ICs' hidden features enhance counter-based designs

ICs designed expressly for counter applications appear in most digital-device data books but might not offer the features you need. Chips dedicated to other applications, however, often include counter functions that you can access.

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When looking for a digital counter, don't limit your search to dedicated ICs, which might require the "wrong" supply voltage, take too much power, operate too slowly or perhaps not be readily available. The function you need might be hidden within other devices aimed at different applications.

For example, frequency-synthesizer/phase-locked-loop ICs generally contain on-chip counters—often more than one. And CMOS-based versions of these devices tolerate wide supply-voltage variations, operate at low current levels and function at input frequencies in the tens-of-megahertz range.

Three devices provide the options

Three devices that meet these requirements, the MC145146, -151 and -157, each contain at least one 10-, 12- or 14-bit counter (**Table 1**) and operate over a 3 to 9V supply range. The counters' programming methods differ, suiting them to a variety of applications.

Table 2 shows the devices' counting ranges and counter-programming requirements: The 14-bit MC145151 accepts parallel counter loading; a 4-bit data bus programs the 10- and 12-bit -146 counters; and the -157's dual 14-bit counters load~~s~~ via a clocked, serial data stream.

You parallel-load **Fig 1a**'s MC145151 via inputs N_0 through N_{13} using **Table 2**'s code sequence. (Note that all three devices achieve full count value for an all-ZERO input and are nonresponsive for inputs of 00...01 and 00...10.) By comparision, the -146's 10- and 12-bit counters require three 4-bit inputs at D_0 through D_3 (**Fig 1b**). Address bits A_0 through A_2 direct these 4-bit nibbles to the appropriate counter locations. The indicated strobe/chip-select signal (ST) allows the data and address lines to share a common bus with other system functions because they achieve an inactive high-impedance state when ST is LOW.

The MC145157's dual 14-bit counters employ only three programming interface controls: the Data, Clock and Enable functions (**Fig 1c**). You accomplish a count-loading operation by clocking the data into the on-chip shift registers, then transfering the information into the latches by taking Enable HIGH. (Conversely, keeping Enable LOW allows you to enter new data into the registers without disturbing what's already in the counters.) The first 14 bits are the count value; the 15th bit selects which counter gets loaded—a ONE loads ÷R, a ZERO loads ÷N.

Other than these programming differences, the counters are sufficiently similar to permit one functional description, and an example application demonstrates their advantages.

A CMOS counter's current consumption generally depends on its supply voltage and the input's frequency

TABLE 1—COUNTER CHARACTERISTICS

OPERATING VOLTAGE	3 TO 9V DC
OPERATING TEMPERATURE	−40 TO +85°C
COUNTERS AVAILABLE:	
MC145146	ONE 12-BIT, ONE 10-BIT
MC145151	ONE 14-BIT
MC145157	TWO 14-BIT
TYPICAL CURRENT DRAIN AT 25°C FOR f_{IN} = 10 MHz, V_{DD} = 5V	
V_{IN} = 2V p-p	2.0 mA DC
V_{IN} = 0.5V p-p	2.4 mA DC
MAXIMUM F_{IN} WITH 500 mV P-P SINE-WAVE INPUT AND V_{DD} = 5V	15 MHz MIN
PACKAGE SIZE (DUAL IN-LINE):	
MC145146	20 PIN, 0.3-IN. WIDE
MC145151	28 PIN, 0.6-IN. WIDE
MC145157	16 PIN, 0.3-IN. WIDE

Programmable counters hide in chip block diagrams

and amplitude. Figs 2 and 3 show this relationship for the -151's 14-bit counter operating at 3 and 5V supply levels; they depict the results of using an external signal source, grounding the OSC_{IN} pin and leaving all other unused pins open. (Although you'll note slight

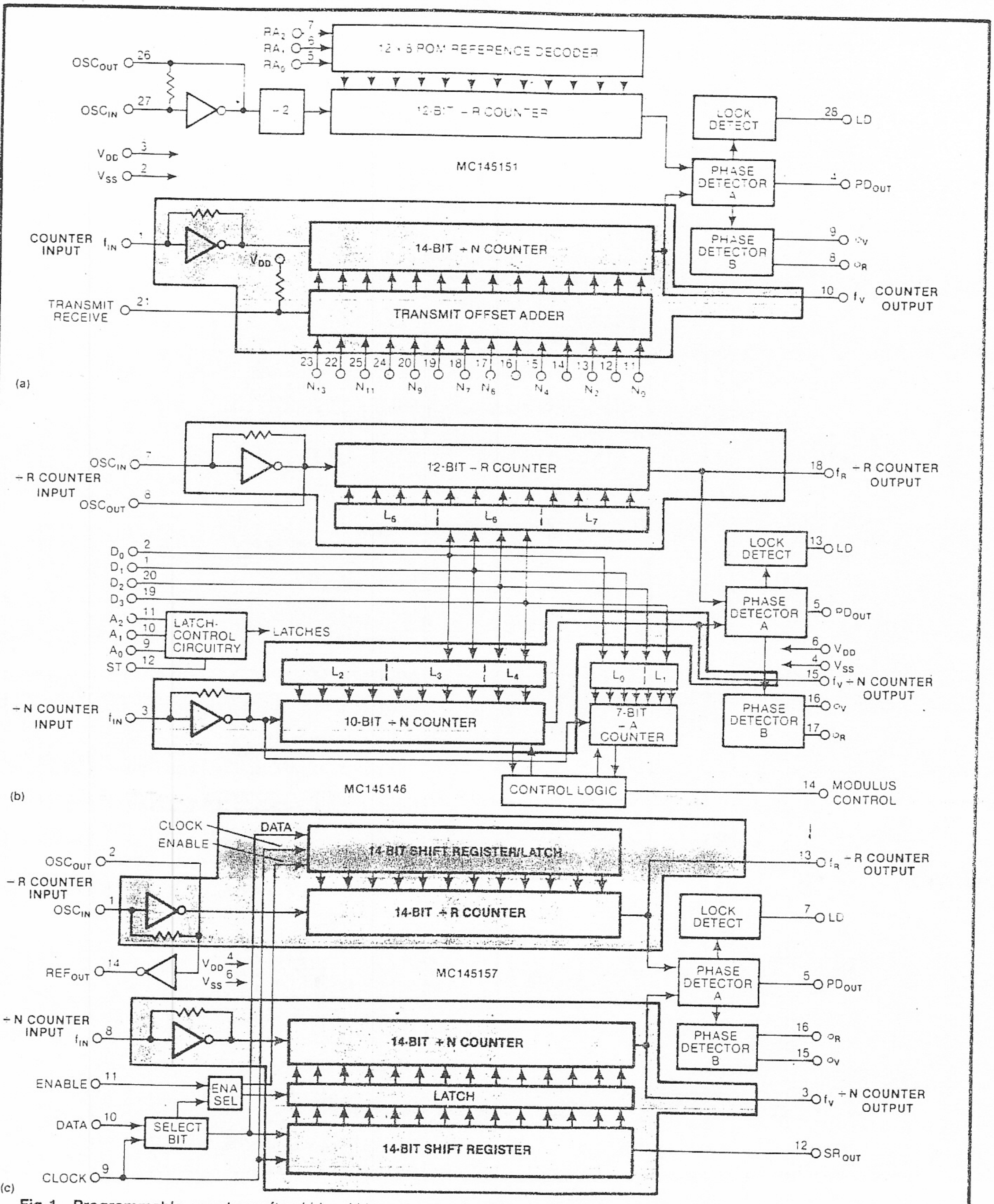

Fig 1—Programmable counters *often hide within more complex ICs such as frequency-synthesizer/phase-locked-loop devices. For example, the MC145151* **(a)** *includes a parallel-programmed 14-bit counter. The MC145146 chip* **(b)** employs two counters—12- and 10-bit—driven by a 4-bit data bus, and the -157 **(c)** *has dual counters programmed by 14-bit shift registers.*

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current differences for different divider ratios, these changes are insignificant above approximately ÷32.)

You can supply a low-level (500 mV p-p) input signal in conjunction with the chip's built-in buffers and ac coupling; however, as **Figs 2** and **3** indicate, a large input amplitude requires less supply current, especially at higher supply voltages. If your application operates at standard CMOS logic levels, use direct coupling; if you employ ac coupling, be sure the waveform is symmetrical to avoid upsetting the on-chip bias levels, thus degrading the counter's sensitivity.

Fig 4 shows a counter's typical frequency capability over a −40 to +85°C span as a function of supply voltage and input-signal amplitude. Guaranteed maxi-

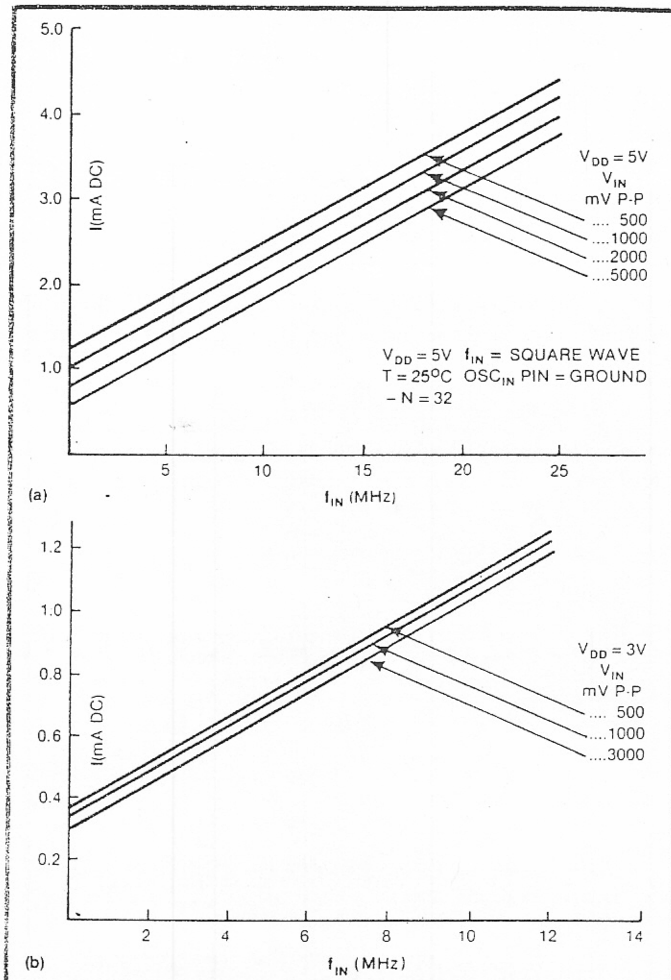


Fig 2—A CMOS counter's dc current drain *depends on the supply voltage and the input signal's frequency and amplitude. Although a higher voltage does permit higher operating frequencies* ***(a),*** *it also causes higher currents at lower frequencies. For example, a 500-mV, 10-MHz input draws 2.4 mA at 5V* ***(a)*** *but only 1.1 mA at 3V* ***(b).***

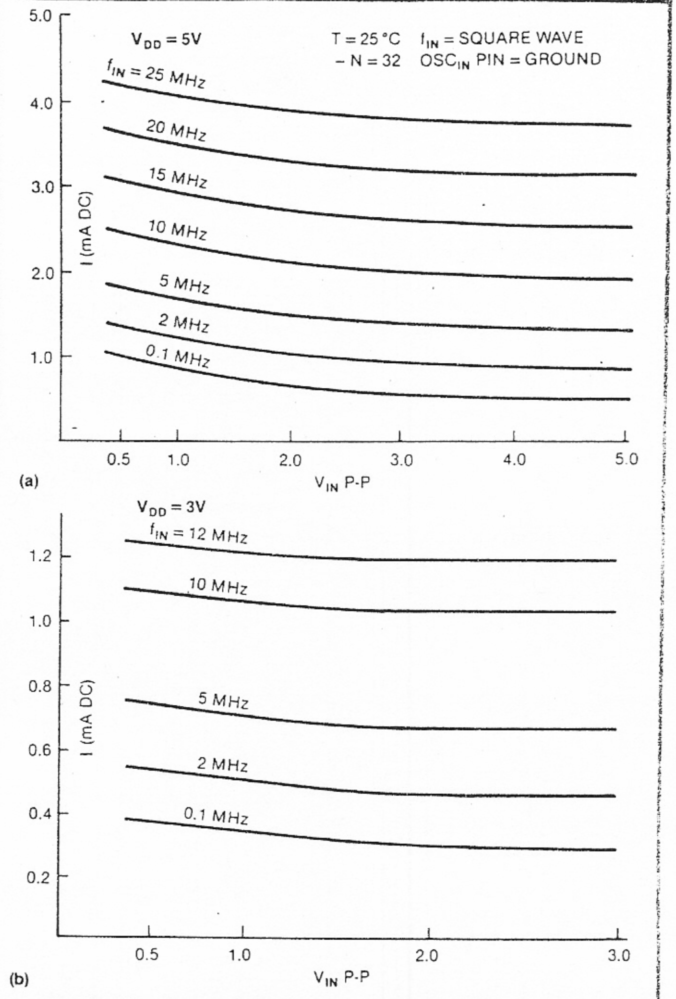


Fig 3—Varying a CMOS counter's input frequency *has more of an effect on its supply current than does an input-amplitude change at a constant frequency. At divider values less than 32, the device's current requirements vary with its count requirements.*

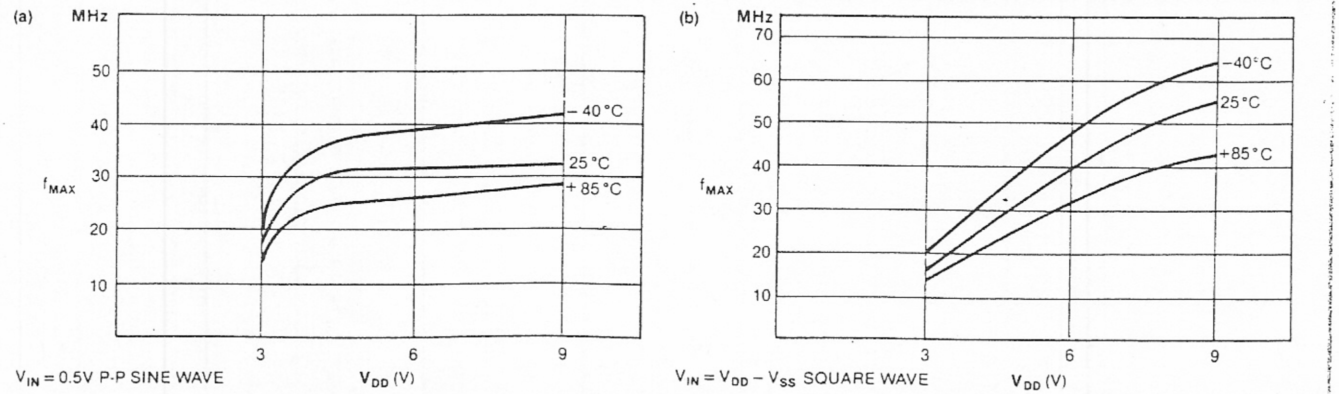


Fig 4—A counter's maximum operating frequency *depends on its supply voltage, temperature and input signal amplitude. A 500-mV p-p sine-wave input* ***(a)*** *limits performance at the higher supply-voltage levels. A rail-to-rail square wave* ***(b),*** *however, provides impressive response at all supply levels.*

CMOS counters reach 12 MHz drawing 1.2 mA from a 3V supply

mum frequency for a 500-mV p-p input level is 15 MHz min at V_{DD}=5V and 6 MHz min at 3V.

You can employ any of these "hidden" counters in many applications requiring a low- to medium-speed count function; they're especially useful in low-power µC-controlled designs.

Before looking at specific applications, however, note two MC145151 characteristics. First, for use in its intended application as a frequency synthesizer, the IC provides a frequency offset between a transmitter and receiver—driving pin 21 LOW adds 856 to the ÷N's value. Second, the device has on-chip pull-up resistors of approximately 360 kΩ on pins 21, 5, 6 and 7 and the count-controlling inputs N_0 through N_{13}. Thus, when operating at V_{DD}=5V, each pin that's held LOW consumes 14 µA. The current drains shown in **Figs 2** and 3 reflect this situation—the ÷32 input code (all but one input is LOW) pulls 180 µA from a 5V supply and 110 µA from a 3V unit.

A low-power-drain, variable-time-base-generator design (**Fig 5**) demonstrates how to use the -151's hidden counter. You can use either the IC's on-chip crystal-oscillator circuit or an external source for f_{REF}. In either case, determine the output signal's interval:

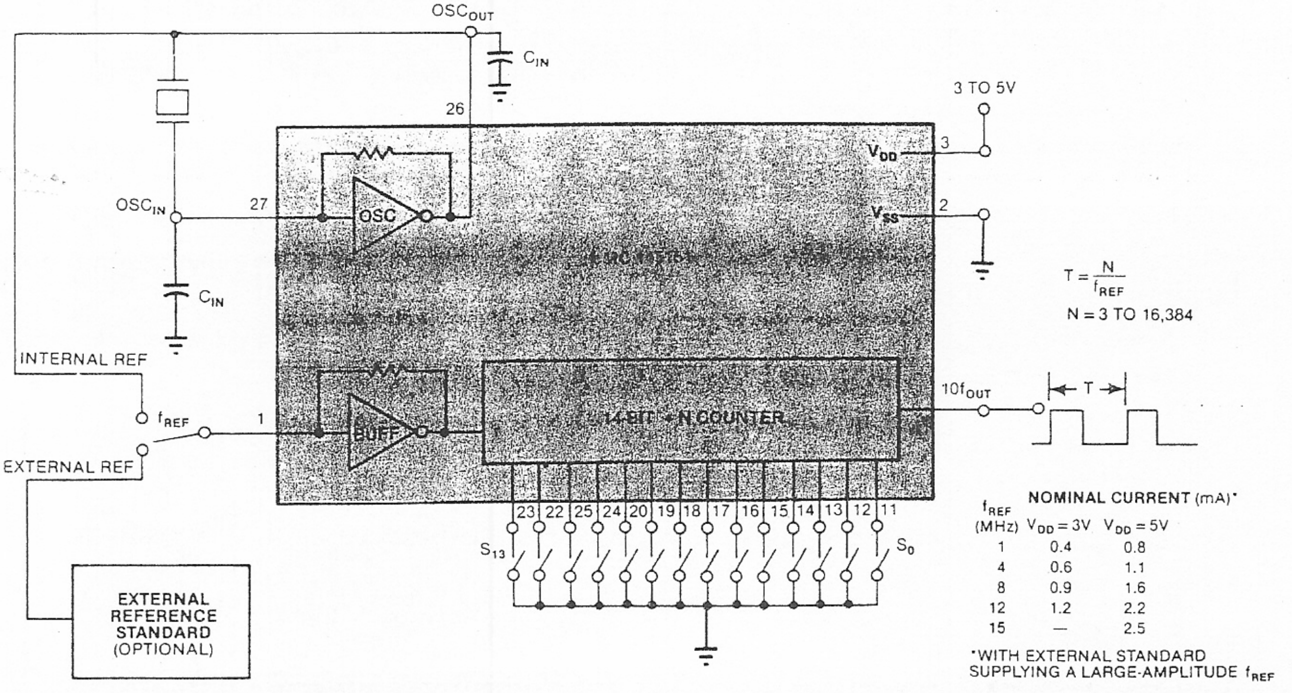
$$T=N/f_{REF},$$

where N is the divide value, entered via switches S_0 through S_{13} according to **Table 2**'s coding sequence.

TABLE 2—COUNTER DIVIDE RANGES AND PROGRAMMING METHODS

BINARY PROGRAMMING CODE RANGE (SHOWN IN DECIMAL)	AVAILABLE COUNTERS AND THEIR DIVISION VALUES			
	PARALLEL PROGRAMMING MC145151 14-BIT COUNTER	4-BIT DATA-BUS PROGRAMMING MC145146 12-BIT COUNTER	4-BIT DATA-BUS PROGRAMMING MC145146 10-BIT COUNTER	SERIAL PROGRAMMING MC145157 TWO 14-BIT COUNTERS
0	16,384	4096	1024	16,384
1	*	*	*	*
2	*	*	*	*
3	3	3	3	3
1023			1023	
4095		4095		
16,383	16,383			16,383

*COUNTER NOT SPECIFIED FOR DIVIDE VALUES LESS THAN 3



f_{REF} (MHz)	NOMINAL CURRENT (mA)* V_{DD}=3V	V_{DD}=5V
1	0.4	0.8
4	0.6	1.1
8	0.9	1.6
12	1.2	2.2
15	—	2.5

*WITH EXTERNAL STANDARD SUPPLYING A LARGE-AMPLITUDE f_{REF}

Fig 5—A variable-time-base-generator design *employs the 14-bit counter section of a frequency-synthesizer/phase-locked-loop IC. By combining the chip's programmable 3 to 16,384 divide ratio with a reference-frequency range of 1 to 15 MHz, you can vary the output's interval from 16.384 msec to 0.2 µsec.*

Large input amplitudes reduce supply currents

And because N can equal any integer value from 3 to 16,384, you can vary T from 16.384 msec to 0.2 µsec using common f_{REF} frequencies between 1 and 15 MHz.

To use the on-chip oscillator, connect a parallel resonant, fundamental-mode crystal between the OSC_{IN} and OSC_{OUT} pins. $C_{IN(TOT)}$ and $C_{OUT(TOT)}$—the crystal's loading capacitances—are functions of the operating frequency, f_{REF}. The crystal's total loading, C_L, APPROXIMATELY equals $C_{IN(TOT)}$ in series with $C_{OUT(TOT)}$ and shouldn't exceed 32 pF for frequencies to approximately 8 MHz, 20 pF for the 8- to 15-MHz range and 10 pF for frequencies higher than 15 MHz. $C_{IN(TOT)}$, for example, equals the IC's input capacitance, $C_{IN(IC)}$, plus that of circuit strays, $C_{IN(STRAY)}$, plus Fig 5's indicated C_{IN}. Add this last component value to properly load the crystal. Although $C_{IN(TOT)}$ and $C_{OUT(TOT)}$ are usually approximately equal, you can frequency-trim the crystal by making C_{IN} variable. **EDN**

Authors' biographies

John Hatchett, principal staff engineer with Motorola's Semiconductor Products Sector, is responsible for the systems engineering that leads to the definition, development and application of semiconductors in entertainment and radio-communication equipment. A member of the Society of Professional Engineers, John received his BSEE degree from the University of Illinois and his MSEE from the Illinois Institute of Technology; he has two patents pending. Besides attending Phoenix Suns basketball games, he enjoys camping and golfing.

William Morgan, a senior technician with Motorola for 16 yrs, provides technical support for new semiconductor-product developments. He studied electrical engineering for 2½ yrs at the University of New Mexico and lists camping, hiking and gardening among his outside activities.

A deeper look

This article considers only one aspect of the MC145146, -151 and -157 chips. For more information and ~~a~~ data sheetS Circle No 741.

Article Interest Quotient (Circle One)
High 473 *Medium* 474 *Low* 475