WORKING WITH LED DISPLAY DRIVERS

Let's take an in-depth look at LED display drivers.

RAY MARSTON

IT'S EASIER THAN YOU THINK TO DEsign LED display drivers with National Semiconductor's LM391X and LM2917 series IC's. In this article, we'll show you how to use those IC's to build moving-dot and bar-graph voltmeters as well as frequency-to-voltage converters. We'll also give you an introduction to binary coded decimal (BCD) to 7-segment decoder/driver circuits that are commonly used in electronics design.

LM391X-series basics

National Semiconductor's LM391X dot/bar display drivers are versatile 18-pin DIP IC's that can be used to drive up to 10 LED's in either dot or bar mode. The three members of the LM391X display driver series are the LM3914, LM3915, and LM3916. All three versions use the same basic internal circuitry, as shown in Fig. 1, but have different output scaling modes, as shown in Table 1.

The LM3914 is a linearly-scaled device that's intended for use in LED voltmeters, with the number of lit LED's being directly proportional to the input voltage (pin 5). The LM3915 is a logarithmically-scaled device that's intended for use in power meters, and spans a range of 0–30 dB in ten 3-dB steps. Finally, the LM3916 is a semi-logarithmically-scaled device that's intended for use in volume-unit (VU) meters.

Figure 1 shows an LM3914 used in a simple 10-LED voltmeter, which ranges from 0 to 1.25 volts DC. The LM3914 has 10 internal comparators, each with its non-inverting terminal connected to a specific tap on a floating, precision, 10-stage, internal resistive voltage-divider. The inverting terminals on all ten of the comparators are fed by a unity-gain buffer on pin 5. Each comparator is externally accessible, and can sink up to 30 milliamps. The sink currents are internally limited, and are externally pre-set via R1.

The LM3914 also has a floating 1.25-volt DC reference between pins 7 and 8, externally connected to the 10-stage internal voltage divider on pins 4 and

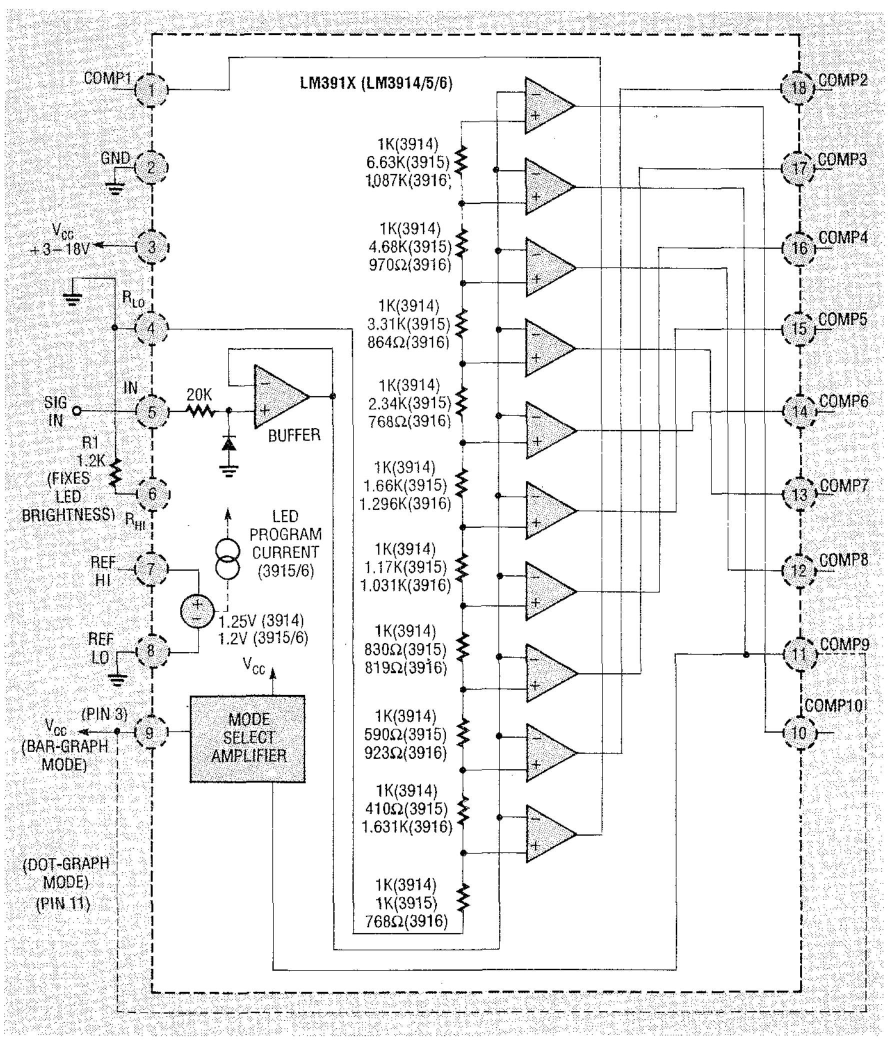

FIG. 1—INTERNAL CIRCUIT OF THE LM3914, with connections for making a 10-LED, 0 to 1.25 volts DC, linear meter using either dot or bar mode.

TABLE 1—COMPARISON OF TYPICAL INPUT THRESHOLDS FOR THE LM391X IC FAMILY

LED	LM3914	LM3915		LM3916		
	V	V	dB	V	dB	VU
1	1.000	0.447	−27	0.708	−23	−20
2	2.000	0.631	−24	2.239	−13	−10
3	3.000	0.891	−21	3.162	−10	− 7
4	4.000	1.259	−18	3.981	− 8	− 5
5	5.000	1.778	−15	5.012	− 6	− 3
6	6.000	2.512	−12	6.310	− 4	− 1
7	7.000	3.548	− 9	7.079	− 3	0
8	8.000	5.012	− 6	7.943	− 2	+ 1
9	9.000	7.079	− 3	8.913	− 1	+ 2
10	10.000	10.00	0	10.000	0	+ 3

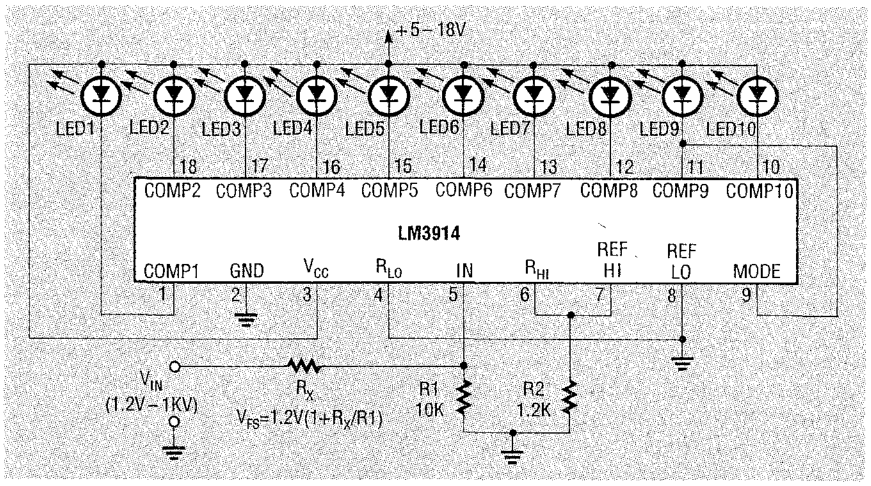

FIG. 2—A MOVING-DOT VOLTMETER with a range of 1.25 volts to 1 kilovolt DC.

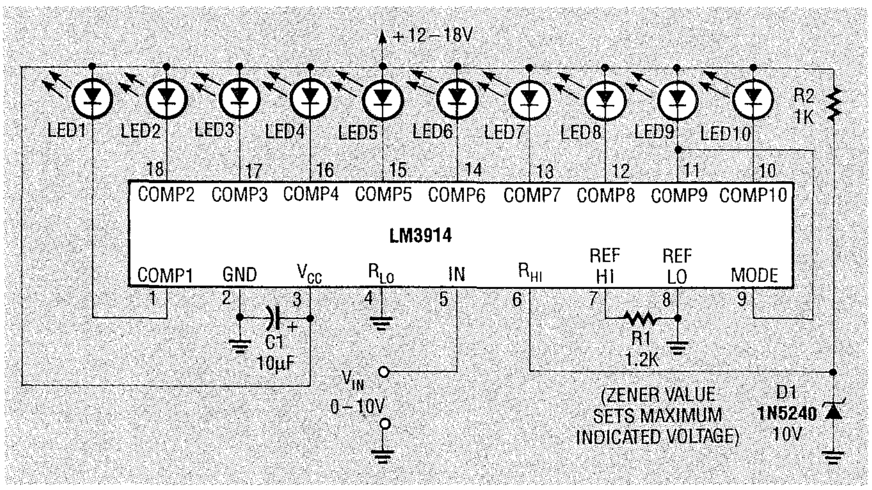

FIG. 3—A VOLTMETER RANGING from 0 to 10 volts DC using an external reference.

6. Pins 4 and 8 are grounded, so that the bottom of the 10-stage internal voltage divider is at ground, and the top is at 1.25 volts DC. The LM3914 also has an internal logic network that can be used to select either moving-dot or bar-graph mode.

If the LM3914 is set for bar mode, the 1.25-volt DC reference is connected across the 10-stage internal voltage divider. Because of the linear scaling of that divider, each succeeding inverting comparator input has an additional 0.125 volts DC applied to it.

When there is no signal on the input, pin 5 is at ground, all 10 internal comparators are disabled, and LED's 1–10 are off. With a slowly rising signal on the input, the voltage increases to 1.25 volts DC, and an LED lights for each 125-millivolt increment, until LED's 1–10 are on. In other words, at the 125-millivolt DC threshold of the first comparator, LED1 lights, at 250 millivolts DC, LED2 also lights, and so on. When used in dot mode, only one LED at a time lights.

Some finer details

In Fig. 1, R1 is connected between pins 6 and 4, fixing the current through each LED. The current through each LED is ten times that drawn from the 1.25-volt DC reference. The 1.25-volt DC reference can source up to 3 milliamps, so the maximum current through each LED is 30 milliamps, set by R1, but the LED current doesn't normally get that high.

The nominal value of 1.25 volts DC can also be varied between 1.20 and 1.32 volts DC, or its value can be externally programmed to produce up to 12 volts DC. If R1 equals 1.2K, then R1 in parallel with the full 10K value of the internal voltage divider is equivalent to 1.07K. The current drawn from the 1.25-volt DC source is

$$1.25\ V/1.07K = 1.2\ mA,$$

so that each LED nominally draws 12 milliamps when it's lit.

Since the maximum individual current through each LED is 30 milliamps, then the LM3914 draws up to 300 milliamps total in bar mode with LED's 1–10 on. The maximum power rating of an LM3914 is only 660 milliwatts, which can easily be exceeded in bar mode if you're not careful. The LM391X series runs on a supply of 3–25 volts DC, and the LED's can use the same voltage supply, or they can use an independent supply for minimal IC heat dissipation.

The internal voltage divider is floating, with both ends externally available for maximum

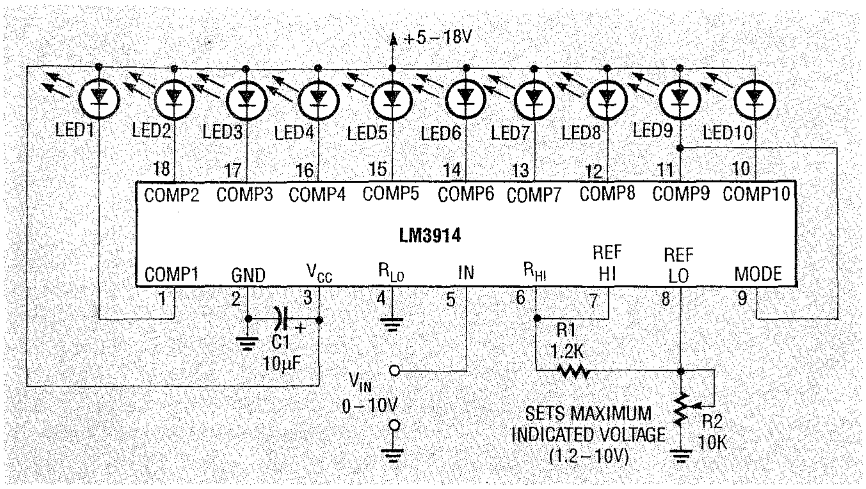

FIG. 4—AN ALTERNATE VARIABLE-RANGE voltmeter that can allow a variation in the maximum value of its range from +1.25 to 10 volts DC.

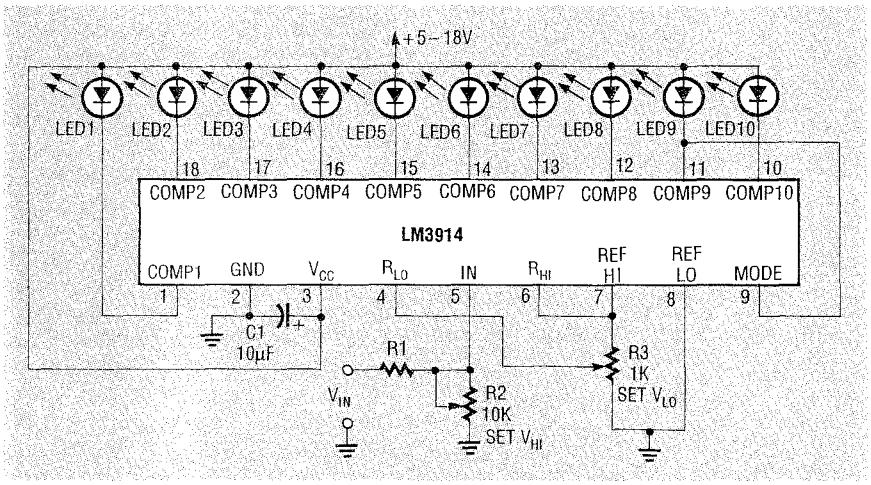

FIG. 5—AN EXPANDED-SCALE MOVING-DOT voltmeter that ranges from 10 to 15 volts DC.

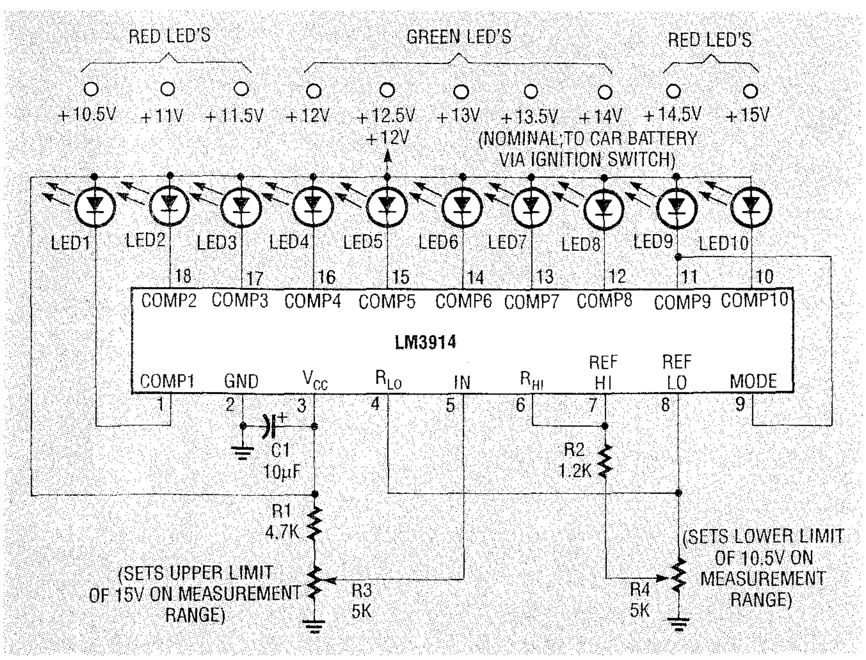

FIG. 6—AN EXPANDED-SCALE DOT-GRAPH voltmeter for use with a car battery.

versatility, and it can be powered by either the internal reference or an external source. If pin 6 is connected to 10 volts DC, then the LM3914 becomes a voltmeter ranging from 0 to +10-volts DC if pin 4 is grounded, or a restricted-range DC voltmeter ranging from 5 to 10 volts DC if pin 4 is connected to 5 volts DC.

The only constraint is that pin 4 cannot go more than 2 volts below V_{CC}. The input is fully protected against overloads up to ±35 volts DC.

As we mentioned earlier, the major difference between the three members of the LM391X family is in the weighting of the ten-stage internal voltage dividers. In the LM3914, the values are equal, producing a ten-step linear display. In the LM3915, the values are logarithmically-weighted, producing a log display spanning 30 dB in ten 3-dB steps. The values are semi-logarithmically weighted in the LM3916, producing a volume unit (VU) meter display. Let's now examine some LM391X applications, focusing on the LM3914.

Moving-dot voltmeters

Figures 2–6 show the LM3914 used in various 10-LED moving-dot voltmeters. In all of them, pin 9 is connected to pin 11, and a 10 µF capacitor is connected between pins 2 and 3 for stability.

Figure 2 shows a variable-range moving-dot voltmeter that can cover a range of 1.25 volts to 1 kilovolt DC. The low ends of the internal reference and the 10-stage internal voltage divider are grounded, while the top ends are joined. The voltmeter has a basic full-scale sensitivity of 1.25 volts DC, with variable ranging provided by voltage divider Rx-R1. When Rx equals 0 ohms, the full-scale value is 1.25 volts DC, and when Rx equals 90K, the full-scale value is 12.5 volts DC. Also, R2 is connected across the internal reference and sets the current through each LED at 10 milliamps, as before.

Figure 3 shows a fixed-range moving-dot voltmeter that can

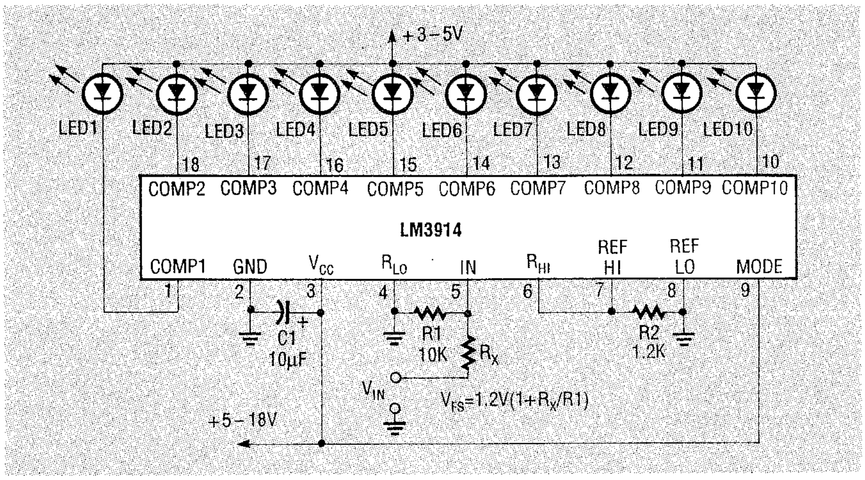

FIG. 7—A BAR-GRAPH VOLTMETER USING a separate supply for LED's 1–10.

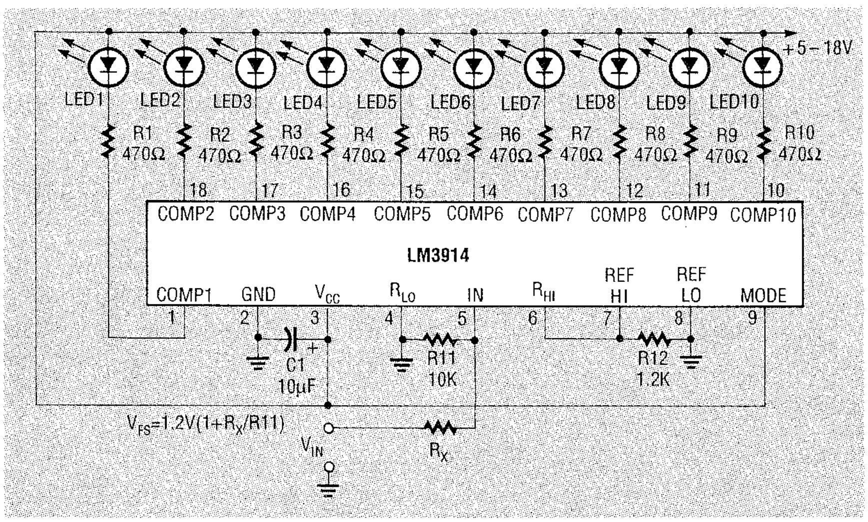

FIG. 8—A BAR-GRAPH VOLTMETER USING a common supply for both IC1 and LED's 1–10.

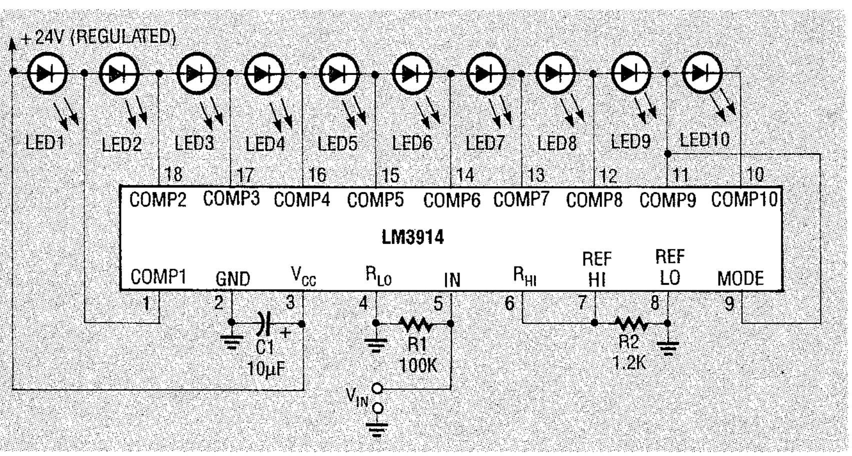

FIG. 9—A BAR-GRAPH USING dot-mode operation and consuming minimal current.

cover a range of 0 to 10 volts DC. It uses an external Zener diode reference D1 going to the top of the 10-stage internal voltage divider for a 10-volt DC reference. Also, the supply must be at least 2 volts DC above the Zener reference level, or a value of

$$V_{CC} = V_{D1} + 2\ V$$
$$= 10\ V + 2\ V,$$
$$= 12\ V.$$

Figure 4 shows an alternate voltmeter with its internal reference providing a variable voltage for a full-scale value ranging from 1.25 to 10 volts DC. The 1.2-milliamp current fixed by R1 goes to ground via R2, raising the reference value on pins 7 and 8 above zero. If R2 equals 2.4K, then pin 8 will be at 2.50 volts DC, and pin 7 at 3.75 volts DC. Thus, R2 lets pin 7 be varied from 1.25 to 10 volts DC.

Figure 5 shows an expanded-scale moving-dot voltmeter that can cover a range of 10 to 15 volts DC. Here, R3 sets the current through each LED at 12 milliamps, and enables a reference level of 0 to 1.25-volts DC to be set on pin 4, the low end of the 10-stage internal voltage divider. If R3 is set for 0.8 volts DC on pin 4, then the voltmeter will read in the range of 0.8 to 1.25 volts DC only. By designing voltage divider R1-R2 for a specific circuit, the range can be amplified as desired.

Figure 6 shows an expanded-scale moving-dot voltmeter that's intended for use in your car to continually measure the status of its 12-volt battery. Here, R2-R4 provides a basic range of 2.50 to 3.75 volts DC, but the input is derived from the positive supply via R1-R3. The reading thus corresponds to a pre-set multiple of the basic range value. The display uses red and green LED's, with the green LED's lighting when the V_{CC} range is within 12 to 14 volts DC. The red LED's light with 10 to 15 volts DC.

To calibrate the voltmeter, set V_{CC} to 15 volts DC, and adjust R3 so that LED10 just turns on. Next, reduce V_{CC} to 10 volts DC, then adjust R4 so that LED1 just turns on, and then recheck both R3 and R4. Finally, place the voltmeter between ground and the 12-volt-DC lead on the ignition switch.

Bar-graph voltmeters

The moving-dot voltmeter versions of Figs. 2–6 can be made into bar-graph voltmeters by connecting pin 9 to pin 3 instead of to pin 11. However, as we mentioned earlier, don't exceed the IC power rating in bar mode with excessive output voltages when LED's 1–10 are on. Figure 7 is a bar-graph voltmeter that uses a separate supply for its ten LED's.

Most LED's drop about 2 volts when on, so one way around that problem is to use a separate 3 to 5-volt DC source for them, as shown in Fig. 7. Figure 8 is another variation of the bar-graph voltmeter using the same supply for the LM3914 and the ten LED's. If you use the same supply to operate both the IC and the LED's, then be sure to use a current-limiting resistor in series with each LED as shown in Fig. 8, so the IC output terminals saturate when they are lit.

Figure 9 shows another bar-graph display, one that doesn't exhibit excessive power loss. Here, LED's 1–10 are all in series, but each one is connected to an individual IC output, and the IC is in dot mode. Thus, if LED5 was on, its current would be drawn through LED's 1–4, so LED's 1–5 would also be on, creating a bar-graph display. In that case, the total current through all of the LED's is that of a single LED, so the total power dissipation is very low.

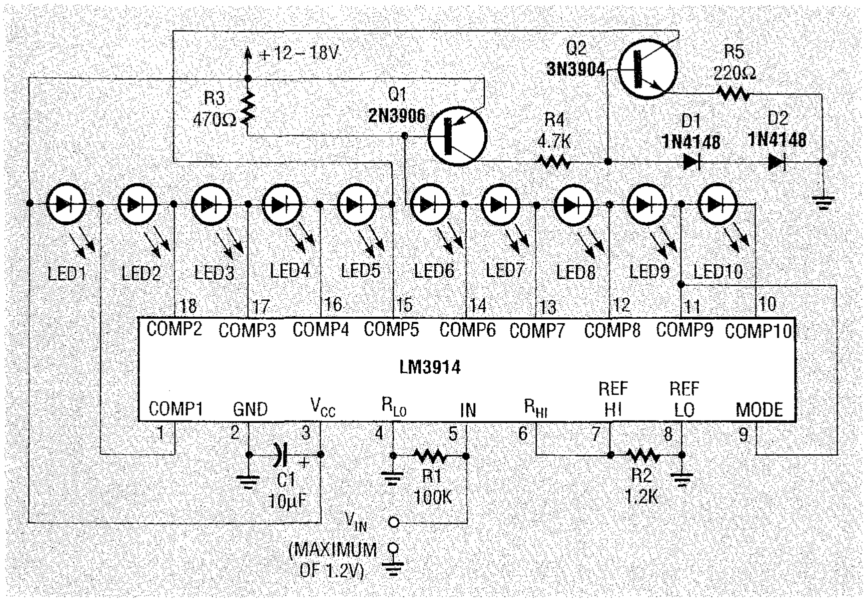

FIG. 10—A MODIFICATION OF THE VERSION in Fig. 9, using an unregulated 12 to 18-volt DC supply.

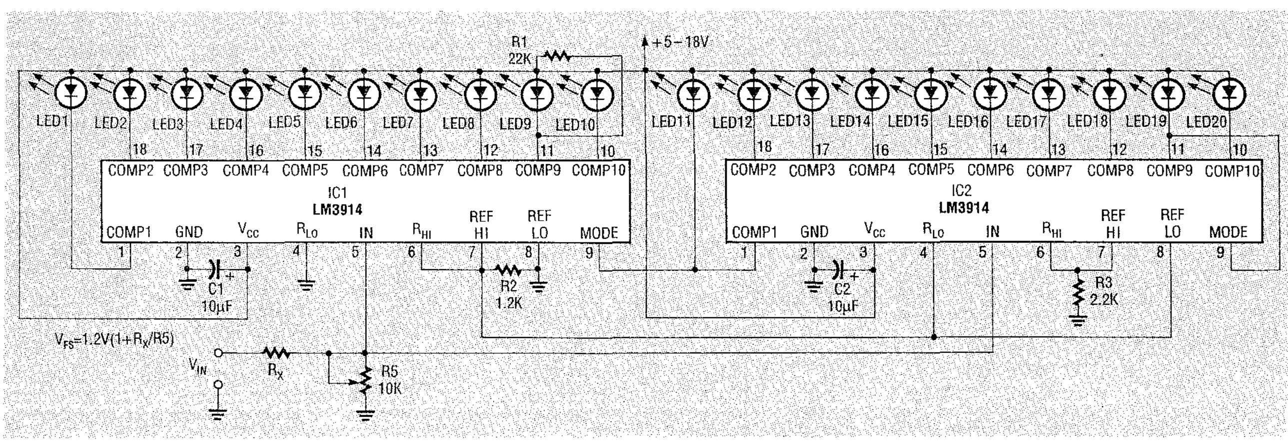

FIG. 11—A MOVING-DOT 20-LED VOLTMETER that ranges from 0 to 2.56 volts DC when Rx equals 0 ohms.

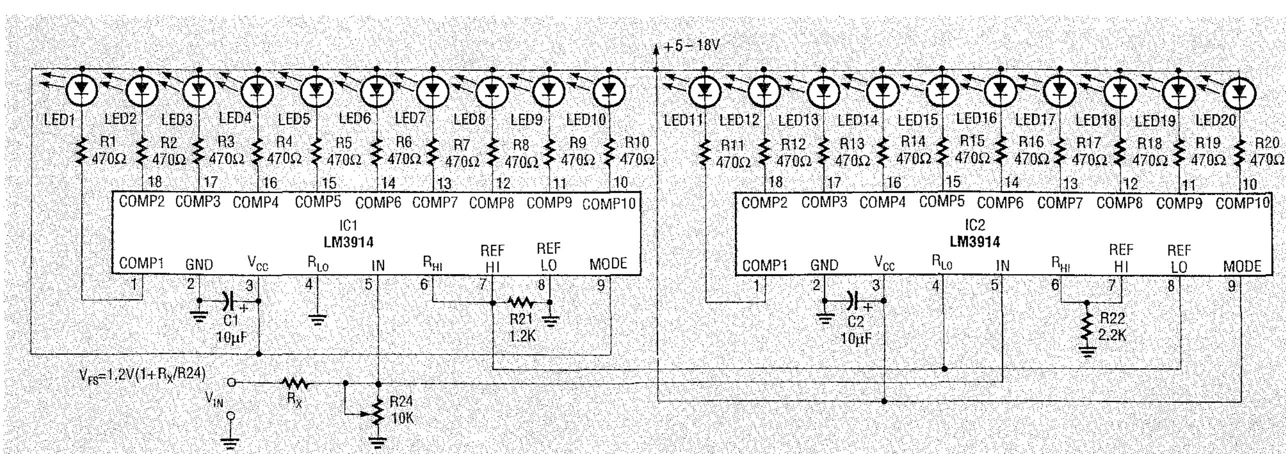

FIG. 12—A BAR-GRAPH 20-LED VOLTMETER that ranges from 0 to 2.56 volts DC when Rx equals 0 ohms.

The supply for the LED's has to be greater than the sum of the total drop with LED's 1–10 on, but within the voltage limits of the IC. Here the V_{CC} is a regulated value of 24 volts.

Figure 10 shows a modification of Fig. 9, using an unregulated V_{CC} ranging between 12 and 18 volts. In that case, LED's 1–10 are split into two chains, with Q1 and Q2 switching LED's 1–5 on when any of LED's 6–10 are active; the maximum total current through the LED's is twice that of a single LED.

The 20-LED voltmeter

The circuit in Fig. 11 uses two LM3914's in a 20-LED moving-dot voltmeter. The inputs of IC1 and IC2 go in parallel, but IC1 reads 0 to 1.25 volts DC, while IC2 reads 1.25 to 2.50 volts DC.

For the latter range, the low end of the 10-stage internal voltage divider in IC2 is connected to the 1.25-volt DC reference of IC1, while the top end is connected to the top of the 1.25-volt DC reference of IC2, 1.25 volts DC above that of IC1. The circuit is in dot mode, with pin 9 of IC1 going to pin 1 of IC2, and pin 9 of IC2 to pin 11 of IC2; note that R1 is in parallel with LED9 of IC1.

Figure 12 shows a 20-LED bar-graph voltmeter that ranges from 0 to 2.56 volts DC. The connections are like those of Fig. 11, except that pin 9 is connected to pin 3 of each IC, and R1–R20 go in series with LED's 1–20 to reduce power dissipation.

Finally, Fig. 13 shows a frequency-to-voltage converter circuit, capable of converting the circuits in either Figs. 11 or 12 into a 20-LED tachometer suitable for use in automobiles. Here, IC1 is a National Semiconductor LM2917 monolithic frequency-to-voltage converter IC connected between the vehicle contact-breaker points (used in older cars) and the input of the voltmeter. In Fig. 13, 0.022 µF is the optimal value of C2 for a 10,000-RPM range on a 4-cylinder, 4-stroke engine. For much lower full-scale speeds, the value of C2 might need to be changed for vehicles that have

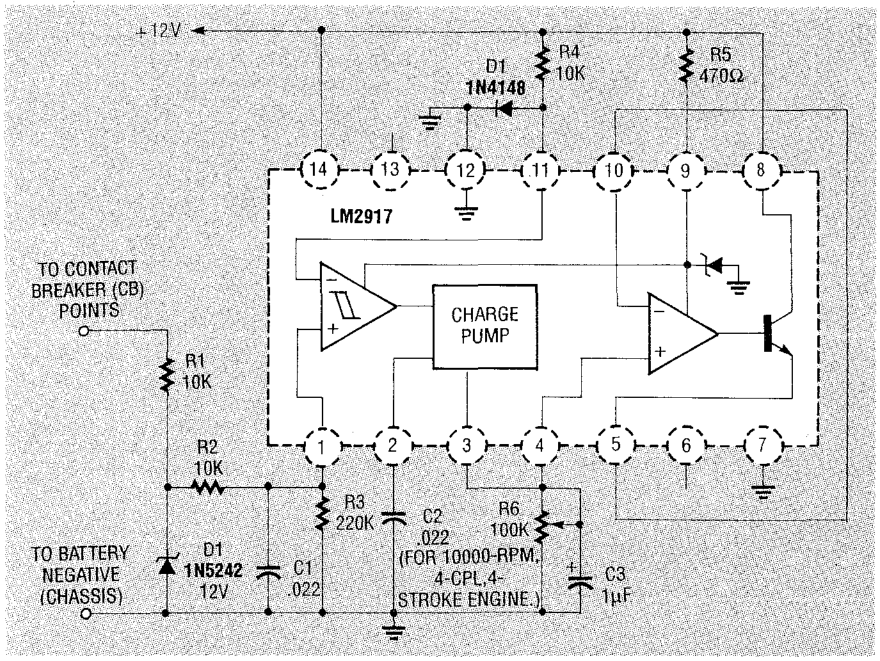

FIG. 13—A CONVERSION CIRCUIT FOR A car tachometer, for use with a 20-LED voltmeter, as shown in Figs. 11 and 12.

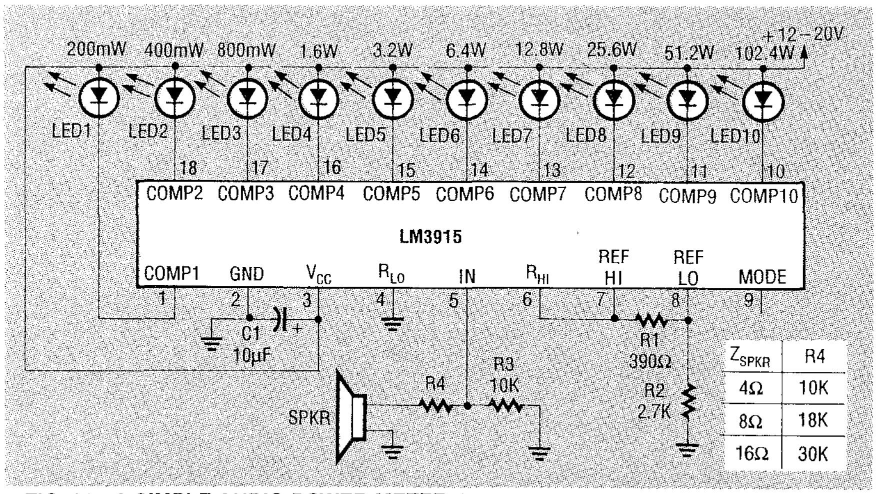

FIG. 14—A SIMPLE AUDIO POWER METER.

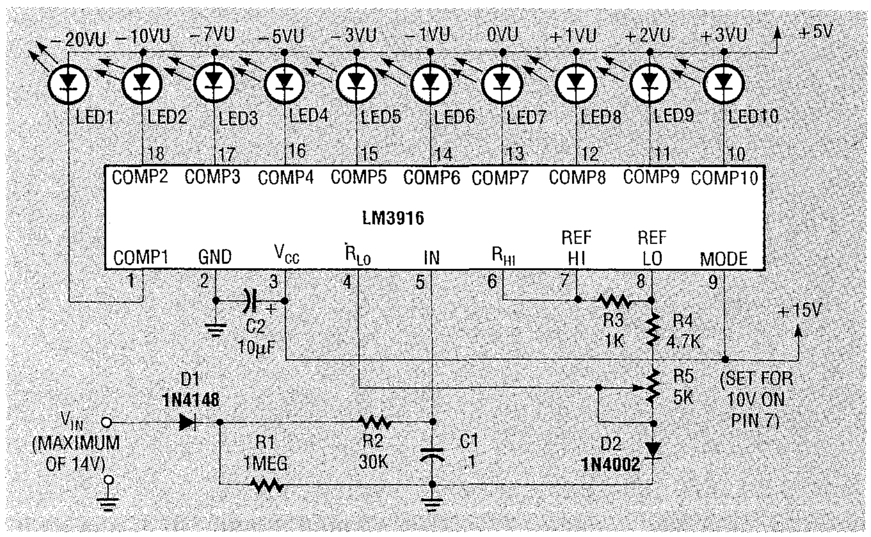

FIG. 15—A SIMPLE VOLUME-UNIT (VU) METER.

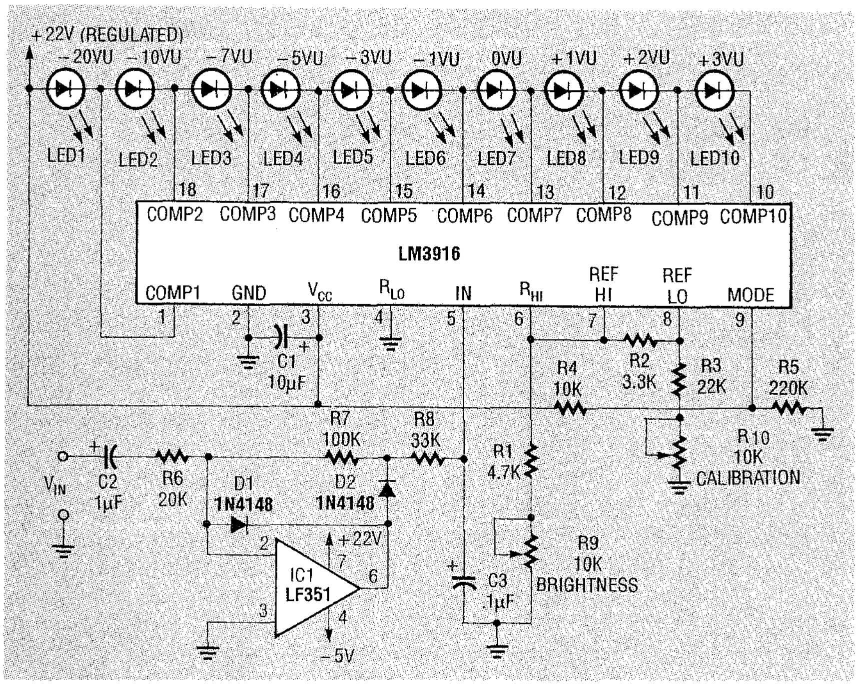

FIG. 16—A PRECISION VU METER with low current drain.

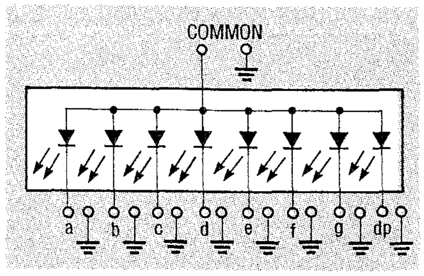

FIG. 19—THE SCHEMATIC OF a common-anode 7-segment LED display.

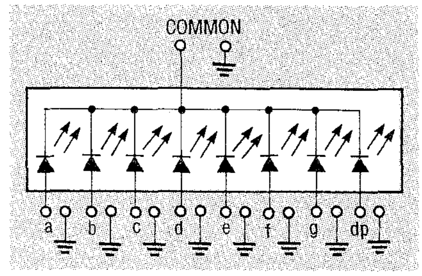

FIG. 20—THE SCHEMATIC OF a common-cathode 7-segment LED display.

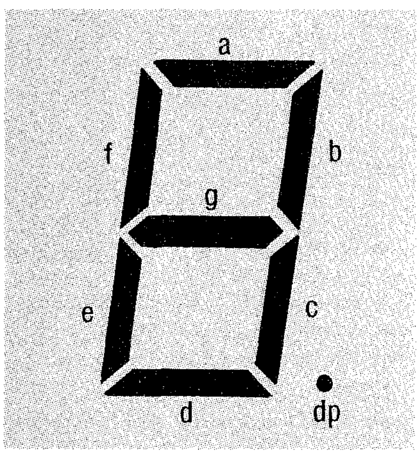

FIG. 17—THE STANDARD CONFIGURATION for a 7-segment LED display.

six or more cylinders.

LM3915 and LM3916 circuits

The LM3915 logarithmic and LM3916 semi-logarithmic versions basically work the same way as the LM3914, and can be directly substituted in most of the circuits shown in Figs. 2–12. The LM3915 and LM3916 will give an LED meter reading for an AC signal going to the input, and respond only to positive halves of the signal, with the number of LED's lit being proportional to the instantaneous peak value. The IC should be in dot mode, and set for 30 milliamps of LED drive.

Figure 14 shows an LM3915-based audio power meter. Pin 9 is left open for dot mode, and R1 equals 390 ohms, for an LED current of 30 milliamps. The range of the audio power meter is 200 milliwatts–100 watts. A better approach is to half-wave rectify the signal on the input and feed in the resulting DC, as shown in the VU-meter circuits of Figs. 15 and 16.

Figure 15, a simple volume-unit (VU) meter, uses an LM3915 in bar mode; the signal at the input is rectified by D1 and filtered by R1-R2-C1, with D2 compensating for the forward drop of D1. Figure 16, a precision VU meter offering low current drain, uses an LM3916, with the combination of IC1-D1-D2 acting as a precision half-wave rectifier.

Also, LED's 1–10 are in series, and IC2 is in dot mode, giving a low-power bar-graph display. To calibrate the audio power meter, adjust R10 for 10 volts DC on pin 7; R9 controls the level of display brightness.

SEGMENTS							DISPLAY	SEGMENTS							DISPLAY
a	b	c	d	e	f	g		a	b	c	d	e	f	g	
1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	8
0	1	1	0	0	0	0	1	1	1	1	0	0	1	1	9
1	1	0	1	1	0	1	2	1	1	1	0	1	1	1	A
1	1	1	1	0	0	1	3	0	0	1	1	1	1	1	b
0	1	1	0	0	1	1	4	1	0	0	1	1	1	0	C
1	0	1	1	0	1	1	5	0	1	1	1	1	0	1	d
1	0	1	1	1	1	1	6	1	0	0	1	1	1	1	E
1	1	1	0	0	0	0	7	1	0	0	0	1	1	1	F

FIG. 18—THE TRUTH TABLE for a 7-segment LED display.

The 7-segment LED display

Alphanumeric displays are used in electronics, in digital watches, pocket calculators, and in test equipment such as multimeters and frequency counters. The most common

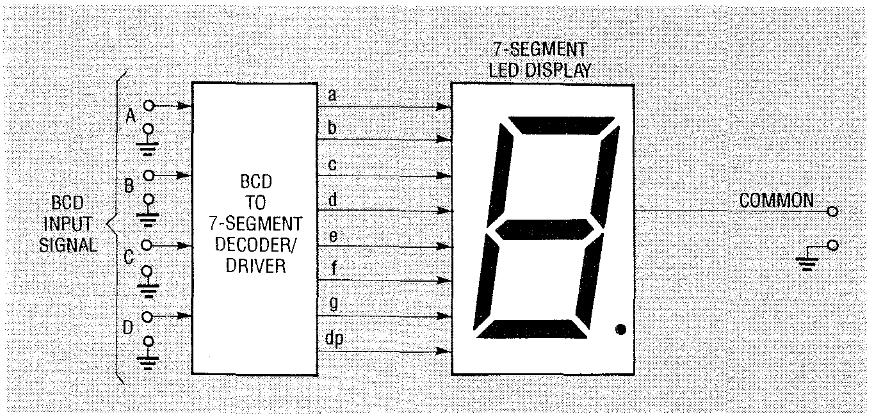

FIG. 21—BASIC CONNECTIONS for a BCD-to-7-segment LED-display decoder/driver.

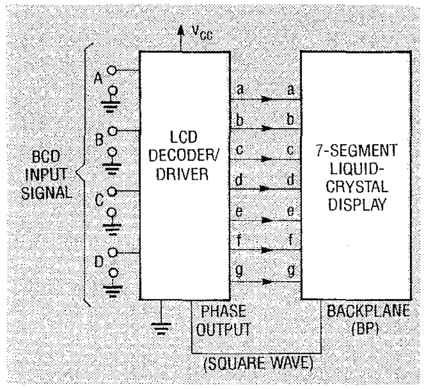

FIG. 25—HERE'S HOW to drive a liquid-crystal display (LCD).

BCD SIGNAL				DISPLAY	BCD SIGNAL				DISPLAY
D	C	B	A		D	C	B	A	
0	0	0	0	0	0	1	0	1	5
0	0	0	1	1	0	1	1	0	6
0	0	1	0	2	0	1	1	1	7
0	0	1	1	3	1	0	0	0	8
0	1	0	0	4	1	0	0	1	9

FIG. 22—THE TRUTH TABLE of a BCD-to-7-segment LED-display decoder/driver.

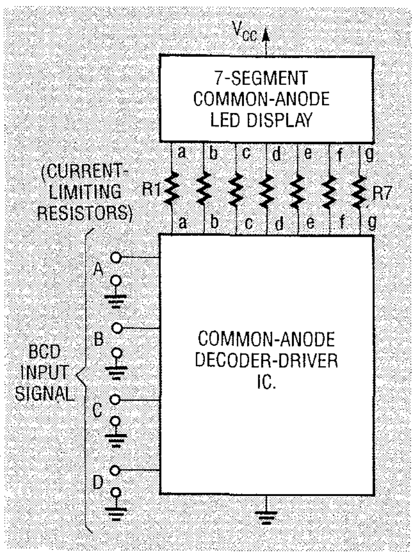

FIG. 23—HERE'S HOW to drive a common-anode 7-segment LED display.

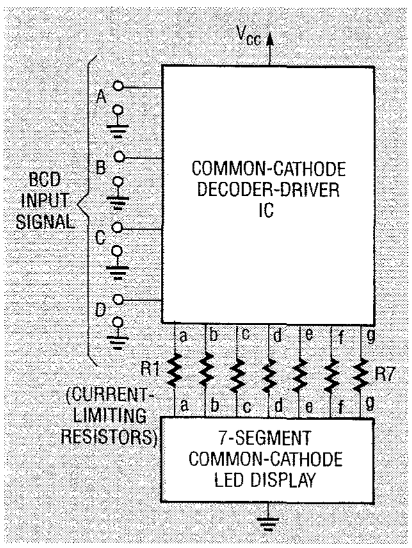

FIG. 24—HERE'S HOW to drive a common-cathode 7-segment LED display.

type of alphanumeric display is the 7-segment LED or LCD display, as shown in Fig. 17. The segments are labeled a–g, and the decimal point is labeled dp. You can display either the digits 0–9, or the letters A–F (a mixture of upper and lower case letters), as shown in Fig. 18.

Most 7-segment LED displays need at least nine external connections. Seven of those connections access the segments, one the decimal point, and the eighth is common. If the display is an LED type, the seven segments are arranged as shown in Figs. 19 and 20. A common-anode version (Fig. 19) has all LED anodes going to common, while a common-cathode version (Fig. 20) is configured in the reverse format.

7-segment display/driver

A 7-segment LED display gives the output states of digital IC's such as decade counters and latches. They are usually internally arranged in 4-bit binary-coded decimal (BCD), and cannot directly drive a display. A special IC called a BCD-to-7-segment LED-display decoder/driver must go between the BCD and the display, as shown in Fig. 21, to convert BCD to a suitable form.

Figure 22 shows the relationship between the BCD representation, and the 7-segment LED-display digits. Normally, BCD-to-7-segment LED-display decoder/driver IC's are available in dedicated form suitable for driving only a special class of displays, whether the display is an LCD, or a common-anode or common-cathode LED display. Figures 23–25 show how such 7-segment LED displays and BCD-to-7-segment LED-display decoder/driver IC's are connected.

Figures 23 and 24 show how to drive common-anode and cathode 7-segment LED displays. Note that if the BCD-to-7-segment LED-display decoder/driver IC outputs are unprotected, as is the case in most TTL IC's, a resistor in series with each segment limits current; most CMOS IC's have such resistors internally. In Fig. 25 you can see how to drie an LCD. The common or backplane (BP) display terminal is driven with a symmetric square-wave, which is derived from the phase output terminal. R-E