Dot/Bar-Graph Display Drivers

New IC's simplify the design of LED displays. They're capable of doing a lot more than that, too!

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THE USE OF MULTIPLE LED'S IN A BAR-graph fashion to display analog signals is becoming increasingly popular. The reasons include low cost, ruggedness, high visibility, ease of interpretation, fast response time, low voltage and current requirements, and long life. No other display technology combines all those advantages. For example, electromechanical meters can have better resolution, but they respond less quickly and are sensitive to shock and vibration. Liquid-crystal displays draw less power but are slow, and difficult to read in dim light. Bar graph displays based on LED's are used in stereo amplifiers for power meters, in tuners for signal-strength indicators, and in cameras for light meters. In all of those examples, the display must be interpreted quickly and easily, but high resolution is not required.

Recently, IC's have been introduced that considerably simplify the task of driving a LED array with analog signals. Examples of those include National Semiconductor's LM3914 and LM3915 LED Dot/Bar Display Drivers. Those extremely versatile devices have a reference, a voltage divider, and ten comparators all on one chip. Besides the LED's, only a few resistors and a capacitor are required to complete the display circuit. Either a bar or dot display (only one LED on at a time) is possible. The on-chip voltage reference is fully regulated, remaining constant while the power supply feeding the IC can be anywhere between 3 volts and 25 volts!

How it works

A block diagram of the LM3914 is shown in Fig. 1 where the IC is wired up as a simple 2.5 volt full-scale meter. The IC's internal reference forces the voltage drop across R1 to 1.25 volts, causing a current equal to 1.25V/R1 or 1.25 mA to flow thru R1 and R2. The small 75-microampere current from pin 8 can usually be neglected so that the voltage at pin 7 is approximately 1.25V × (1 + R2/R1) or 2.5 volts. The display range is set by the voltages at pins 6 and 4, the top and bottom ends of the LM3914's internal voltage divider. For the 0-to-2.5-volt meter shown, pin 6 is wired to the 2.5-volt reference while pin 4 is grounded. The reference load current (I_{REF}) in this example is equal to the 1.25 mA flowing through R1 plus the 0.25 mA flowing through the 10K divider or 1.5 milliamperes total.

The signal to be displayed is applied to pin 5, where it is buffered by a high impedance follower and fed to the inverting inputs of the ten comparators that drive the LED's. The comparators' non-inverting inputs are connected to the taps along the voltage divider. In the LM3914, those taps are all equally spaced. Here, another comparator turns on for every 250-mV increase of the input voltage, lighting up another LED.

Current drive to each LED illuminated is set at ten times the reference-

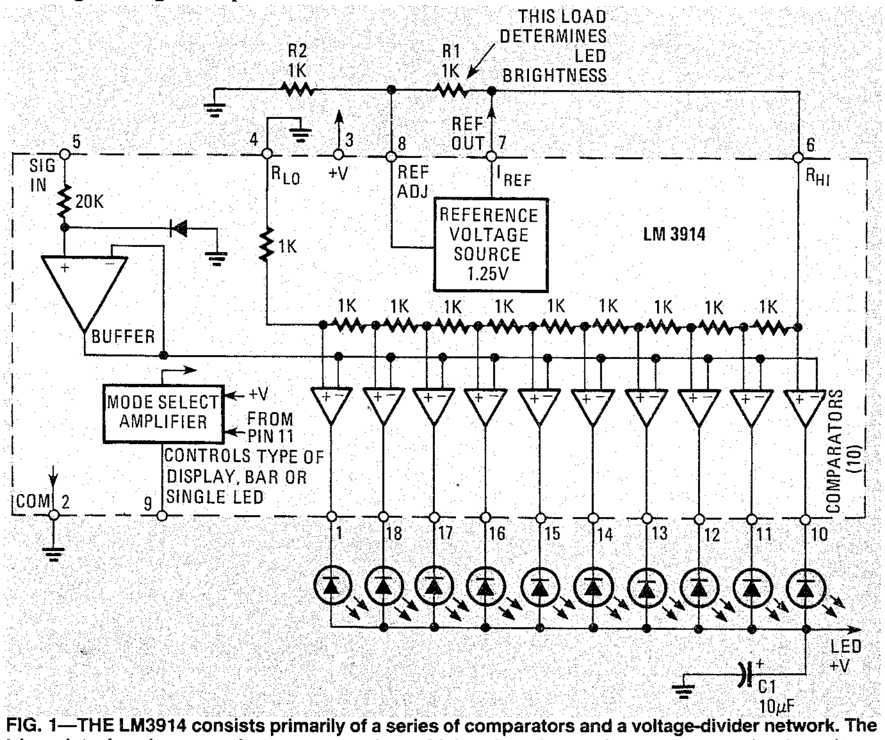
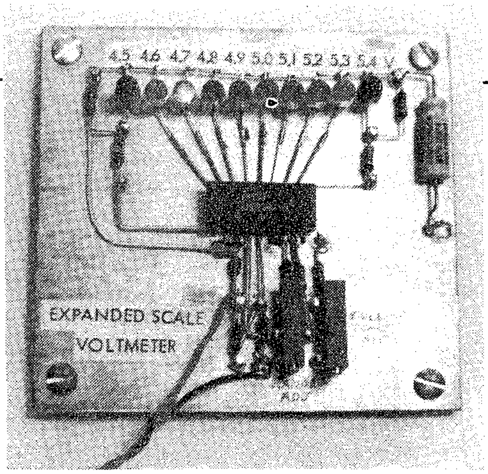
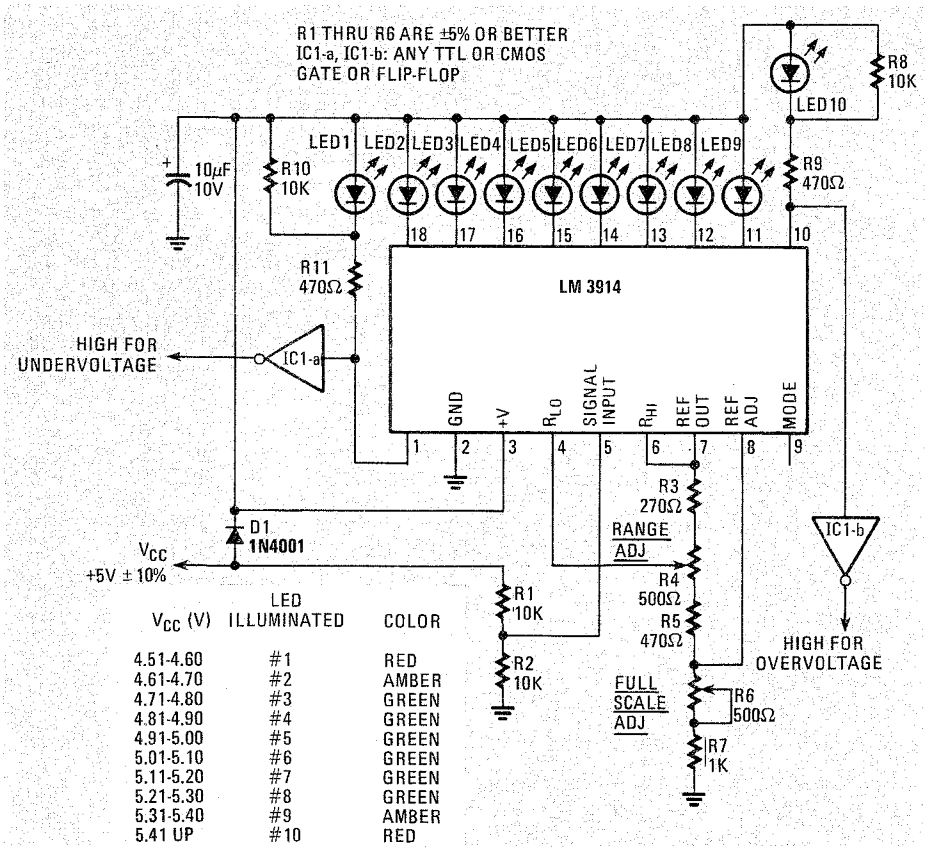


FIG. 1—THE LM3914 consists primarily of a series of comparators and a voltage-divider network. The trip point of each successive comparator is set higher than the previous comparator by the voltage divider. As the input voltage applied to pin 5 increases, the comparators trip in sequence. The comparators, in turn, illuminate their respective LED's.





V_{CC} (V)	LED ILLUMINATED	COLOR
4.51-4.60	#1	RED
4.61-4.70	#2	AMBER
4.71-4.80	#3	GREEN
4.81-4.90	#4	GREEN
4.91-5.00	#5	GREEN
5.01-5.10	#6	GREEN
5.11-5.20	#7	GREEN
5.21-5.30	#8	GREEN
5.31-5.40	#9	AMBER
5.41 UP	#10	RED

FIG. 2—EXPANDED-SCALE VOLTMETER for monitoring the output voltage of a 5-volt logic-power supply. Each LED corresponds to a predetermined voltage, as shown in the chart.

load current (I_{REF}) or 15 mA in this example. Generally, LED currents from 10 to 20 mA produce adequate brightness. A pot in series with a resistor connected from pin 7 to ground makes a simple intensity control, since it varies I_{REF} without affecting the reference voltage. Trimming the reference output voltage can be accomplished by varying R2.

For a DOT-mode display, pin 9 may be left open; for BAR-mode, pin 9 is connected to the LED supply, which can be different from the IC's V^+. Watch the IC's power dissipation in BAR mode, however. At 15 mA per LED, the LED supply should be no higher than 6 volts. To power the LED's from a higher-supply voltage, place a dropping resistor between the LED anodes and the supply. The LED supply should always be bypassed with a 10 μF electrolytic capacitor to prevent oscillations. The LM3914's ^+V supply (pin 3) must be at least 1.5 volts above the pin 7 reference output and can be as low as 3 volts when the reference is run at 1.25 volts (pin 8 grounded).

Simple voltage monitor for TTL

The LM3914's low voltage-requirements and flexibility make for some interesting applications. Figure 2 shows an expanded-scale voltage monitor for a TTL system that runs off the same single 5-volt supply it monitors! As shown in the table, each LED covers a 100-mV range from 4.5 to 5.5 volts. A simple two-step calibration is all that's required.

Here the supply voltage is attenuated by a factor of two and fed to the LM3914 signal input. Resistor R6 sets the top of the internal divider network at 2.705 volts (5.41V/2) and potentiometer R4 sets the bottom of the divider at 2.205 volts (4.41V/2). Adjust R6 until LED10 just turns on with V_{CC} set at 5.41 volts. Then adjust R4 until LED1 just turns on with V_{CC} set at 4.41 volts. There's a slight interaction so that running through that procedure a second time may improve accuracy.

TTL and CMOS-compatible undervoltage and overvoltage signals are provided, which can be used to shut down a system before damage (to either data or hardware) occurs. Optional diode D1 protects the IC in the event the 5-volt supply leads are reversed. For a simple go/no-go display, use red LED's at pins 1 and 18 for undervoltage and overvoltage and wire-OR pins 10 through 17 to the cathode of a single green LED.

Audio metering

A logarithmic scale using the decibel (dB) is a convenient and popular one for measuring audio levels. A 3-dB increase corresponds to a 41 percent voltage increase and a doubling of power. The LM3915 features a (22K ohm) logarith-

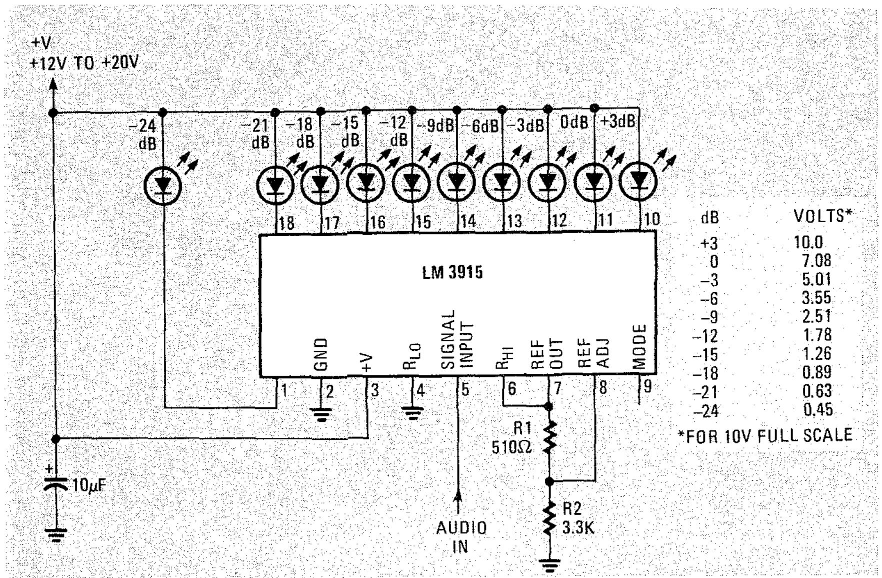


FIG. 3—AUDIO-LEVEL METER displays the instantaneous value of the audio input signal. The LM3915 provides a logarithmic response.

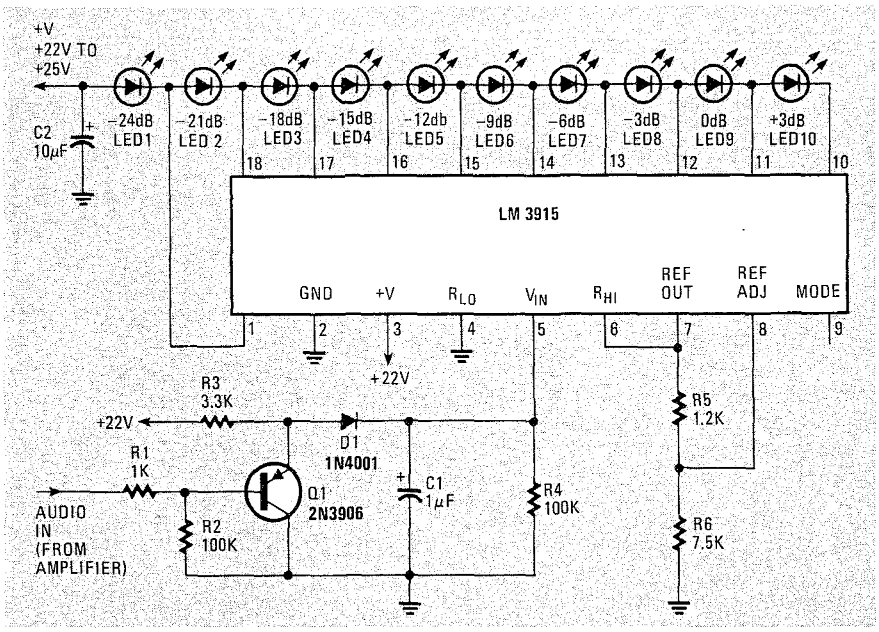


FIG. 4—PEAK-READING AUDIO-LEVEL METER is obtained by using a peak-detecting circuit on input pin 5.

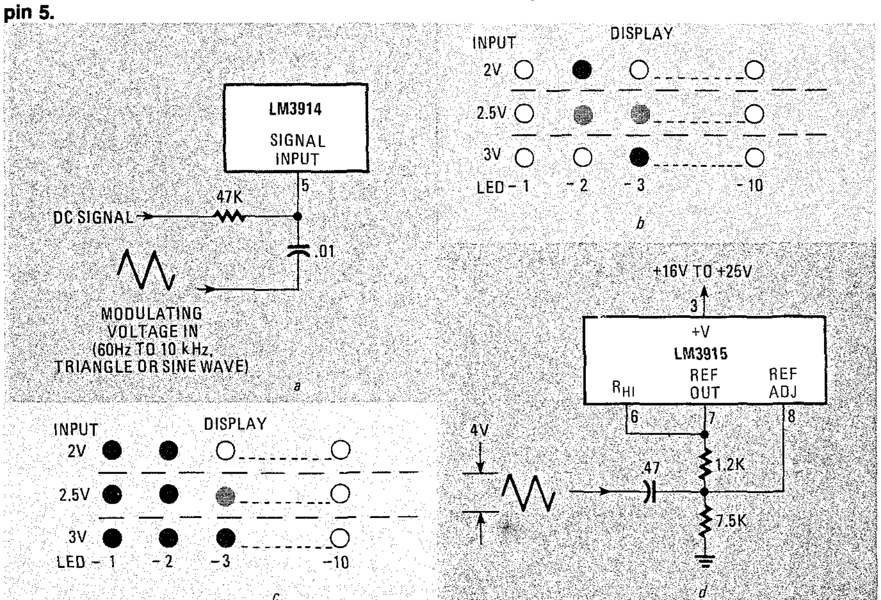
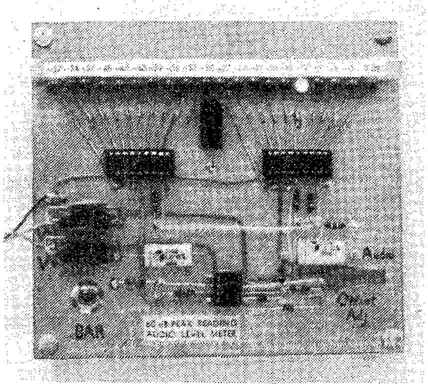


FIG. 5—INCREASED DISPLAY RESOLUTION is obtained by modulating the input signal on pin 5 with either a sine or triangular waveform as shown in *a*. The resulting display shown in *b* and *c* has twice the original resolution. (The display shown in *b* obtained in the DOT mode, while the display shown in *c* is obtained in the BAR GRAPH mode.) The same effect is obtained with the logarithmic LM3915 by using the configuration shown in *d*.



mic voltage-divider for a 3-dB-per-step display; otherwise, it's identical to the LM3914. The LM3915 is useful for displaying signals with wide dynamic range, such as RF signal strength, power level, or light intensity, in addition to audio level.

Figure 3 illustrates how simple it is to construct an audio-level indicator with the LM3915. The audio is fed straight to the IC's signal input without any rectification. Using the DOT mode, the LED illuminated represents the instantaneous value of the audio waveform. Both peak and average levels can be easily discerned. Since the dot will be constantly moving, the LED's are run at 30 mA for adequate intensity. The full-scale reading (+3 dB) is 10 volts; that is easily altered by changing R2. The LM3915's signal input can withstand signals up to ±35 volts, which corresponds to 150 watts peak into an 8-ohm load. If there is a chance that the audio input could exceed this range, either attenuate it or include enough series resistance to limit the current to 5 mA.

If a peak-reading meter is desired, Fig. 4 shows how it's done. Since the thresholds for the first few LED's are less than 1 volt, a simple diode-capacitor peak detector won't do. The diode's 600 mV turn-on threshold would not pass low-level signals. In the circuit shown, the voltage drop across D1 is canceled out by the emitter-base voltage of PNP transistor Q1, connected as an emitter follower. These voltages usually track within 100 mV, causing a small error at low input levels.

The LED connections in Fig. 4 illustrate a tricky way to get a bar-graph display with very low current drain. With pin 9 left open, the LM3915 thinks it's in DOT mode, so only one output will be on at a time. For an input between −24 and −21 dB, the pin-1 current source turns on, lighting up LED1. When the input increases to −21 to −18 dB, the pin-18 current source turns on while pin 1 turns off. With the LED's in series, the pin-18 output current flows through LED2 and LED1, lighting them both. For every 3-dB increase in input voltage, the current shifts over to

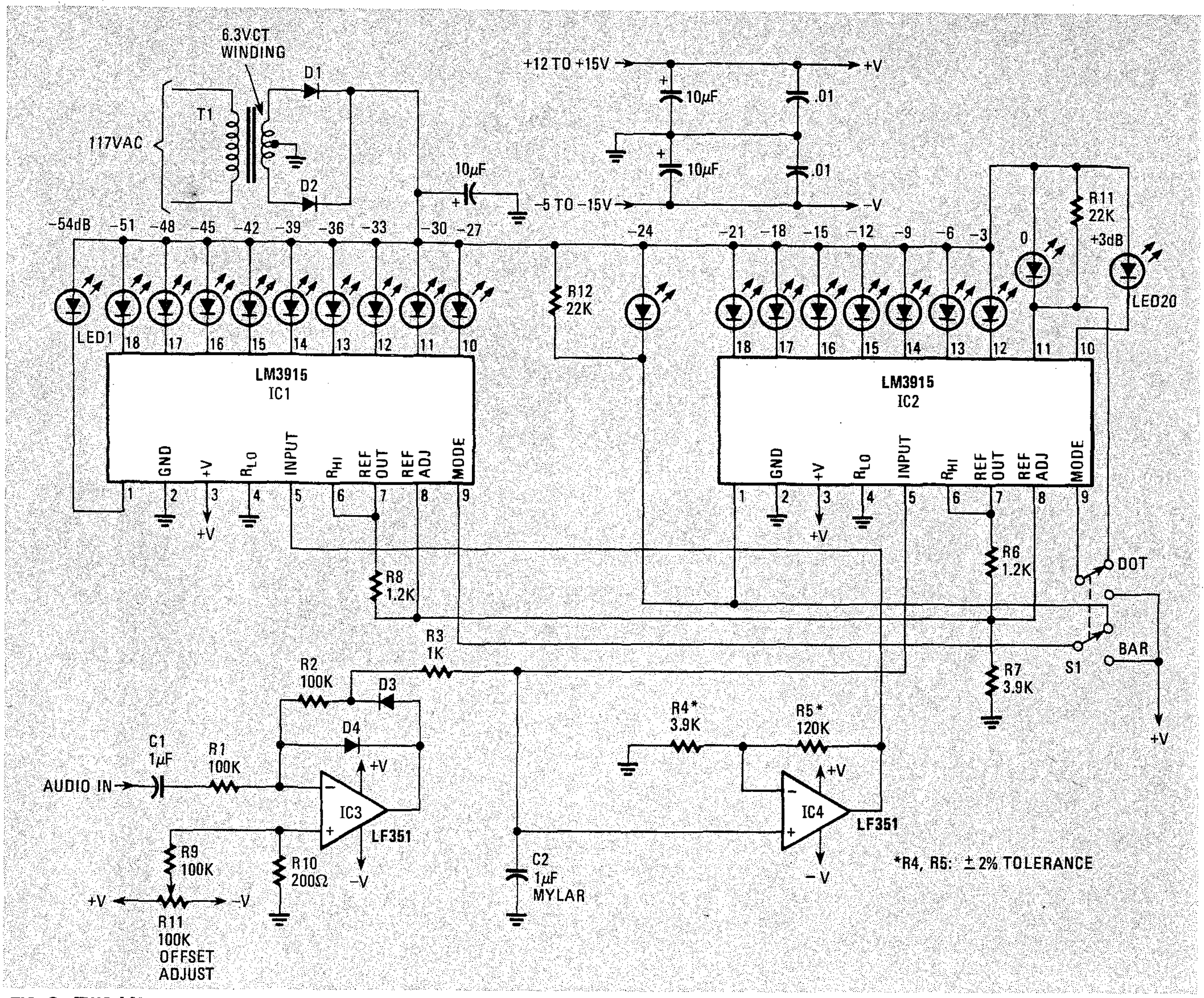


FIG. 6—TWO LM3915's can be cascaded together to obtain wide dynamic range. The circuit shown above is a peak-reading audio-level meter with a dynamic range of 60 dB.

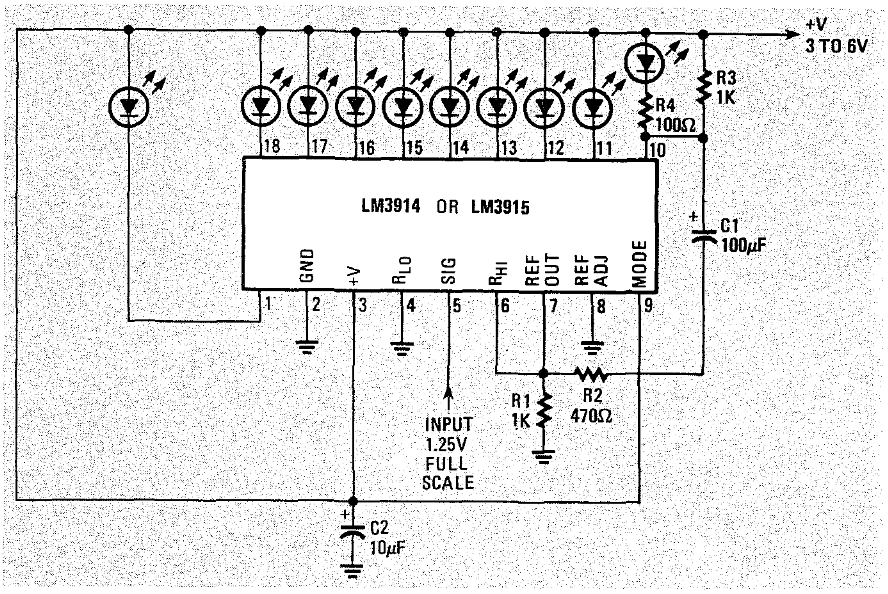


FIG. 7—OVERRANGE INDICATION with the bar-graph display is obtained with the above circuit. When the overrange condition occurs, the LED's flash.

another output pin and lights another LED. That results in a bar-graph display that draws only 20 mA while lighting ten LED's, instead of 200mA for the standard bar-graph configuration. A higher supply voltage is required, however, because all the LED forward voltages are in series. The IC still stays cool since the current drain is low. That connection may be useful when "stealing" power from pre-existing stereo equipment that cannot supply much current.

Other display ideas

For increased resolution, modulate the LM3914's input signal with an AC voltage as in Fig. 5-a. The LED's will appear to turn on gradually, producing a display that changes smoothly like a meter. For the modulating voltage, a triangle wave works best, although a sinewave (60 Hz from a transformer, for example) can be used. The peak-to-peak amplitude of the AC voltage should be equal to the voltage step between LED's. Figures 5-b and 5-c depict the resulting displays in either the bar or dot mode. To obtain the same effect using an LM3915, where the voltage step between LED's varies, one should modulate the R_{HI} voltage by 3 dB as in Figure 5-d.

Most program material has a dynamic range of over 40 dB. It's a simple matter to obtain a 60-dB display by cascading two LM3915's together, as shown in Fig. 6. A better peak-detector circuit is required because the threshold for the first LED is only 15 mV! The precision peak detector uses op-amp IC3 to overcome diode offset error. Operational amplifier IC4 is run at a gain of 30 dB or 31.6. BiFET op-amps, such as the

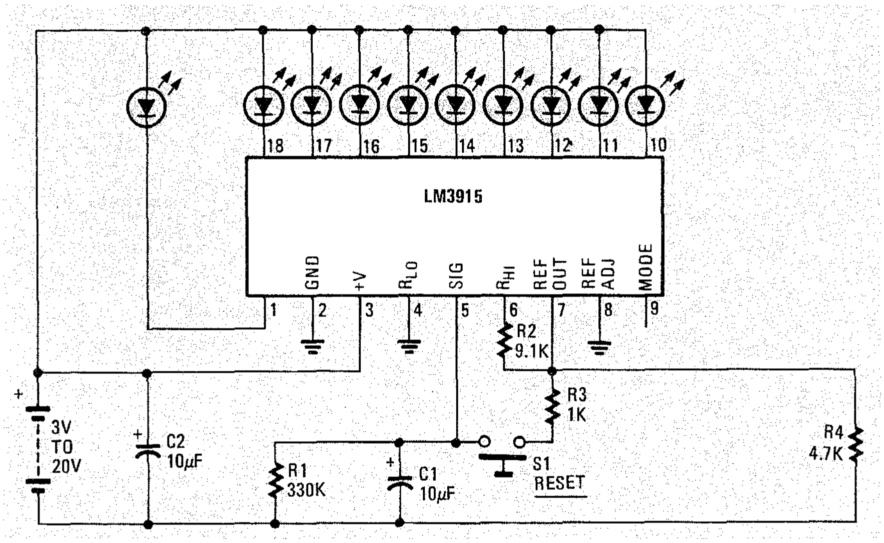


FIG. 8—TEN-STEP TIMER CIRCUIT. The LED's turn off sequentially, with each LED representing the time constant of R1—C1.

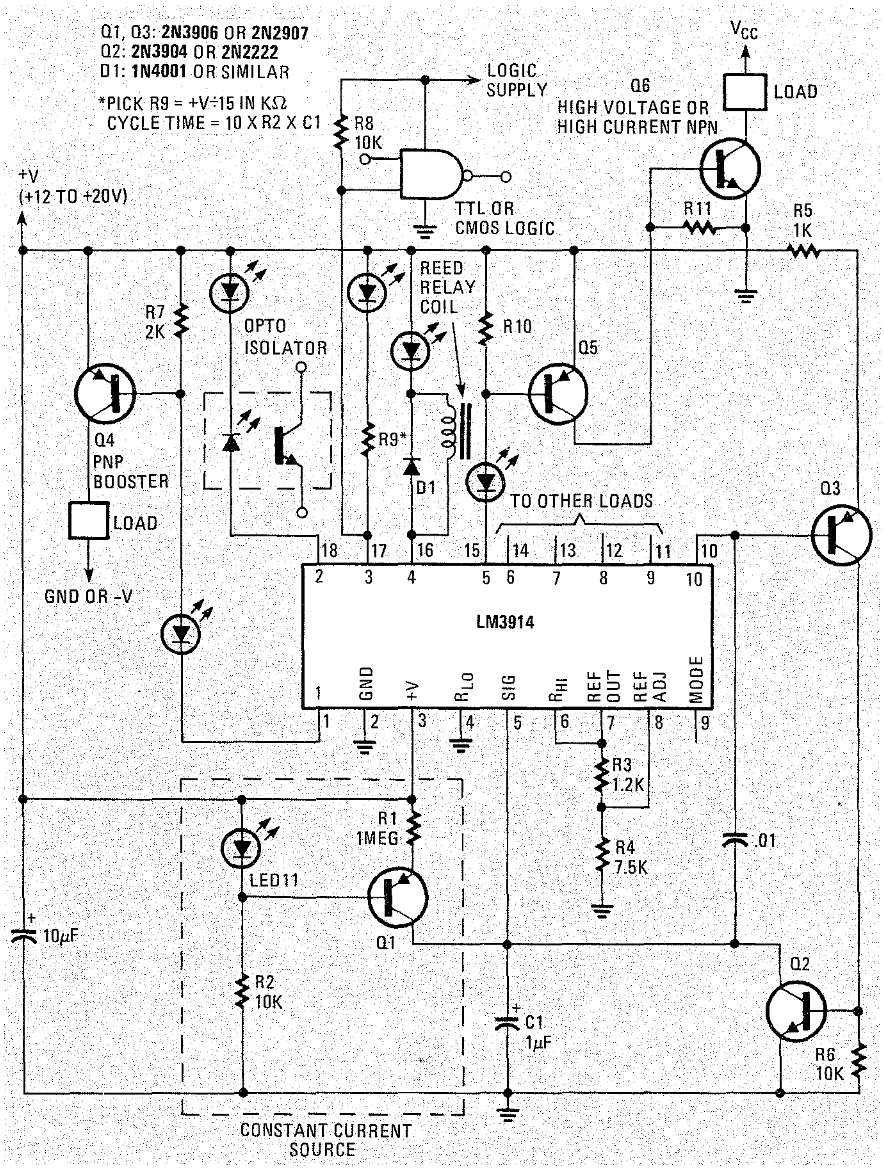


FIG. 9—NINE-STEP SEQUENCER is a variation of the principle used in the ten-step timer shown in Fig. 8 and can be used to turn various loads on and off sequentially.

LF351, that combine low bias current with a high slew rate are recommended. The offset-adjust pot R11 is adjusted for a 0-volt output from IC4 with no audio input applied.

As that example shows, the LED's can be run from an unregulated, unfiltered power supply. The 6.3-volt center-tapped transformer, and diodes D1 and D2, provide a full-wave rectified voltage of about 4 volts to the LED anodes. That greatly reduces the load on the V^+ supply in the bar-graph mode and also reduces heat dissipation in the LM3915 integrated circuits.

In this circuit, resistor R7 sets the reference voltage for both IC's. Since both IC's have identical loading on their reference outputs, the reference voltage can be changed (from the 10 volts shown here) by lowering R5 without affecting the LED intensities. The time constant R3–C2 sets the display decay-time and can be optimized by varying the capacitance of C2.

It's very easy to add an alarm that will flash the LED's when the input voltage exceeds full scale. The circuit is shown in Fig. 7. If desired, that scheme can be used to flash the display when the input voltage exceeds the threshold of any of the ten LED's, by simply moving the resistor-capacitor network (made up of R2 and C1) over to a different output of the IC.

Timers and sequencers

Use an LM3915 to monitor the voltage on a discharging capacitor, as in Fig. 8, and you've got a simple timer. Even though the capacitor voltage decays to zero logarithmically, displaying it via an LM3915 results in equal time steps. Each time step is approximately R1× C1/3.

The sequencer shown in Fig. 9 is a variation on that. Capacitor C1 is charged linearly by the current source made up of Q1, LED11 and R1. When output 10 starts to turn on, Q2 and Q3 conduct and C1 is rapidly discharged. Cycle time is about 10×R1×C1. The LM3914 outputs could be used to drive relays, opto-isolators, or logic circuits, for example.

Other ideas

Don't think the LM3914 and LM3915 can drive *only* bars of LEDs. The LED's can be arranged in circles, or as X-Y displays, for instance. LCD's, vacuum fluorescents, and low-current incandescent bulbs can also be driven. As the examples show, outputs may interface with CMOS, TTL, opto-isolators and relays for a variety of automatic measurement and control functions. The decibel display of the LM3915 is especially attractive for audiophiles. Like the op-amp, applications of those display drivers are limited only by the imagination of the designer. **R-E**