Mutliplexing technique yields a reduced-pin-count LED display

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"Charlieplexing" as a method of multiplexing LED displays has recently attracted a lot of attention because it allows you, with N I/O lines, to control $N \times (N-1)$ LEDs (**references 1** through **5**). On the other hand, the standard multiplexing technique manages to control far fewer LEDs. **Table 1** lists the number of LEDs that you can control using Charlieplexing and standard multiplexing by splitting the available number of N I/O lines into a suitable number of rows and columns. **Table 1** also shows the duty cycle of the current that flows through the LEDs when they are on.

Clearly, Charlieplexing allows you to control a much larger number of LEDs with a given number of I/O lines. However, the downside of this technique is the reduced duty cycle of the current that flows through the LEDs; thus, to maintain a given brightness, the peak current through the LEDs must increase proportionately. This current can quickly reach the peak-current limit of the LED. Nonetheless, Charlieplexing is a feasible technique for as many as 10 I/O lines, allowing you to control as many as 90 LEDs. To control an equivalent number of LEDs using the standard

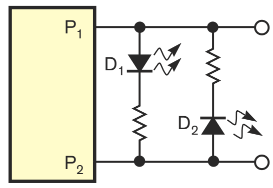

Figure 1 "Charlieplexing" with two I/O lines allows you to control two LEDs.

TABLE 1 NO. OF LEDs AND DUTY CYCLE

No. of I/O lines	Multiplexing-controlled LEDs	Duty cycle with multiplexing (%)	Charlieplexing-controlled LEDs	Duty cycle with Charlieplexing (%)
Two	Two	100	Two	50
Three	Three	100	Six	16.67
Four	Four	50	12	8.33
Five	Six	50	20	5
Six	Nine	33	30	3.33
Seven	12	33	42	2.4
Eight	16	25	56	1.78
Nine	20	25	72	1.38
10	25	20	90	1.11

TABLE 2 OUTPUT VOLTAGE

P_1	P_2	Voltage at node PR_1
0	0	V_{CC}
0	1	V_{CC}
0	Z	V_{CC}
1	0	0
1	1	0
1	Z	0
Z	0	$V_{CC}/2$
Z	1	$V_{CC}/2$
Z	Z	$V_{CC}/2$

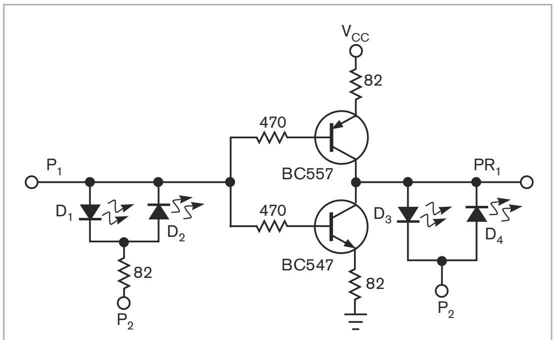

Figure 2 "GuGaplexing" with two I/O lines allows you to control four LEDs.

multiplexing technique would require 19 I/O lines.

This Design Idea proposes a modification to the Charlieplexing technique that allows you to control twice as many LEDs. Thus, the proposed method, "GuGaplexing," allows $2 \times N \times (N-1)$ LEDs using only N I/O lines and a few additional discrete components (**Figure 1**). To turn on LED D_1 using the Charlieplexing method, set P_1 to logic one and P_2 to logic zero. To turn on LED D_2, set P_1 to logic zero and P_2 to logic one. **Figure 2** shows the proposed GuGaplexing scheme with two I/O lines controlling four LEDs. The

TABLE 3 I/O LINES AND PR_1 VOLTAGE

P_1	P_2	Voltage at node PR_1	LED that turns on
0	0	V_{CC}	L_3
0	1	V_{CC}	L_2
1	0	0	L_1
1	1	0	L_4
Z	Z	$V_{CC}/2$	None

GuGaplexing technique exploits the fact that each I/O line has three states: one, zero, and high impedance. Thus, with two I/O lines, states 00, 01, 10, and 11 of eight possible states control the LEDs.

Table 2 lists the voltage at the output of the transistor pair for various states of the two I/O lines, P_1 and P_2. The transistor pair comprises a BC547 NPN and a BC557 PNP transistor; matched transistor pairs are recommended. For N I/O lines, the GuGaplexing technique requires $N-1$ transistor pairs. **Table 3** shows the state of the I/O lines P_1 and P_2 and the voltage at node PR_1 to control the four LEDs. The circuit requires that the LED turn-on voltage should be slightly more than $V_{CC}/2$. Thus, for red LEDs with a turn-on voltage of approximately 1.8V, a suitable supply voltage is 2.4V. Similarly, for blue or white LEDs, you can use a 5V supply voltage. Modern microcontrollers, especially the AVR series of microcontrollers from Atmel (www.atmel.com), operate at a wide variety of supply voltages ranging from 1.8 to

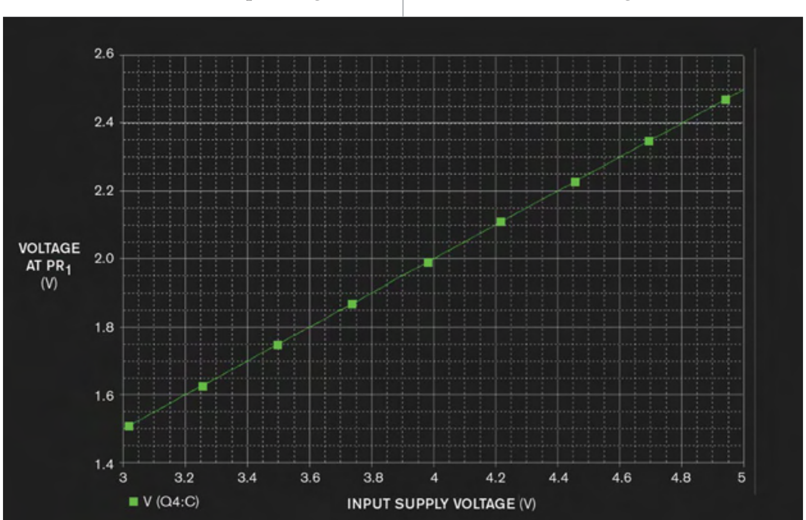

Figure 3 This graph plots the voltage at node PR_1 for various supply-voltage values when the input to the transistor pair is floating.

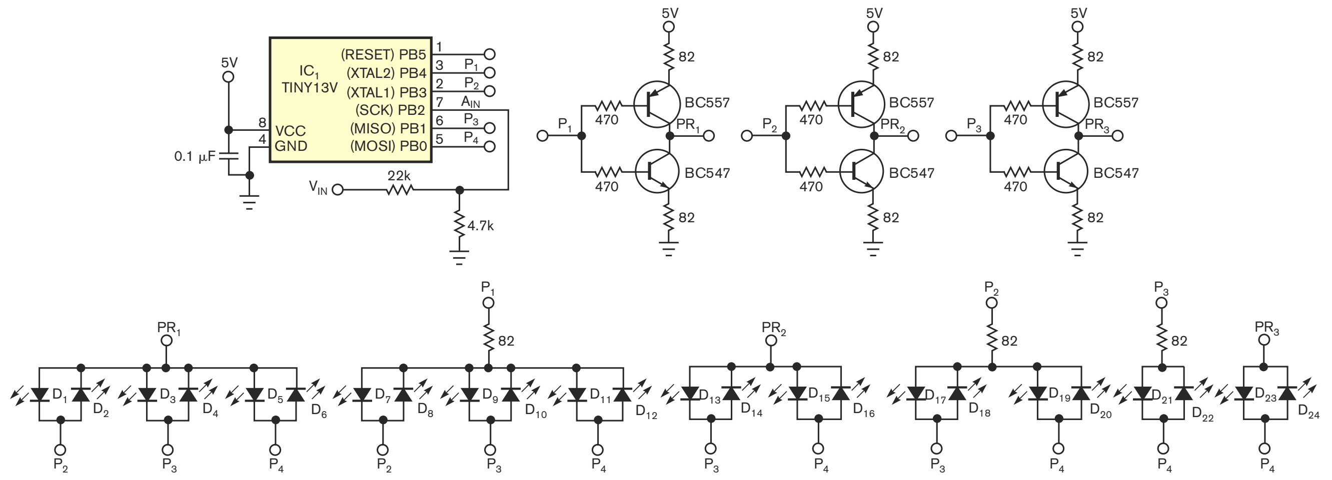

Figure 4 With the GuGaplexing technique, controlling 24 LEDs requires only four I/O lines and three sets of transistors.

5.5V, and this design uses a Tiny13 microcontroller to implement the GuGaplexing technique.

Figure 3 plots the voltage at node PR_1 for various supply-voltage values when the input to the transistor pair is floating. The Spice simulation ensures that the circuit would work properly to provide $V_{CC}/2$ at the PR_1 node for wide operating-supply-voltage values when the input is floating.

A 24-LED bar display validates the scheme in a real application (**Figure 4**). The display is programmable and uses a linear-display scheme for the input analog voltage. The input analog voltage displays in discrete steps on the 24-LED display. Controlling 24 LEDs requires only four I/O lines and three pairs of transistors. The system uses 5-mm, white LEDs in transparent packaging and a 5V supply voltage. The GuGaplexing implementation uses an AVR ATTiny13 microcontroller. The analog input voltage connects to Pin 7 of the ADC input of the Tiny13 microcontroller.

The control program for the ATTiny13 microcontroller is available with the Web version of this Design Idea at www.edn.com/081016di1. The source code is in C and was compiled using the AVRGCC freeware compiler. You can modify the source code to display only one range of input voltage between 0 and 5V. For example, it is possible to have a linear-display range of 1 to 3V or a logarithmic scale for input voltage of 2 to 3V.EDN

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