Employ pulse-width modulators in a wide range of controllers

Generally considered a power-supply controller, the pulse-width modulator suits many other applications such as lamp-intensity control and motor-speed regulation.

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By applying the pulse-width-modulator (PWM) capabilities that serve so well in high-efficiency power supplies, you can control many diverse functions. PWM ICs such as the LM3524 contain several operational blocks (see **box**, "A pulser plus"), giving them the versatility to simplify control tasks.

Level a lamp's luminosity

As a first example, consider what happens when evaluating optoelectronic sensors or trying to accurately duplicate a 35-mm color slide. The light source used must maintain constant intensity. **Fig 1** demonstrates how you can combine a PWM with a photodiode/amplifier stage to servo-level a lamp's output intensity and thereby meet this need.

In this design, the LF356 op amp functions as a current-to-voltage converter. Thus, as the lamp's output increases, the resulting higher radiant energy causes the photodiode to draw more current out of the op amp's summing junction. The amp responds by generating a positive-going output voltage that feeds back into the input and re-establishes the summing junction's requisite zero balance.

The op amp's output voltage—a function of the photodiode's light-induced current flow—also feeds the PWM's on-chip error amplifier. This amplifier compares the unknown voltage at pin 1 with the intensity-control value set by the 2.5-kΩ potentiometer. (Note that the reference voltage for the intensity setting comes from the PWM's on-chip 5V supply.) This error voltage, amplified by approximately 70 dB as determined by the 1-MΩ resistor loading pin 9, controls the PWM's ON time.

In addition to the 1-MΩ resistor, a 0.001-µF capacitor loads pin 9. This RC combination provides the feedback loop with the proper frequency compensation

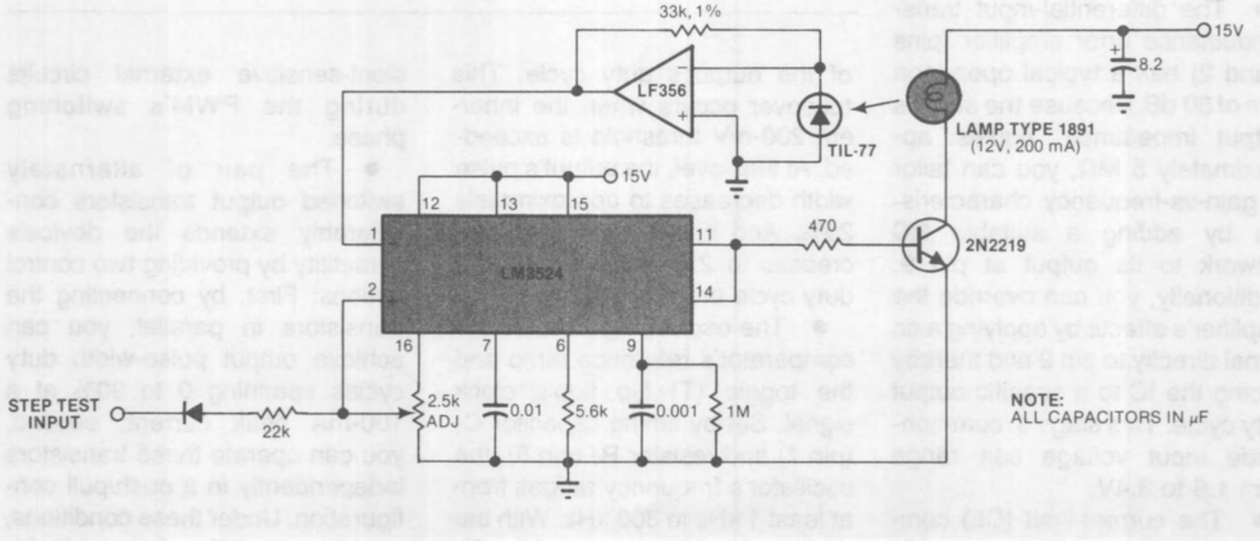


Fig 1—A lamp's intensity remains constant *when you drive the lamp with a pulse-width modulator (PWM) in an optical closed-loop feedback scheme. Here the PWM's ON time is controlled by comparing a photodiode's output with a preset intensity reference level.*

Pulse-width-modulate a lamp to keep its brightness constant

by rolling off with a 1-msec time constant. Similarly, the 5.6-kΩ/0.01-μF combination connected to pins 6 and 7 sets the PWM's oscillator frequency to about 30 kHz.

The lamp is driven by a combination of the IC's on-chip transistors and a discrete 2N2219. **Fig 2a** shows the design's servo action; note that when the 2N2219's collector pulses ON (upper trace), the LM356's output ramps up rapidly (lower trace). But when the drive

ramps up rapidly (lower trace). But when the drive-

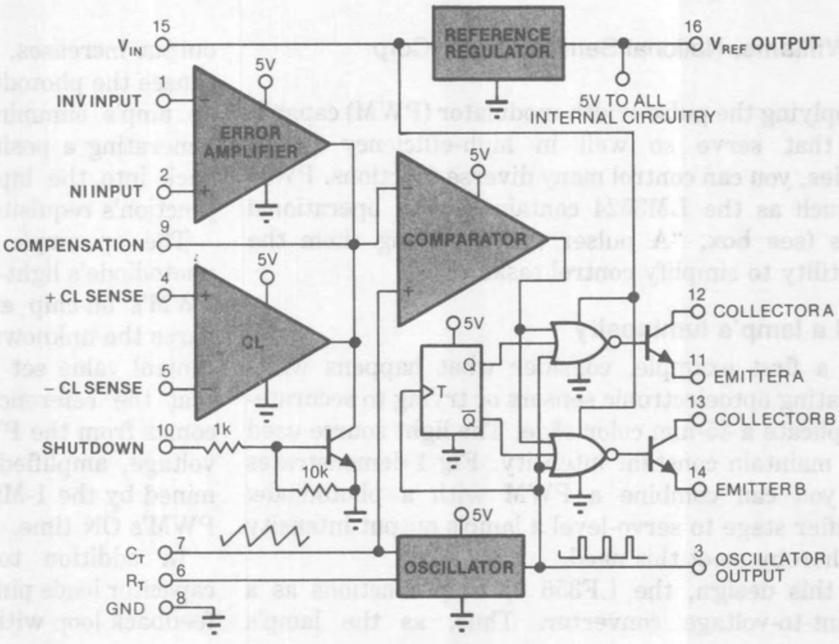
transistor turns off, the resultant negative-going signal ramps much slower because the lamp accepts energy more readily than it gives energy up.

Figs 2b and **c** better illustrate the lamp's action. Here the servo loop is artificially upset by introducing an external pulse via **Fig 1**'s circuit's Step Test port. As shown in **Fig 2b,** when the input pulse (upper trace) goes HIGH, the diode blocks any bias injection, and the op amp's output (lower trace)—and therefore the lamp's brightness—remains constant. However, when the input pulse goes LOW, current flows out of the intensity-control potentiometer's wiper via the 22-kΩ

A pulser plus

Pulse-width-modulator (PWM) ICs—such as the LM3524—include several on-chip function blocks that aid application to circuit designs other than regulated power supplies. By gaining an understanding of these circuits' operation, you'll discover how to employ a PWM in many applications.

The **figure** depicts the PWM's major functions:



Pulse-width-modulator ICs *contain several sense-and-control function blocks that extend the device's capabilities to other application areas. Error-voltage-amplifying, current-sensing and logic-level-shutdown stages are part of the chip's resources.*

- An on-chip voltage regulator supplies a stable 5V, 50-mA output for external usage in addition to handling all on-chip supply requirements. Capable of operating over an input voltage range of 8 to 40V (pin 15), this stage's output (pin 16) varies no more than 30 mV with a varying input. Thus, it provides an excellent reference level for closed-loop feedback schemes.
- The differential-input transconductance error amplifier (pins 1 and 2) has a typical open-loop gain of 80 dB. Because the stage's output impedance equals approximately 5 MΩ, you can tailor its gain-vs-frequency characteristics by adding a suitable RC network to its output at pin 9. Additionally, you can override the amplifier's effects by applying a dc signal directly to pin 9 and thereby forcing the IC to a specific output duty cycle. This stage's common-mode input voltage can range from 1.8 to 3.4V.
- The current-limit (CL) comparator (pins 4 and 5) can override the error amplifier and take control of the output's duty cycle. This takeover occurs when the inherent 200-mV threshold is exceeded. At that level, the output's pulse width decreases to approximately 25%. And if the input signal increases to 210 mV, the output's duty cycle drops to 0%.
- The oscillator generates the comparator's reference ramp and the toggle (T) flip flop's clock signal. Set by timing capacitor C_T (pin 7) and resistor R_T (pin 6), the oscillator's frequency ranges from at least 1 kHz to 300 kHz. With the oscillator's output pulse (pin 3), you can disable ("blank") transient-sensitive external circuits during the PWM's switching phase.
- The pair of alternately switched output transistors considerably extends the device's versatility by providing two control options: First, by connecting the transistors in parallel, you can achieve output pulse-width duty cycles spanning 0 to 90% at a 100-mA peak current; second, you can operate these transistors independently in a push/pull configuration. Under these conditions, you can vary the duty cycle for each device from 0 to 45%.

resistor. This action causes the servo loop to lower the drive level to the lamp proportionately.

Note again how the lamp's ON and OFF times differ. But at high intensity levels, the lamp's on/off characteristics reverse themselves (**Fig 2c**) because the lamp then acts as a more efficient radiant-energy source.

μPs read pulse width vs temperature

In a second application, a μP-based data-acquisition system can directly monitor a wide temperature range, using **Fig** 3's design. The temperature transducer, an LM135 IC, provides a highly linear 10-mV/°K output voltage over its calibrated range of −55 to +150°C. (You can operate the IC to 200°C on an intermittent basis.) The voltage-to-pulse-width conversion circuits—the op amp, PWM and associated networks—can convert any slowly changing 0.1 to 5.0V input signal to a 0 to 500-μsec-wide output pulse with 0.1% linearity. Thus, this scheme satisfies many data-acquisition requirements without modification; just connect an unknown signal to the 100-kΩ input resistor.

In **Fig** 3's configuration, the input resistor string divides down the temperature transducer's output and applies it to the op amp's noninverting (+) input. This positive input voltage, once amplified, directly drives the PWM's on-chip comparator. (The on-chip error amplifier isn't used because its limited common-mode input range of 1.8 to 3.4V can't encompass the overall design's full capability. The off-chip LM358, on the other hand, handles inputs down to 0V.)

The PWM responds to a variable input voltage by generating a variable-width output pulse: 0.1V yields a zero-width output pulse and 5V produces a 500-μsec-wide output. The resulting TTL-compatible output pulse is clipped to 1.235V by the LM185 and integrated by the 1-MΩ/0.1-μF network. This dc feedback voltage gets summed at the op amp's inverting (−) input and linearizes the voltage-to-pulse-width conversion. (The 1000-pF feedback capacitor provides loop stability.) Adjusting the converter to data-acquisition requirements proves simple: Trim the 5-kΩ potentiometer for the proper pulse width at a known input temperature.

Pulse-width-control an oven

Fig 4 shows how you can regulate an oven's temperature using just the pulse-width-modulator chip. Here, a platinum resistance temperature detector (RTD) functions as the variable element in a resistive-bridge circuit. When you first apply power, the RTD—with its positive temperature coefficient—has a lower resistance than the corresponding 2-kΩ resistor in the bridge, and as a result, the LM3524's + input is at a more positive voltage than its inverting input. This imbalance forces the PWM's output pulse to its maximum value of 90%; it also turns on the 2N3507 power transistor and thus the oven's heater. When the oven reaches its operating temperature, the servo shuts down to the value needed to maintain temperature equilibrium.

The 330-kΩ/4.7-μF combination sets the servo's gain

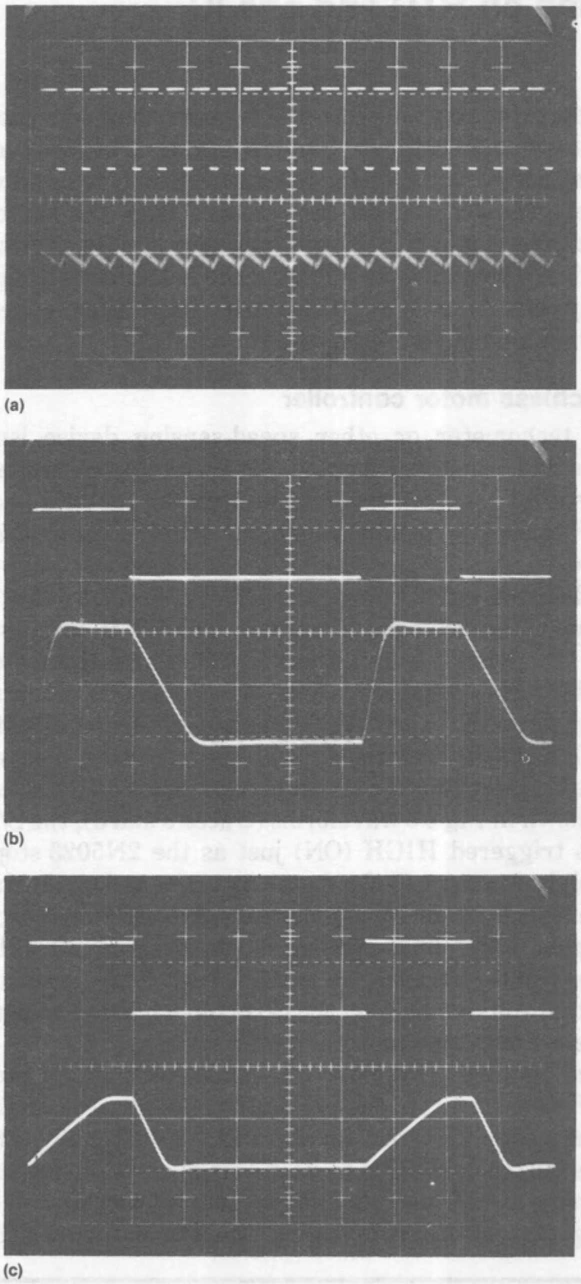


PHOTO	TRACE	VERTICAL	HORIZONTAL
(a)	UPPER	10V/DIV	100 μSEC/DIV
	LOWER	0.005V/DIV (ON 1V DC LEVEL)	
(b)	UPPER	5V/DIV	1 mSEC/DIV
	LOWER	0.05V/DIV (ON 1V DC LEVEL)	
(c)	UPPER	5V/DIV	1 mSEC/DIV
	LOWER	0.05V/DIV (ON 1V DC LEVEL)	

Fig 2—A closed-loop-servo design *closely tracks and corrects for a lamp's changing intensity. As shown in* ***(a)****, when* ***Fig 1****'s lamp-driver transistor pulses ON (upper trace), the loop amplifier's output starts ramping up to re-establish the loop's stability. Note how the lamp's turn-on time is shorter than its turn-off time when operating at low intensity levels* ***(b)****. This situation reverses* ***(c)****, however, at high output levels.*

Hold an oven to within 0.1°C using an RTD and one IC

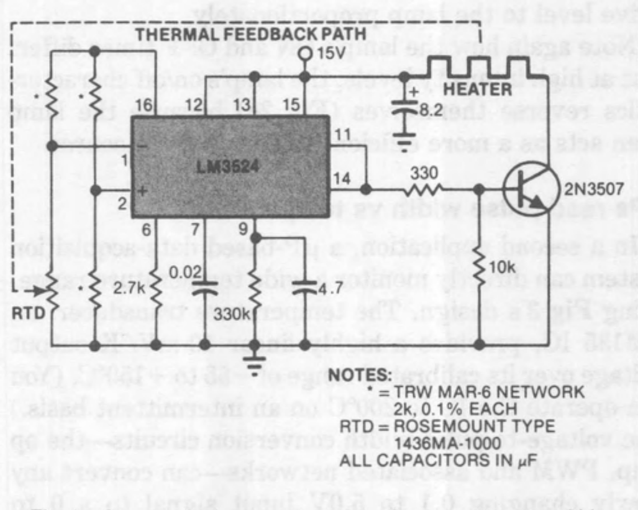
to approximately 55 dB at 1 Hz—more than adequate for most applications. Similarly, the 2.7-kΩ/0.2-µF timing components set the pulse's frequency to approximately 15 kHz, a point far removed from the servo's 1-Hz pole frequency. If you maintain a close thermal proximity between the RTD and the heater, this design easily maintains a 0.1°C control point over widely varying ambient temperatures.

A tachless motor controller

A tachometer or other speed-sensing device isn't necessary when you employ **Fig 5**'s motor controller. Instead of a tach, this scheme uses the motor's back EMF to bias the feedback loop that governs the motor's speed.

When you apply power, the PWM's + input lies at a higher potential than its − input. The PWM outputs a 90% ON pulse that (via the 2N5023) starts the motor turning (**Fig 6**) and feeds the 1000-pF/500-kΩ differentiator network. The LM393 compares this level with the PWM's 5V reference, and the resulting delayed pulse triggers the LF198 sample-and-hold (S/H) device. As shown in **Fig 6**'s waveforms (traces b and d), the S/H IC is triggered HIGH (ON) just as the 2N5023 stops supplying current to the motor (traces a and c). At this instant, the motor coils generate a flyback pulse that's damped by the shunt-opposed diode. But even after the flyback pulse decays, the motor's back EMF remains, and this voltage, held by the S/H chip when the trigger pulse ceases, then controls motor speed.

The 10-kΩ/4-kΩ divider attenuates the motor's back EMF to ensure that the S/H output doesn't exceed the PWM's common-mode input range. Additionally, the S/H's output is filtered to keep things quiet during the sampling period and clamped to prevent any negative-going signals from damaging the PWM input. (The S/H's 10-MΩ bleeder resistor prevents the servo from never achieving stability in the unlikely event that the 0.01-µF sampling capacitor charges to a level greater than the motor's back EMF.) The 39-kΩ/100-µF time constant sets the loop's frequency response, and the 60-kΩ/0.1-µF combination determines the pulse-modulation frequency (300 Hz). You avoid overshoot problems and aid the loop's transient response by employing the 2-kΩ resistor divider and diode network; this configuration limits the maximum output duty cycle to 80%.

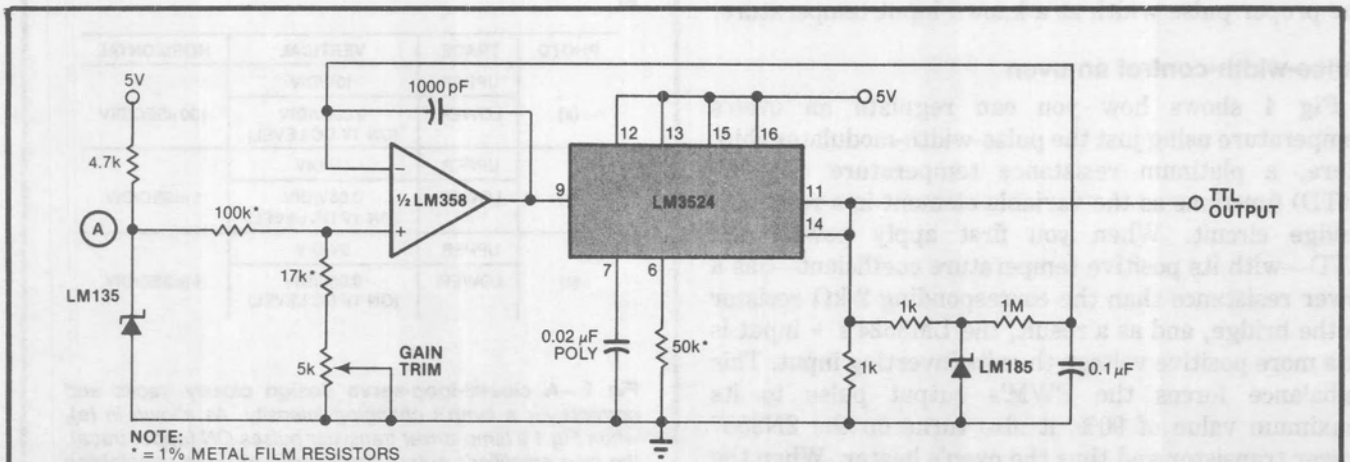


NOTES:
* = TRW MAR-6 NETWORK
2k, 0.1% EACH
RTD = ROSEMOUNT TYPE
1436MA-1000
ALL CAPACITORS IN µF

Fig 4—An oven's temperature remains constant *to within 0.1°C when a pulse-width modulator (PWM) controls the heater's power. Switching at 15 kHz, the PWM obtains the error signal from a platinum resistance temperature detector.*

Supply analog circuits at ±15V

Analog designers interested in the previous circuit seldom have much use for the 5V-only dc power supplies that digital designs thrive on. They will, however, find plenty of use for **Fig 7**'s design; it converts a 5V source into a ±15V, 100-mA supply suitable for analog designs.



NOTE:
* = 1% METAL FILM RESISTORS

Fig 3—Temperature-to-pulse-width conversion *results when an LM135 transducer provides a temperature-dependent error signal directly to the pulse-width modulator's comparator input. The TTL output's pulse width varies from 0 to 500 µsec for a 0.1 to 5V input swing at point A.*

Unlike the previous examples, the LM3524's on-chip output transistors here operate out of phase to provide a pulse-width-modulated push/pull signal to the transformer's driver transistors. Switching at 30 kHz, the transformer's output is rectified and filtered to obtain complementary but unregulated dc output voltages. The 15V output feeds back via an adjustable resistor divider and is compared with a reference voltage by the PWM's error amplifier. (The reference must stay at 2.4V to ensure that the error amplifier operates within its common-mode range.) This feedback loop regulates the +15V output, and an LM137 supplies the −15V.

Overcurrent protection results when the PWM's on-chip current-limit comparator senses a 200-mV level across the 2N2219s' 0.33Ω emitter resistor. When the current exceeds this threshold level, the comparator shuts down the chip's internal drivers and thus the entire converter. You can disable the converter during, for example, power-up sequencing by applying a TTL HIGH at pin 10. **EDN**

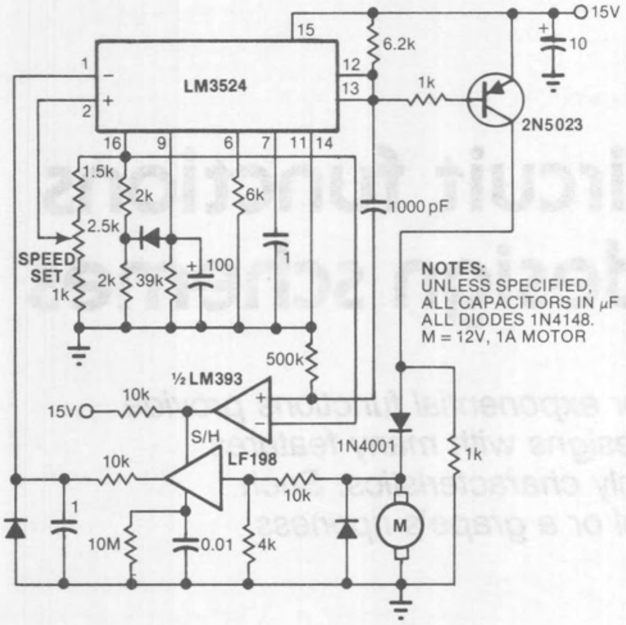


Fig 5—A motor's back EMF *provides the error signal in this motor-speed-control servo loop. After passing through a sample/hold stage* ***(Fig 6),*** *the smoothed error signal feeds the pulse-width modulator's control input.*

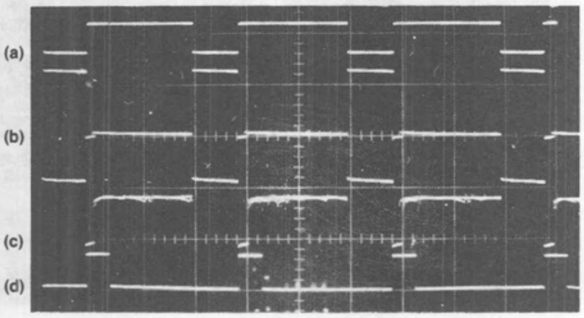


Fig 6—The motor's back EMF is sampled *(traces b and d) at the time* ***Fig 5****'s motor-drive transistor stops conducting (traces a and c). Although the motor generates a flyback pulse when the drive current stops, the remaining back voltage is what's held.*

Author's biography

Jim Williams, applications manager with National Semiconductor's Linear Applications Group (Santa Clara, CA), specializes in analog-circuit and instrumentation development. Before joining the firm, he served as a consultant at Arthur D Little Inc and directed the Instrumentation Development Lab at the Massachusetts Institute of Technology. A former student of psychology at Wayne State University, Jim enjoys tennis, art and collecting antique scientific instruments in his spare time.

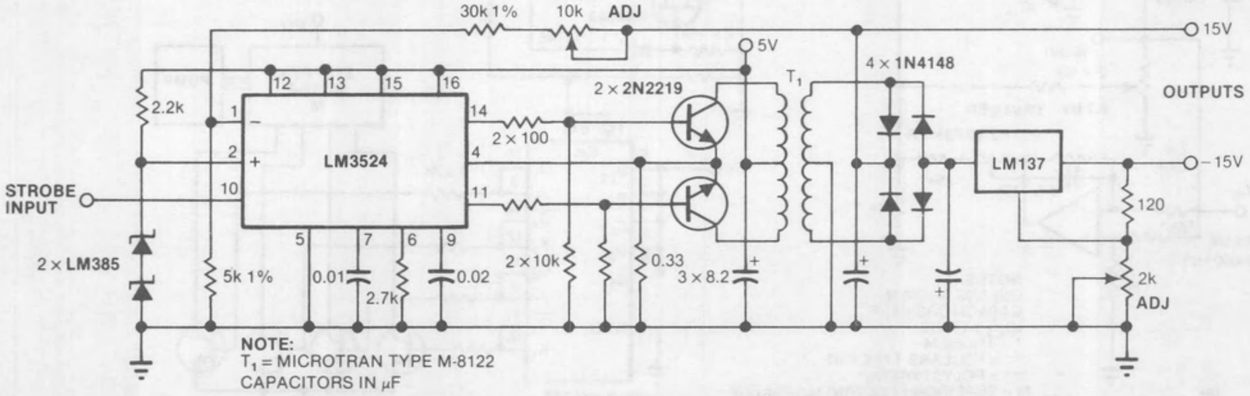


Fig 7—Convert a 5V digital-IC power supply *into a ±15V analog supply by using a pulse-width modulator to control the driver transistor's ON time. The PWM compares the 15V output against a reference and adjusts its output pulse widths accordingly. Overcurrent protection comes from sensing the driver transistors' emitter current, and a TTL-level input permits power-up sequencing.*