE} and I_b which result in a value of device base current equal to or less than that given by the equation for I_b will provide acceptable performance.

The maximum power dissipation in R_1 will be approximately:

$$\text{Max. } P_{R1} = \frac{[V_S \text{ high} - V_{BE}(Q_O) - V_{CE}(\text{sat})(Q_1)]^2 D_{max}}{R_1}$$

when,

V_S high is the worst-case high system voltage

and,

D_{max} is maximum duty factor-typically .80 to .90 which occurs at high engine speed.

In an alternate circuit configuration, shown in Fig. 366, the n-p-n drive transistor Q_1 is replaced by a p-n-p device. This circuit offers the possibility of providing acceptable performance at lower system voltages than can be provided by the circuit of Fig. 365 because the stacking of V_{BE} voltage drops in the drive chain has been reduced. (Note the logic level, output vs. input, has been inverted in this circuit.)

Another popular drive circuit, shown in Fig. 367, employs a collector-coupled drive transistor as opposed to the emitter-follower drive shown in Fig. 365. The basic drive circuit relationship in this configuration is:

$$V_S = I_b(R_1+R_4+R_2)+I_cR_2+V_{BE}(Q_O)$$

and,

$$R_1 = \frac{V_S\ \text{low}-V_{BE}(Q_O)-I_cR_2}{I_b} - R_4 - R_2$$

and I_b (available or supplied with given circuit values) is:

$$I_b = \frac{V_S\ \text{low}-I_cR_2}{R_1+R_2+R_4} - V_{BE}(Q_O)\,\frac{1}{R_1+R_2+R_4}$$

R_4 must be large enough to allow the zener clamp circuit to turn Q_O on in the high-voltage clamp condition without exceeding the current capability of the zener circuit.

$$\text{then } R_2\ \text{Min} \cong \frac{V_{BE}(Q_O) - V_{CE}(\text{sat})(Q_1)}{I_{ZZ}}$$

where I_{ZZ} is the maximum permissible zener current which may be diverted through R_4. (A portion of the total zener current must be used to supply drive to turn Q_O on during clamp conditions.) A value of 5 ohms for R_2 is usually suitable.

The maximum current which Q_1 must handle is:

$$I_{Q1}(\text{max}) \cong \frac{V_S\ \text{high}}{R_1}$$

Where V_S is the highest voltage which will provide acceptable system performance.

The maximum power dissipation in R_1 is:

$$P_{R1}(\text{max}) \cong \frac{(V_S\ \text{high})^2}{R_1}$$

Suitable component parameters for a transistor ignition system are given below:

$R_1=34\ \Omega$ (Fig. 365); $60\ \Omega$ (Fig. 366)
$R_3=75\ \Omega$
$R_2=0.05\ \Omega$
$R_L=0.5\ \Omega$ at 25° C ($0.411\ \Omega$ at −30° C)
$R_4=5\ \Omega$ (Fig. 366)
$I_c=5$ A
V_S low=5.5 V
V_S high=18 V
$V_{CE}(\text{sat})(Q_1) \leq 0.5$ V
$V_{CE}(\text{sat}) \leq 3$ V at $T_A=-30°$ C
$I_c=5$ A
$I_b=0.05$ A
$V_{BE} \leq 2$ V at $T_A=-30°$ C
$I_c=5$ A
$V_{CE}=3$ V
and $I_b \leq 0.136-V_{BE}\times0.043$ (Fig. 365)
$I_b \leq 0.08-V_{BE}\times0.015$ (Fig. 366)

An Automotive Breakerless Ignition System Using a Power Darlington and an Integrated Circuit Control

A breakerless system consists of a distributor with a contactless pick-up, an electronic control unit, and an ignition coil. Operation of the circuit shown in Fig. 368 is based on the accurate amplitude-modulation of a resonant-circuit oscillator in which the inductor acts as the sensor. When the conductive material of a toothed, metallic trigger wheel in the distributor enters the field of the sensor (L), eddy current losses in the non-magnetic wheel-tooth reduce the Q of the resonant circuit and decrease the amplitude of oscillations to a specific level at which discrete transistor Q_a interrupts the coil current. When the oscillator amplitude has decreased below the switching level, a variable-feedback system in the integrated circuit maintains a minimum amplitude of oscillation. This lower amplitude level eliminates timing variations which would occur if the oscillator had to be restarted by random noise. Therefore, either transition may be used to control event timing. The system performance is comparatively independent of dQ/dt; i.e., pulse amplitude and noise immunity are maintained over a wide range of rotor (engine) speeds. In a typical automotive application, capacitor C2 parallel-resonates the circuit at a frequency between 200 and 400 kHz.

An output circuit produces a switching signal ϕ at terminal 4 and its complement ϕ at terminals 6 and 7; signal ϕ is high in response to a high oscillator state. When ϕ is high, the Darlington transistor is driven by base current supplied via resistors R_1 and R_g, so that current flows through the primary winding of the ignition coil. The peak coil current is limited by a "current-setting" transistor Q_a, in response to the voltage-drop developed across current-sampling resistor, R_h.

A spark is generated when ϕ goes low and $\bar{\phi}$ high. Switching is initiated by a low signal at terminal 4; the signal turns transistors Q_b and

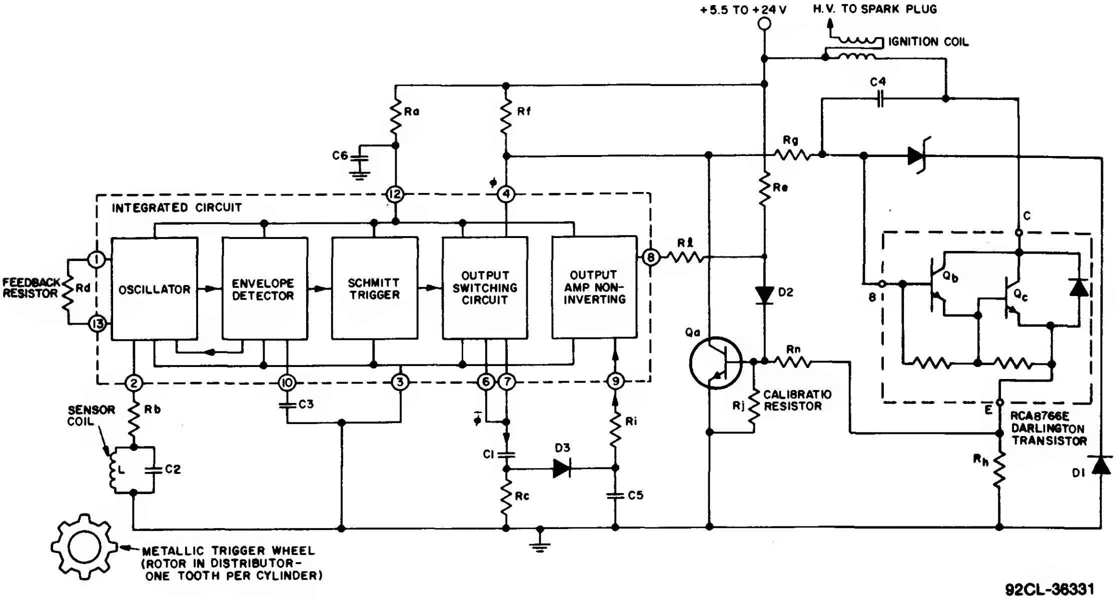

Fig. 368 - Block diagram of the breakerless ignition system.

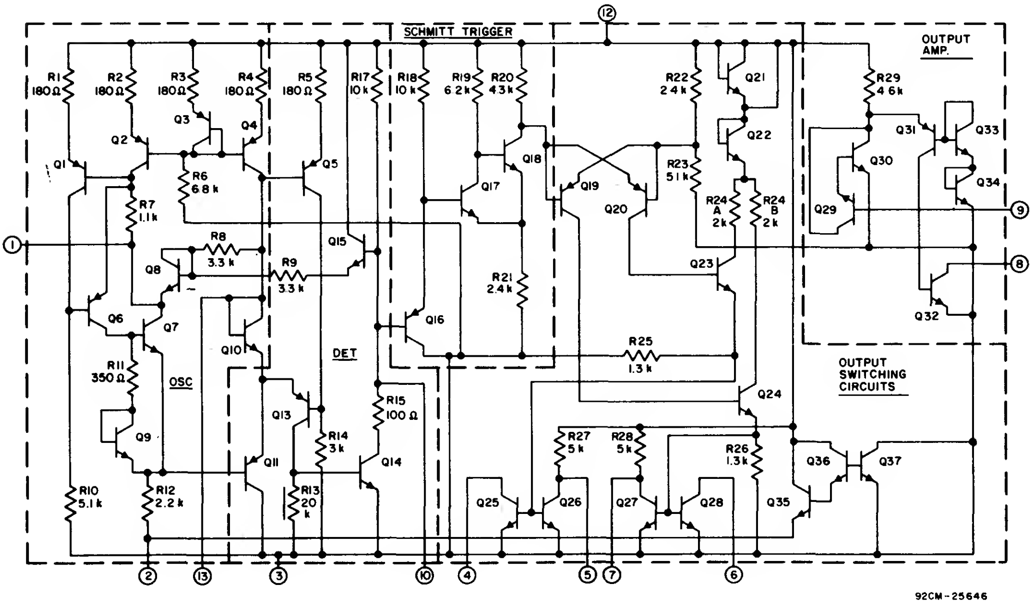

Fig. 369 - Schematic diagram of the integrated circuit.

Q_c off. When the current flowing through the coil primary is interrupted, its stored energy is transferred to the secondary circuit where it produces a high voltage that fires a spark plug. Diode D1 protects Q_b and Q_c against excessive negative voltages and the application of reverse battery voltage. Although noise produced by the spark is suppressed to meet the applicable standards, an additional circuit consisting of C_1, R_c, D_3, C_5, R_1, and the output amplifier in the integrated circuit assures that noise will not affect the switching.

Description of the Integrated Circuit

The block diagram of the integrated circuit is shown in Fig. 368. Fig. 369 shows the schematic diagram. The 0.063 × 0.075-inch chip, is contained in a 14-lead dual-in-line plastic package.

The basic oscillator is of the tuned collector type, with emitter feedback. It comprises transistors Q6, Q7, Q11, associated current-sources, and external integrated circuit. Transistors Q13 and Q14 constitute an active envelope detector. The auxiliary feedback circuitry mentioned above consists of diode-connected Q8, R9, and R8: it is actuated when the output of the detector goes high as the oscillator amplitude decreases. In the low-amplitude state when diode-connected Q8 is turned on, additional feedback is provided to the oscillator through resistor R8.

The Schmitt trigger circuit utilizes transistors Q16, Q17, Q18 and resistors R19, R20, and R21. It is isolated from the envelope detector by transistor Q16 and current-limiting resistor R18. The two threshold voltages are developed across resistor R21; the high threshold voltage is developed when Q18 is driven to saturation.

Transistors Q19 and Q20 develop signals with 180° phase difference; transistor Q20 controls the ϕ-signal at terminal 4, and Q19 controls the $\overline{\phi}$-signal at terminals 6 and 7. Transistors Q29, Q30, and Q32, the active transistors in the output amplifier, provide the noise immunity feature described above.

Since terminal 2 leads into the distributor, it it is imperative that protection against spurious transients which might otherwise damage the integrated circuit be provided. A degree of transient attenuation is supplied by resistor R_b, Fig. 368. Additional protection is provided on-chip by transistors Q35, Q36, and Q37.