

# PLL Frequency Synthesizer Family CMOS

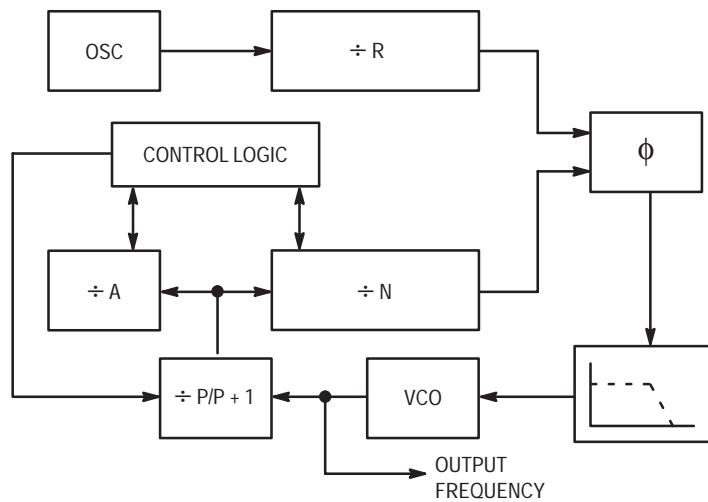
**MC145151-2**  
**MC145152-2**  
**MC145155-2**  
**MC145156-2**  
**MC145157-2**  
**MC145158-2**

The devices described in this document are typically used as low-power, phase-locked loop frequency synthesizers. When combined with an external low-pass filter and voltage-controlled oscillator, these devices can provide all the remaining functions for a PLL frequency synthesizer operating up to the device's frequency limit. For higher VCO frequency operation, a down mixer or a prescaler can be used between the VCO and the synthesizer IC.

These frequency synthesizer chips can be found in the following and other applications:

CATV  
AM/FM Radios  
Two-Way Radios

TV Tuning  
Scanning Receivers  
Amateur Radio



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## MC145151-2

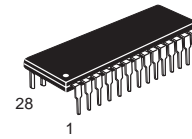
# Parallel-Input PLL Frequency Synthesizer

## Interfaces with Single-Modulus Prescalers

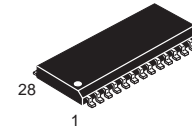
The MC145151-2 is programmed by 14 parallel-input data lines for the N counter and three input lines for the R counter. The device features consist of a reference oscillator, selectable-reference divider, digital-phase detector, and 14-bit programmable divide-by-N counter.

The MC145151-2 is an improved-performance drop-in replacement for the MC145151-1. The power consumption has decreased and ESD and latch-up performance have improved.

- Operating Temperature Range: - 40 to 85°C
- Low Power Consumption Through Use of CMOS Technology
- 3.0 to 9.0 V Supply Range
- On- or Off-Chip Reference Oscillator Operation
- Lock Detect Signal
- ÷ N Counter Output Available
- Single Modulus/Parallel Programming
- 8 User-Selectable ÷ R Values: 8, 128, 256, 512, 1024, 2048, 2410, 8192
- ÷ N Range = 3 to 16383
- "Linearized" Digital Phase Detector Enhances Transfer Function Linearity
- Two Error Signal Options: Single-Ended (Three-State) or Double-Ended
- Chip Complexity: 8000 FETs or 2000 Equivalent Gates



**P SUFFIX**  
PLASTIC DIP  
CASE 710



**DW SUFFIX**  
SOG PACKAGE  
CASE 751F

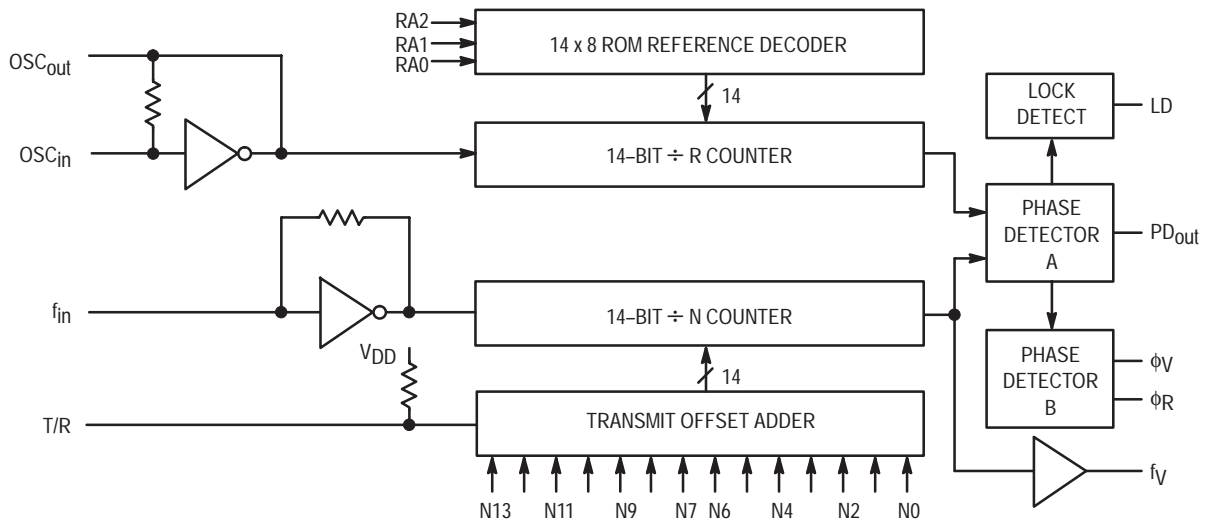
### ORDERING INFORMATION

MC145151P2 Plastic DIP  
MC145151DW2 SOG Package

### PIN ASSIGNMENT

$f_{in}$	1	28	LD
$V_{SS}$	2	27	OSC <sub>in</sub>
$V_{DD}$	3	26	OSC <sub>out</sub>
PD <sub>out</sub>	4	25	N11
RA0	5	24	N10
RA1	6	23	N13
RA2	7	22	N12
$\phi_R$	8	21	T/R
$\phi_V$	9	20	N9
$f_V$	10	19	N8
N0	11	18	N7
N1	12	17	N6
N2	13	16	N5
N3	14	15	N4

## MC145151-2 BLOCK DIAGRAM



NOTE: N0 – N13 inputs and inputs RA0, RA1, and RA2 have pull-up resistors that are not shown.

## PIN DESCRIPTIONS

### INPUT PINS

#### $f_{in}$ Frequency Input (Pin 1)

Input to the  $\div N$  portion of the synthesizer.  $f_{in}$  is typically derived from loop VCO and is ac coupled into the device. For larger amplitude signals (standard CMOS logic levels) dc coupling may be used.

#### RA0 – RA2 Reference Address Inputs (Pins 5, 6, 7)

These three inputs establish a code defining one of eight possible divide values for the total reference divider, as defined by the table below.

Pull-up resistors ensure that inputs left open remain at a logic 1 and require only a SPST switch to alter data to the zero state.

Reference Address Code			Total Divide Value
RA2	RA1	RA0	
0	0	0	8
0	0	1	128
0	1	0	256
0	1	1	512
1	0	0	1024
1	0	1	2048
1	1	0	2410
1	1	1	8192

#### N0 – N11 N Counter Programming Inputs (Pins 11 – 20, 22 – 25)

These inputs provide the data that is preset into the  $\div N$  counter when it reaches the count of zero. N0 is the least significant and N13 is the most significant. Pull-up resistors en-

sure that inputs left open remain at a logic 1 and require only an SPST switch to alter data to the zero state.

#### T/R Transmit/Receive Offset Adder Input (Pin 21)

This input controls the offset added to the data provided at the N inputs. This is normally used for offsetting the VCO frequency by an amount equal to the IF frequency of the transceiver. This offset is fixed at 856 when T/R is low and gives no offset when T/R is high. A pull-up resistor ensures that no connection will appear as a logic 1 causing no offset addition.

#### OSCin, OSCout Reference Oscillator Input/Output (Pins 27, 26)

These pins form an on-chip reference oscillator when connected to terminals of an external parallel resonant crystal. Frequency setting capacitors of appropriate value must be connected from OSCin to ground and OSCout to ground. OSCin may also serve as the input for an externally-generated reference signal. This signal is typically ac coupled to OSCin, but for larger amplitude signals (standard CMOS logic levels) dc coupling may also be used. In the external reference mode, no connection is required to OSCout.

### OUTPUT PINS

#### PDout Phase Detector A Output (Pin 4)

Three-state output of phase detector for use as loop-error signal. Double-ended outputs are also available for this purpose (see  $\phi_V$  and  $\phi_R$ ).

Frequency  $f_V > f_R$  or  $f_V$  Leading: Negative Pulses

Frequency  $f_V < f_R$  or  $f_V$  Lagging: Positive Pulses

Frequency  $f_V = f_R$  and Phase Coincidence: High-Impedance State

$\phi_R$ ,  $\phi_V$

**Phase Detector B Outputs (Pins 8, 9)**

These phase detector outputs can be combined externally for a loop-error signal. A single-ended output is also available for this purpose (see **PD<sub>out</sub>**).

If frequency  $f_V$  is greater than  $f_R$  or if the phase of  $f_V$  is leading, then error information is provided by  $\phi_V$  pulsing low.  $\phi_R$  remains essentially high.

If the frequency  $f_V$  is less than  $f_R$  or if the phase of  $f_V$  is lagging, then error information is provided by  $\phi_R$  pulsing low.  $\phi_V$  remains essentially high.

If the frequency of  $f_V = f_R$  and both are in phase, then both  $\phi_V$  and  $\phi_R$  remain high except for a small minimum time period when both pulse low in phase.

$f_V$

**N Counter Output (Pin 10)**

This is the buffered output of the  $\div N$  counter that is inter-

nally connected to the phase detector input. With this output available, the  $\div N$  counter can be used independently.

**LD**

**Lock Detector Output (Pin 28)**

Essentially a high level when loop is locked ( $f_R$ ,  $f_V$  of same phase and frequency). Pulses low when loop is out of lock.

**POWER SUPPLY**

**V<sub>DD</sub>**

**Positive Power Supply (Pin 3)**

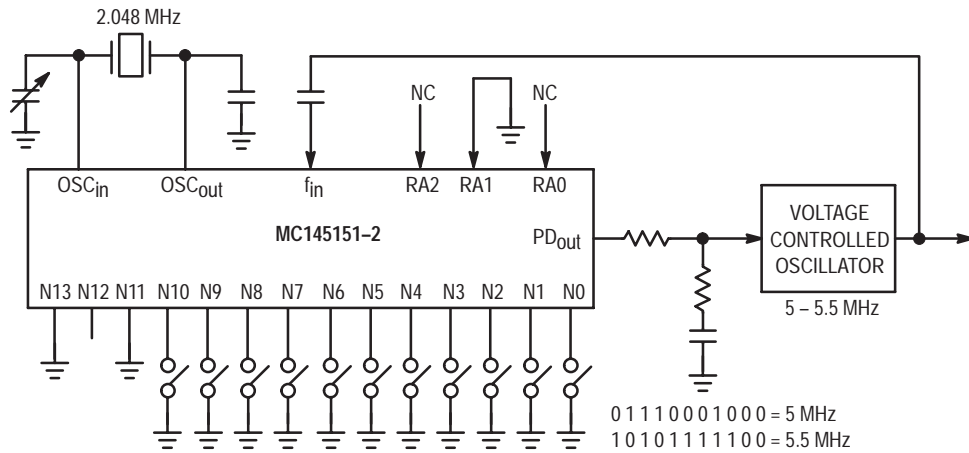
The positive power supply potential. This pin may range from +3 to +9 V with respect to  $V_{SS}$ .

**V<sub>SS</sub>**

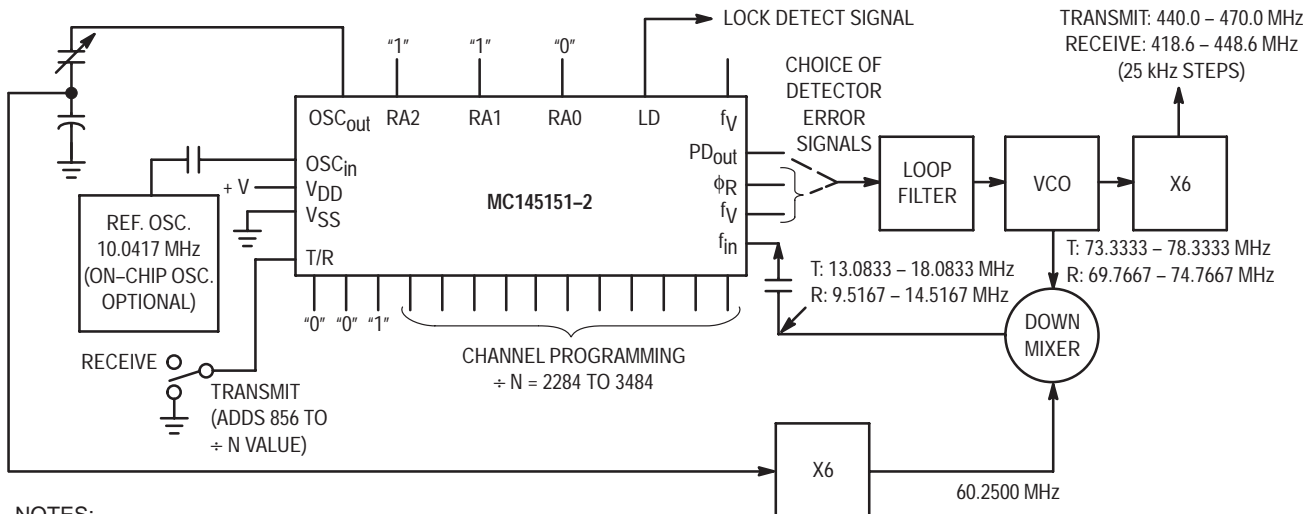
**Negative Power Supply (Pin 2)**

The most negative supply potential. This pin is usually ground.

**TYPICAL APPLICATIONS**



**Figure 1. 5 MHz to 5.5 MHz Local Oscillator Channel Spacing = 1 kHz**



NOTES:

1.  $f_R = 4.1667$  kHz;  $\div R = 2410$ ; 21.4 MHz low side injection during receive.
2. Frequency values shown are for the 440 - 470 MHz band. Similar implementation applies to the 406 - 440 MHz band. For 470 - 512 MHz, consider reference oscillator frequency X9 for mixer injection signal (90.3750 MHz).

**Figure 2. Synthesizer for Land Mobile Radio UHF Bands**

**MC145151-2 Data Sheet Continued on Page 15**

## MC145152-2

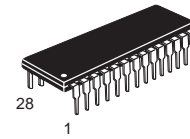
# Parallel-Input PLL Frequency Synthesizer

## Interfaces with Dual-Modulus Prescalers

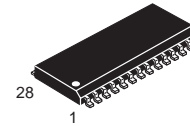
The MC145152-2 is programmed by sixteen parallel inputs for the N and A counters and three input lines for the R counter. The device features consist of a reference oscillator, selectable-reference divider, two-output phase detector, 10-bit programmable divide-by-N counter, and 6-bit programmable ÷ A counter.

The MC145152-2 is an improved-performance drop-in replacement for the MC145152-1. Power consumption has decreased and ESD and latch-up performance have improved.

- Operating Temperature Range: - 40 to 85°C
- Low Power Consumption Through Use of CMOS Technology
- 3.0 to 9.0 V Supply Range
- On- or Off-Chip Reference Oscillator Operation
- Lock Detect Signal
- Dual Modulus/Parallel Programming
- 8 User-Selectable ÷ R Values: 8, 64, 128, 256, 512, 1024, 1160, 2048
- ÷ N Range = 3 to 1023, ÷ A Range = 0 to 63
- Chip Complexity: 8000 FETs or 2000 Equivalent Gates
- See Application Note AN980



**P SUFFIX**  
PLASTIC DIP  
CASE 710



**DW SUFFIX**  
SOG PACKAGE  
CASE 751F

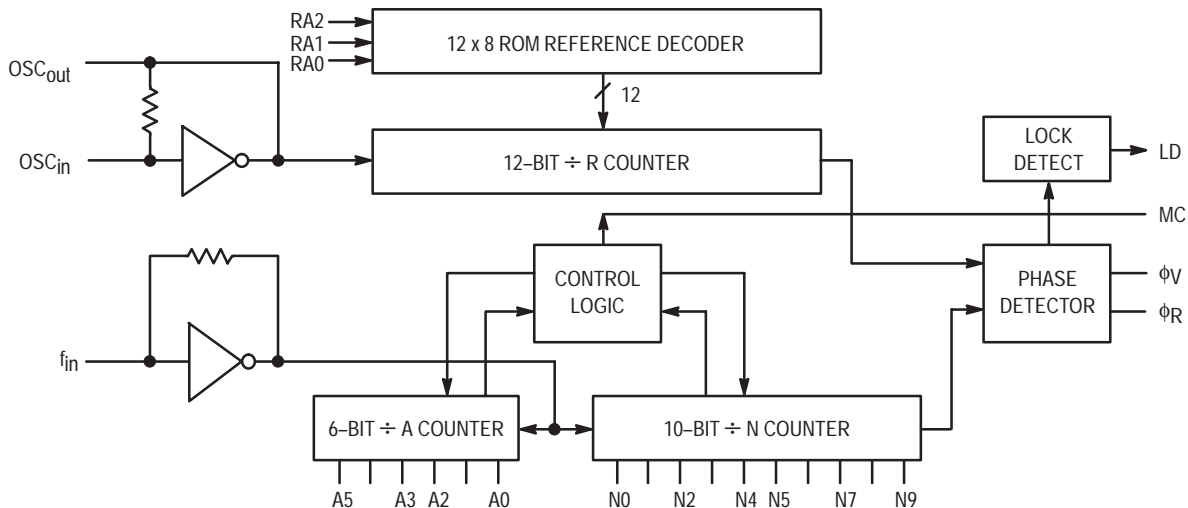
### ORDERING INFORMATION

MC145152P2 Plastic DIP  
MC145152DW2 SOG Package

### PIN ASSIGNMENT

$f_{in}$	1	28	LD
VSS	2	27	OSC <sub>in</sub>
V <sub>DD</sub>	3	26	OSC <sub>out</sub>
RA0	4	25	A4
RA1	5	24	A3
RA2	6	23	A0
$\phi_R$	7	22	A2
$\phi_V$	8	21	A1
MC	9	20	N9
A5	10	19	N8
N0	11	18	N7
N1	12	17	N6
N2	13	16	N5
N3	14	15	N4

## MC145152-2 BLOCK DIAGRAM



NOTE: N0 – N9, A0 – A5, and RA0 – RA2 have pull-up resistors that are not shown.

## PIN DESCRIPTIONS

### INPUT PINS

#### $f_{in}$ Frequency Input (Pin 1)

Input to the positive edge triggered  $\div N$  and  $\div A$  counters.  $f_{in}$  is typically derived from a dual-modulus prescaler and is ac coupled into the device. For larger amplitude signals (standard CMOS logic levels) dc coupling may be used.

#### RA0, RA1, RA2 Reference Address Inputs (Pins 4, 5, 6)

These three inputs establish a code defining one of eight possible divide values for the total reference divider. The total reference divide values are as follows:

Reference Address Code			Total Divide Value
RA2	RA1	RA0	
0	0	0	8
0	0	1	64
0	1	0	128
0	1	1	256
1	0	0	512
1	0	1	1024
1	1	0	1160
1	1	1	2048

#### N0 – N9 N Counter Programming Inputs (Pins 11 – 20)

The N inputs provide the data that is preset into the  $\div N$  counter when it reaches the count of 0. N0 is the least significant digit and N9 is the most significant. Pull-up resistors ensure that inputs left open remain at a logic 1 and require only a SPST switch to alter data to the zero state.

#### A0 – A5 A Counter Programming Inputs (Pins 23, 21, 22, 24, 25, 10)

The A inputs define the number of clock cycles of  $f_{in}$  that require a logic 0 on the MC output (see **Dual-Modulus**

**Prescaling** section). The A inputs all have internal pull-up resistors that ensure that inputs left open will remain at a logic 1.

#### OSC<sub>in</sub>, OSC<sub>out</sub> Reference Oscillator Input/Output (Pins 27, 26)

These pins form an on-chip reference oscillator when connected to terminals of an external parallel resonant crystal. Frequency setting capacitors of appropriate value must be connected from OSC<sub>in</sub> to ground and OSC<sub>out</sub> to ground. OSC<sub>in</sub> may also serve as the input for an externally-generated reference signal. This signal is typically ac coupled to OSC<sub>in</sub>, but for larger amplitude signals (standard CMOS logic levels) dc coupling may also be used. In the external reference mode, no connection is required to OSC<sub>out</sub>.

### OUTPUT PINS

#### $\phi_R$ , $\phi_V$ Phase Detector B Outputs (Pins 7, 8)

These phase detector outputs can be combined externally for a loop-error signal.

If the frequency  $f_V$  is greater than  $f_R$  or if the phase of  $f_V$  is leading, then error information is provided by  $\phi_V$  pulsing low.  $\phi_R$  remains essentially high.

If the frequency  $f_V$  is less than  $f_R$  or if the phase of  $f_V$  is lagging, then error information is provided by  $\phi_R$  pulsing low.  $\phi_V$  remains essentially high.

If the frequency of  $f_V = f_R$  and both are in phase, then both  $\phi_V$  and  $\phi_R$  remain high except for a small minimum time period when both pulse low in phase.

#### MC Dual-Modulus Prescale Control Output (Pin 9)

Signal generated by the on-chip control logic circuitry for controlling an external dual-modulus prescaler. The MC level will be low at the beginning of a count cycle and will remain low until the  $\div A$  counter has counted down from its programmed value. At this time, MC goes high and remains high until the  $\div N$  counter has counted the rest of the way down from its programmed value ( $N - A$  additional counts since both  $\div N$  and  $\div A$  are counting down during the first

portion of the cycle). MC is then set back low, the counters preset to their respective programmed values, and the above sequence repeated. This provides for a total programmable divide value ( $N_T$ ) =  $N \cdot P + A$  where P and P + 1 represent the dual-modulus prescaler divide values respectively for high and low MC levels, N the number programmed into the ÷ N counter, and A the number programmed into the ÷ A counter.

**LD**  
**Lock Detector Output (Pin 28)**

Essentially a high level when loop is locked ( $f_R$ ,  $f_V$  of same phase and frequency). Pulses low when loop is out of lock.

**POWER SUPPLY**

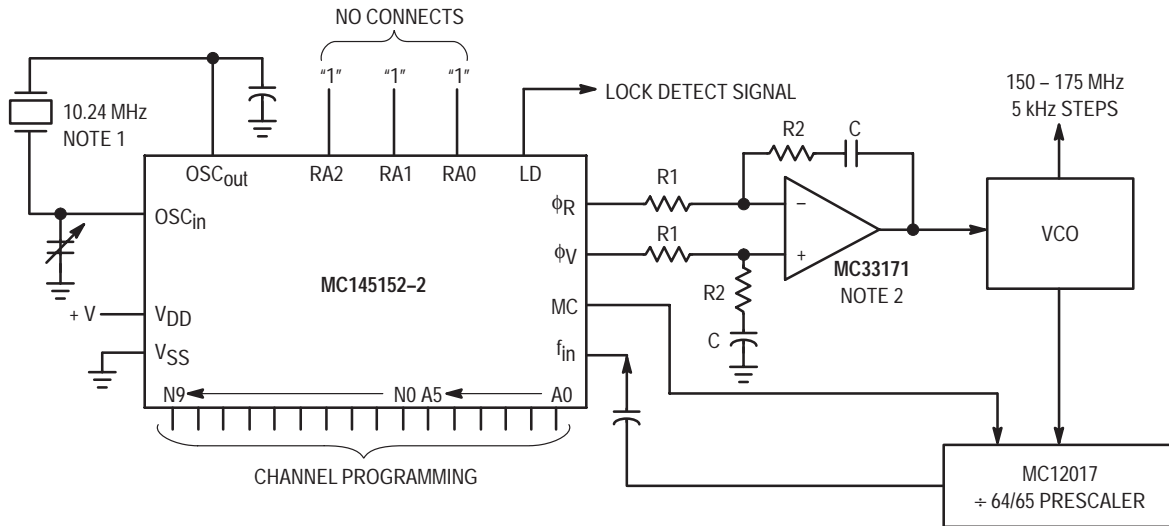
**V<sub>DD</sub>**  
**Positive Power Supply (Pin 3)**

The positive power supply potential. This pin may range from + 3 to + 9 V with respect to V<sub>SS</sub>.

**V<sub>SS</sub>**  
**Negative Power Supply (Pin 2)**

The most negative supply potential. This pin is usually ground.

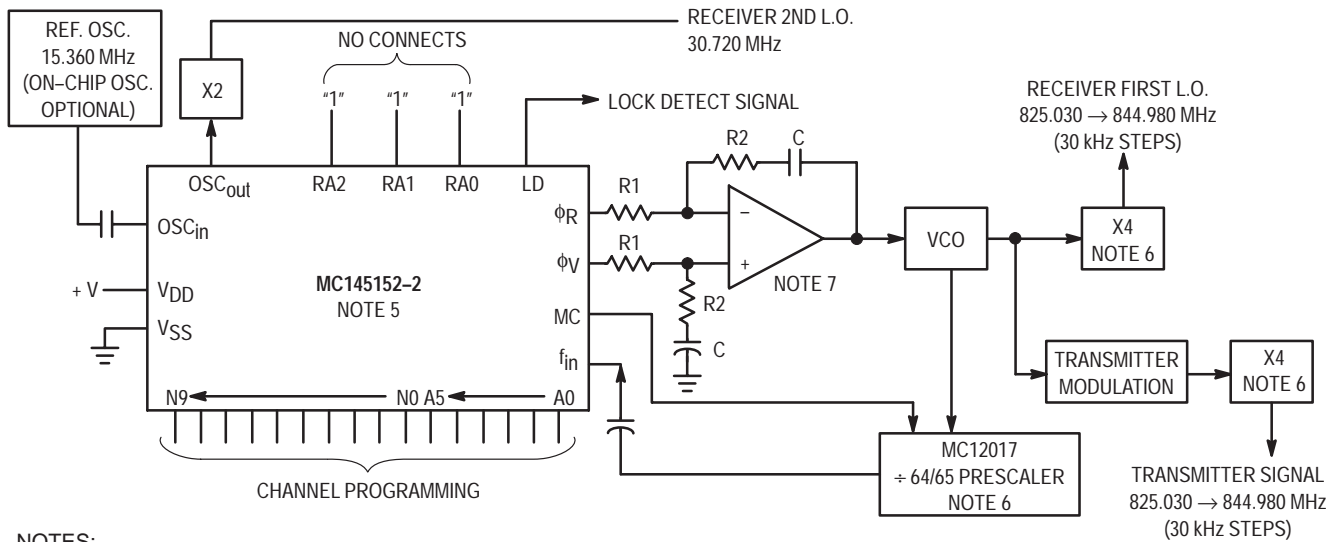
**TYPICAL APPLICATIONS**



**NOTES:**

1. Off-chip oscillator optional.
2. The  $\phi_R$  and  $\phi_V$  outputs are fed to an external combiner/loop filter. See the Phase-Locked Loop — Low-Pass Filter Design page for additional information. The  $\phi_R$  and  $\phi_V$  outputs swing rail-to-rail. Therefore, the user should be careful not to exceed the common mode input range of the op amp used in the combiner/loop filter.

**Figure 1. Synthesizer for Land Mobile Radio VHF Bands**



**NOTES:**

1. Receiver 1st I.F. = 45 MHz, low side injection; Receiver 2nd I.F. = 11.7 MHz, low side injection.
2. Duplex operation with 45 MHz receiver/transmit separation.
3.  $f_R = 7.5 \text{ kHz}$ ;  $\pm R = 2048$ .
4.  $N_{\text{total}} = N \bullet 64 + A = 27501 \text{ to } 28166$ ;  $N = 429 \text{ to } 440$ ;  $A = 0 \text{ to } 63$ .
5. MC145158-2 may be used where serial data entry is desired.
6. High frequency prescalers (e.g., MC12018 [520 MHz] and MC12022 [1 GHz]) may be used for higher frequency VCO and  $f_{\text{ref}}$  implementations.
7. The  $\phi_R$  and  $\phi_V$  outputs are fed to an external combiner/loop filter. See the Phase-Locked Loop — Low-Pass Filter Design page for additional information. The  $\phi_R$  and  $\phi_V$  outputs swing rail-to-rail. Therefore, the user should be careful not to exceed the common mode input range of the op amp used in the combiner/loop filter.

**Figure 2. 666-Channel, Computer-Controlled, Mobile Radiotelephone Synthesizer for 800 MHz Cellular Radio Systems**



## MC145157-2

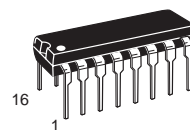
# Serial-Input PLL Frequency Synthesizer

## Interfaces with Single-Modulus Prescalers

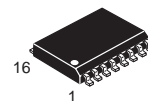
The MC145157-2 has a fully programmable 14-bit reference counter, as well as a fully programmable  $\div N$  counter. The counters are programmed serially through a common data input and latched into the appropriate counter latch, according to the last data bit (control bit) entered.

The MC145157-2 is an improved-performance drop-in replacement for the MC145157-1. Power consumption has decreased and ESD and latch-up performance have improved.

- Operating Temperature Range:  $-40$  to  $85^{\circ}\text{C}$
- Low Power Consumption Through Use of CMOS Technology
- 3.0 to 9.0 V Supply Range
- Fully Programmable Reference and  $\div N$  Counters
- $\div R$  Range = 3 to 16383
- $\div N$  Range = 3 to 16383
- $f_V$  and  $f_R$  Outputs
- Lock Detect Signal
- Compatible with the Serial Peripheral Interface (SPI) on CMOS MCUs
- "Linearized" Digital Phase Detector
- Single-Ended (Three-State) or Double-Ended Phase Detector Outputs
- Chip Complexity: 6504 FETs or 1626 Equivalent Gates



**P SUFFIX**  
PLASTIC DIP  
CASE 648



**DW SUFFIX**  
SOG PACKAGE  
CASE 751G

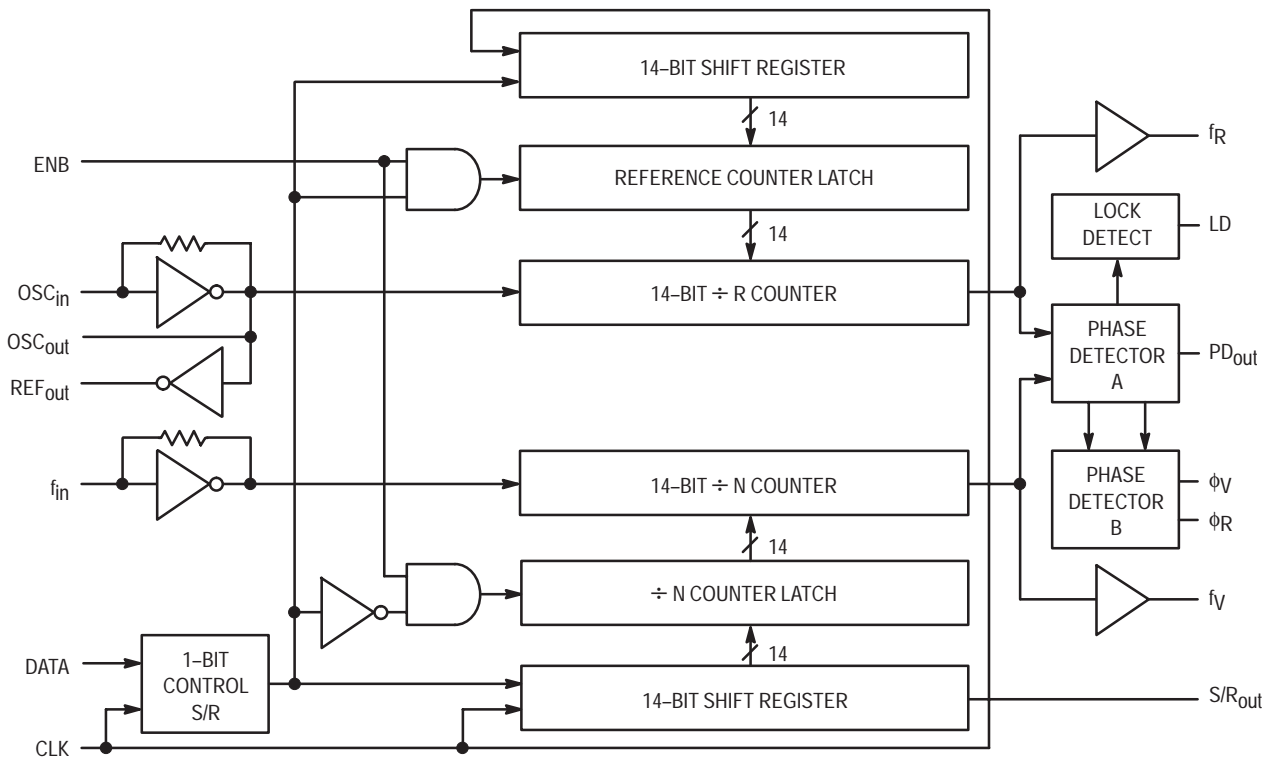
### ORDERING INFORMATION

MC145157P2 Plastic DIP  
MC145157DW2 SOG Package

### PIN ASSIGNMENT

OSC <sub>in</sub>	1	16	$\phi_R$
OSC <sub>out</sub>	2	15	$\phi_V$
$f_V$	3	14	REF <sub>out</sub>
V <sub>DD</sub>	4	13	$f_R$
PD <sub>out</sub>	5	12	S/R <sub>out</sub>
V <sub>SS</sub>	6	11	ENB
LD	7	10	DATA
$f_{in}$	8	9	CLK

## MC145157-2 BLOCK DIAGRAM



## PIN DESCRIPTIONS

### INPUT PINS

#### $f_{in}$ Frequency Input (Pin 8)

Input frequency from VCO output. A rising edge signal on this input decrements the  $\div N$  counter. This input has an inverter biased in the linear region to allow use with ac coupled signals as low as 500 mV p-p. For larger amplitude signals (standard CMOS logic levels), dc coupling may be used.

#### CLK, DATA Shift Clock, Serial Data Inputs (Pins 9, 10)

Each low-to-high transition of the clock shifts one bit of data into the on-chip shift registers. The last data bit entered determines which counter storage latch is activated; a logic 1 selects the reference counter latch and a logic 0 selects the  $\div N$  counter latch. The entry format is as follows:



#### ENB Latch Enable Input (Pin 11)

A logic high on this pin latches the data from the shift register into the reference divider or  $\div N$  latches depending on the control bit. The reference divider latches are activated if the control bit is at a logic high and the  $\div N$  latches are activated

if the control bit is at a logic low. A logic low on this pin allows the user to change the data in the shift registers without affecting the counters. ENB is normally low and is pulsed high to transfer data to the latches.

#### OSCin, OSCout Reference Oscillator Input/Output (Pins 1, 2)

These pins form an on-chip reference oscillator when connected to terminals of an external parallel resonant crystal. Frequency setting capacitors of appropriate value must be connected from OSCin to ground and OSCout to ground. OSCin may also serve as the input for an externally-generated reference signal. This signal is typically ac coupled to OSCin, but for larger amplitude signals (standard CMOS logic levels) dc coupling may also be used. In the external reference mode, no connection is required to OSCout.

### OUTPUT PINS

#### PDout Single-Ended Phase Detector A Output (Pin 5)

This single-ended (three-state) phase detector output produces a loop-error signal that is used with a loop filter to control a VCO.

Frequency  $f_V > f_R$  or  $f_V$  Leading: Negative Pulses  
 Frequency  $f_V < f_R$  or  $f_V$  Lagging: Positive Pulses  
 Frequency  $f_V = f_R$  and Phase Coincidence: High-Impedance State

#### $\phi_R, \phi_V$ Double-Ended Phase Detector B Outputs (Pins 16, 15)

These outputs can be combined externally for a loop-error signal. A single-ended output is also available for this purpose (see PDout).

If frequency  $f_V$  is greater than  $f_R$  or if the phase of  $f_V$  is leading, then error information is provided by  $\phi_V$  pulsing low.  $\phi_R$  remains essentially high.

If the frequency  $f_V$  is less than  $f_R$  or if the phase of  $f_V$  is lagging, then error information is provided by  $\phi_R$  pulsing low.  $\phi_V$  remains essentially high.

If the frequency of  $f_V = f_R$  and both are in phase, then both  $\phi_V$  and  $\phi_R$  remain high except for a small minimum time period when both pulse low in phase.

#### **$f_R, f_V$**

#### **R Counter Output, N Counter Output (Pins 13, 3)**

Buffered, divided reference and  $f_{in}$  frequency outputs. The  $f_R$  and  $f_V$  outputs are connected internally to the  $\div R$  and  $\div N$  counter outputs respectively, allowing the counters to be used independently, as well as monitoring the phase detector inputs.

#### **LD**

#### **Lock Detector Output (Pin 7)**

This output is essentially at a high level when the loop is locked ( $f_R, f_V$  of same phase and frequency), and pulses low when loop is out of lock.

#### **REF<sub>out</sub>**

#### **Buffered Reference Oscillator Output (Pin 14)**

This output can be used as a second local oscillator, reference oscillator to another frequency synthesizer, or as the system clock to a microprocessor controller.

#### **S/R<sub>out</sub>**

#### **Shift Register Output (Pin 12)**

This output can be connected to an external shift register to provide band switching, control information, and counter programming code checking.

#### **POWER SUPPLY**

#### **V<sub>DD</sub>**

#### **Positive Power Supply (Pin 4)**

The positive power supply potential. This pin may range from +3 to +9 V with respect to  $V_{SS}$ .

#### **V<sub>SS</sub>**

#### **Negative Power Supply (Pin 6)**

The most negative supply potential. This pin is usually ground.

## MC145158-2

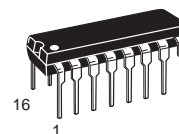
# Serial-Input PLL Frequency Synthesizer

## Interfaces with Dual-Modulus Prescalers

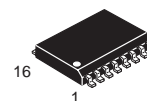
The MC145158-2 has a fully programmable 14-bit reference counter, as well as fully programmable  $\div N$  and  $\div A$  counters. The counters are programmed serially through a common data input and latched into the appropriate counter latch, according to the last data bit (control bit) entered.

The MC145158-2 is an improved-performance drop-in replacement for the MC145158-1. Power consumption has decreased and ESD and latch-up performance have improved.

- Operating Temperature Range:  $-40$  to  $85^{\circ}\text{C}$
- Low Power Consumption Through Use of CMOS Technology
- 3.0 to 9.0 V Supply Range
- Fully Programmable Reference and  $\div N$  Counters
- $\div R$  Range = 3 to 16383
- $\div N$  Range = 3 to 1023
- Dual Modulus Capability;  $\div A$  Range = 0 to 127
- $f_V$  and  $f_R$  Outputs
- Lock Detect Signal
- Compatible with the Serial Peripheral Interface (SPI) on CMOS MCUs
- "Linearized" Digital Phase Detector
- Single-Ended (Three-State) or Double-Ended Phase Detector Outputs
- Chip Complexity: 6504 FETs or 1626 Equivalent Gates



**P SUFFIX**  
PLASTIC DIP  
CASE 648



**DW SUFFIX**  
SOG PACKAGE  
CASE 751G

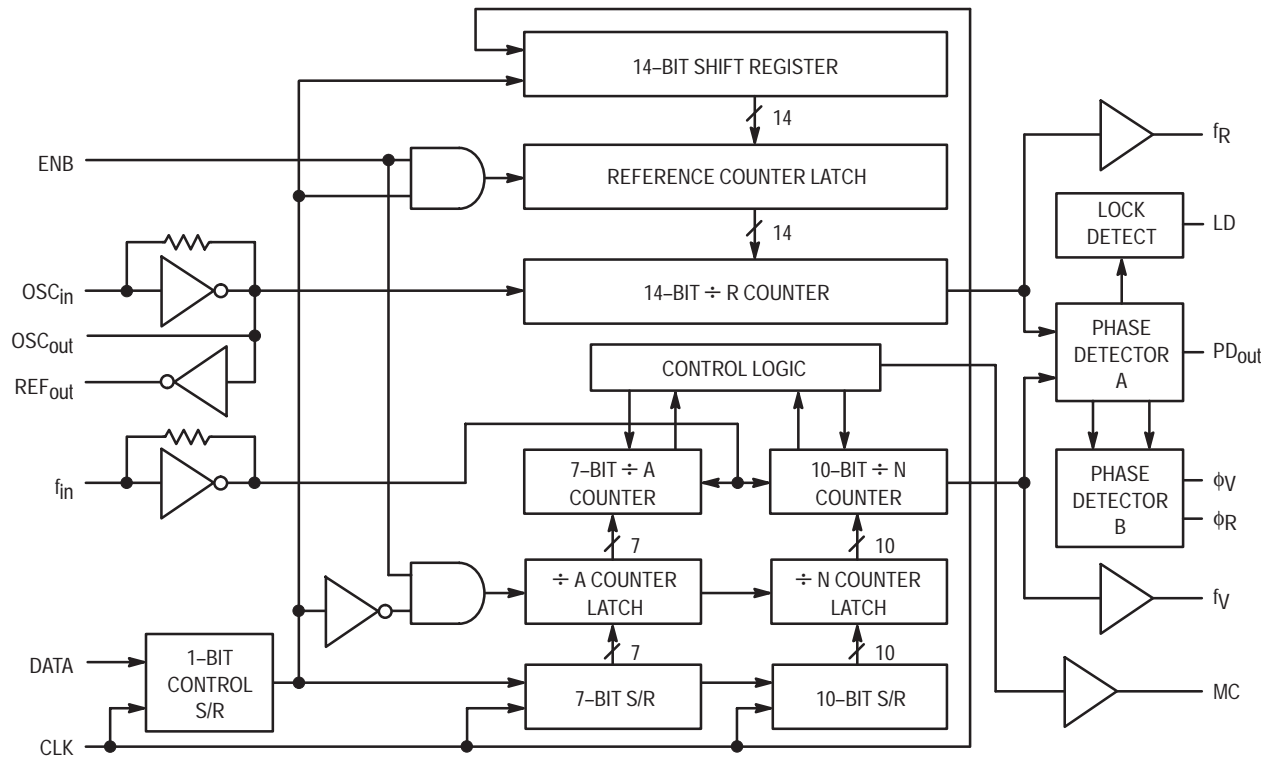
### ORDERING INFORMATION

MC145158P2	Plastic DIP
MC145158DW2	SOG Package

### PIN ASSIGNMENT

OSC <sub>in</sub>	1	16	$\phi_R$
OSC <sub>out</sub>	2	15	$\phi_V$
$f_V$	3	14	REF <sub>out</sub>
V <sub>DD</sub>	4	13	$f_R$
PD <sub>out</sub>	5	12	MC
V <sub>SS</sub>	6	11	ENB
LD	7	10	DATA
$f_{in}$	8	9	CLK

## MC145158-2 BLOCK DIAGRAM



## PIN DESCRIPTIONS

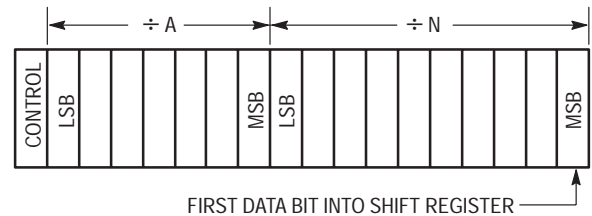
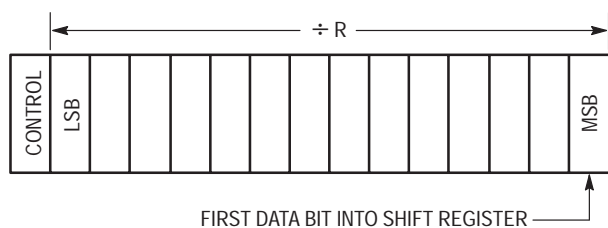
### INPUT PINS

#### $f_{in}$ Frequency Input (Pin 8)

Input frequency from VCO output. A rising edge signal on this input decrements the  $\div A$  and  $\div N$  counters. This input has an inverter biased in the linear region to allow use with ac coupled signals as low as 500 mV p-p. For larger amplitude signals (standard CMOS logic levels), dc coupling may be used.

#### CLK, DATA Shift Clock, Serial Data Inputs (Pins 9, 10)

Each low-to-high transition of the CLK shifts one bit of data into the on-chip shift registers. The last data bit entered determines which counter storage latch is activated; a logic 1 selects the reference counter latch and a logic 0 selects the  $\div A$ ,  $\div N$  counter latch. The data entry format is as follows:



#### ENB Latch Enable Input (Pin 11)

A logic high on this pin latches the data from the shift register into the reference divider or  $\div N$ ,  $\div A$  latches depending on the control bit. The reference divider latches are activated if the control bit is at a logic high and the  $\div N$ ,  $\div A$  latches are activated if the control bit is at a logic low. A logic low on this pin allows the user to change the data in the shift registers without affecting the counters. ENB is normally low and is pulsed high to transfer data to the latches.

#### OSC<sub>in</sub>, OSC<sub>out</sub> Reference Oscillator Input/Output (Pins 1, 2)

These pins form an on-chip reference oscillator when connected to terminals of an external parallel resonant crystal. Frequency setting capacitors of appropriate value must be connected from OSC<sub>in</sub> to ground and OSC<sub>out</sub> to ground. OSC<sub>in</sub> may also serve as the input for an externally-generated reference signal. This signal is typically ac coupled to OSC<sub>in</sub>, but for larger amplitude signals (standard CMOS logic levels) dc coupling may also be used. In the external reference mode, no connection is required to OSC<sub>out</sub>.

## OUTPUT PINS

### PD<sub>out</sub>

#### Phase Detector A Output (Pin 5)

This single-ended (three-state) phase detector output produces a loop-error signal that is used with a loop filter to control a VCO.

Frequency  $f_V > f_R$  or  $f_V$  Leading: Negative Pulses

Frequency  $f_V < f_R$  or  $f_V$  Lagging: Positive Pulses

Frequency  $f_V = f_R$  and Phase Coincidence: High-Impedance State

### $\phi_R, \phi_V$

#### Phase Detector B Outputs (Pins 16, 15)

Double-ended phase detector outputs. These outputs can be combined externally for a loop-error signal. A single-ended output is also available for this purpose (see PD<sub>out</sub>).

If frequency  $f_V$  is greater than  $f_R$  or if the phase of  $f_V$  is leading, then error information is provided by  $\phi_V$  pulsing low.  $\phi_R$  remains essentially high.

If the frequency  $f_V$  is less than  $f_R$  or if the phase of  $f_V$  is lagging, then error information is provided by  $\phi_R$  pulsing low.  $\phi_V$  remains essentially high.

If the frequency of  $f_V = f_R$  and both are in phase, then both  $\phi_V$  and  $\phi_R$  remain high except for a small minimum time period when both pulse low in phase.

### MC

#### Dual-Modulus Prescale Control Output (Pin 12)

This output generates a signal by the on-chip control logic circuitry for controlling an external dual-modulus prescaler. The MC level is low at the beginning of a count cycle and remains low until the  $\div A$  counter has counted down from its programmed value. At this time, MC goes high and remains high until the  $\div N$  counter has counted the rest of the way down from its programmed value ( $N - A$  additional counts since both  $\div N$  and  $\div A$  are counting down during the first portion of the cycle). MC is then set back low, the counters preset to their respective programmed values, and the above sequence repeated. This provides for a total programmable divide value ( $N_T$ ) =  $N \cdot P + A$  where  $P$  and  $P + 1$  represent the

dual-modulus prescaler divide values respectively for high and low modulus control levels,  $N$  the number programmed into the  $\div N$  counter, and  $A$  the number programmed into the  $\div A$  counter. Note that when a prescaler is needed, the dual-modulus version offers a distinct advantage. The dual-modulus prescaler allows a higher reference frequency at the phase detector input, increasing system performance capability, and simplifying the loop filter design.

### $f_R, f_V$

#### R Counter Output, N Counter Output (Pins 13, 3)

Buffered, divided reference and  $f_{in}$  frequency outputs. The  $f_R$  and  $f_V$  outputs are connected internally to the  $\div R$  and  $\div N$  counter outputs respectively, allowing the counters to be used independently, as well as monitoring the phase detector inputs.

### LD

#### Lock Detector Output (Pin 7)

This output is essentially at a high level when the loop is locked ( $f_R, f_V$  of same phase and frequency), and pulses low when loop is out of lock.

### REF<sub>out</sub>

#### Buffered Reference Oscillator Output (Pin 14)

This output can be used as a second local oscillator, reference oscillator to another frequency synthesizer, or as the system clock to a microprocessor controller.

## POWER SUPPLY

### V<sub>DD</sub>

#### Positive Power Supply (Pin 4)

The positive power supply potential. This pin may range from +3 to +9 V with respect to V<sub>SS</sub>.

### V<sub>SS</sub>

#### Negative Power Supply (Pin 6)

The most negative supply potential. This pin is usually ground.

## MC14515X–2 FAMILY CHARACTERISTICS AND DESCRIPTIONS

### MAXIMUM RATINGS\* (Voltages Referenced to $V_{SS}$ )

Symbol	Parameter	Value	Unit
$V_{DD}$	DC Supply Voltage	– 0.5 to + 10.0	V
$V_{in}$ , $V_{out}$	Input or Output Voltage (DC or Transient) except SW1, SW2	– 0.5 to $V_{DD} + 0.5$	V
$V_{out}$	Output Voltage (DC or Transient), SW1, SW2 ( $R_{pull-up} = 4.7\text{ k}\Omega$ )	– 0.5 to + 15	V
$I_{in}$ , $I_{out}$	Input or Output Current (DC or Transient), per Pin	$\pm 10$	mA
$I_{DD}$ , $I_{SS}$	Supply Current, $V_{DD}$ or $V_{SS}$ Pins	$\pm 30$	mA
$P_D$	Power Dissipation, per Package†	500	mW
$T_{stg}$	Storage Temperature	– 65 to + 150	°C
$T_L$	Lead Temperature, 1 mm from Case for 10 seconds	260	°C

\* Maximum Ratings are those values beyond which damage to the device may occur. Functional operation should be restricted to the limits in the Electrical Characteristics tables or Pin Descriptions section.

† Power Dissipation Temperature Derating:

Plastic DIP: – 12 mW/°C from 65 to 85°C

SOG Package: – 7 mW/°C from 65 to 85°C

These devices contain protection circuitry to protect against damage due to high static voltages or electric fields. However, precautions must be taken to avoid applications of any voltage higher than maximum rated voltages to these high-impedance circuits. For proper operation,  $V_{in}$  and  $V_{out}$  should be constrained to the range  $V_{SS} \leq (V_{in} \text{ or } V_{out}) \leq V_{DD}$  except for SW1 and SW2.

SW1 and SW2 can be tied through external resistors to voltages as high as 15 V, independent of the supply voltage.

Unused inputs must always be tied to an appropriate logic voltage level (e.g., either  $V_{SS}$  or  $V_{DD}$ ), except for inputs with pull-up devices. Unused outputs must be left open.

### ELECTRICAL CHARACTERISTICS (Voltages Referenced to $V_{SS}$ )

Symbol	Parameter	Test Condition	$V_{DD}$ V	– 40°C		25°C		85°C		Unit
				Min	Max	Min	Max	Min	Max	
$V_{DD}$	Power Supply Voltage Range		—	3	9	3	9	3	9	V
$I_{SS}$	Dynamic Supply Current	$f_{in} = OSC_{in} = 10\text{ MHz}$ , 1 V p-p ac coupled sine wave $R = 128, A = 32, N = 128$	3 5 9	— — —	3.5 10 30	— — —	3 7.5 24	— — —	3 7.5 24	mA
$I_{SS}$	Quiescent Supply Current (not including pull-up current component)	$V_{in} = V_{DD}$ or $V_{SS}$ $I_{out} = 0\ \mu\text{A}$	3 5 9	— — —	800 1200 1600	— — —	800 1200 1600	— — —	1600 2400 3200	$\mu\text{A}$
$V_{in}$	Input Voltage — $f_{in}$ , $OSC_{in}$	Input ac coupled sine wave	—	500	—	500	—	500	—	mV p-p
$V_{IL}$	Low-Level Input Voltage — $f_{in}$ , $OSC_{in}$	$V_{out} \geq 2.1\text{ V}$ Input dc $V_{out} \geq 3.5\text{ V}$ coupled $V_{out} \geq 6.3\text{ V}$ square wave	3 5 9	— — —	0 0 0	— — —	0 0 0	— — —	0 0 0	V
$V_{IH}$	High-Level Input Voltage — $f_{in}$ , $OSC_{in}$	$V_{out} \leq 0.9\text{ V}$ Input dc $V_{out} \leq 1.5\text{ V}$ coupled $V_{out} \leq 2.7\text{ V}$ square wave	3 5 9	3.0 5.0 9.0	— — —	3.0 5.0 9.0	— — —	3.0 5.0 9.0	— — —	V
$V_{IL}$	Low-Level Input Voltage — except $f_{in}$ , $OSC_{in}$		3 5 9	— — —	0.9 1.5 2.7	— — —	0.9 1.5 2.7	— — —	0.9 1.5 2.7	V
$V_{IH}$	High-Level Input Voltage — except $f_{in}$ , $OSC_{in}$		3 5 9	2.1 3.5 6.3	— — —	2.1 3.5 6.3	— — —	2.1 3.5 6.3	— — —	V
$I_{in}$	Input Current ( $f_{in}$ , $OSC_{in}$ )	$V_{in} = V_{DD}$ or $V_{SS}$	9	$\pm 2$	$\pm 50$	$\pm 2$	$\pm 25$	$\pm 2$	$\pm 22$	$\mu\text{A}$
$I_{IL}$	Input Leakage Current (Data, CLK, ENB — without pull-ups)	$V_{in} = V_{SS}$	9	—	– 0.3	—	– 0.1	—	– 1.0	$\mu\text{A}$
$I_{IH}$	Input Leakage Current (all inputs except $f_{in}$ , $OSC_{in}$ )	$V_{in} = V_{DD}$	9	—	0.3	—	0.1	—	1.0	$\mu\text{A}$

(continued)

DC ELECTRICAL CHARACTERISTICS (continued)

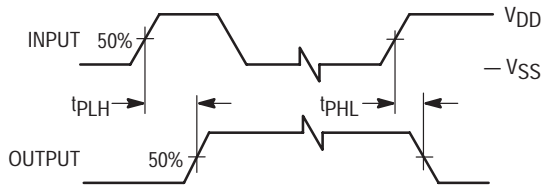
Symbol	Parameter	Test Condition	V <sub>DD</sub> V	- 40°C		25°C		85°C		Unit
				Min	Max	Min	Max	Min	Max	
I <sub>IL</sub>	Pull-up Current (all inputs with pull-ups)	V <sub>in</sub> = V <sub>SS</sub>	9	- 20	- 400	- 20	- 200	- 20	- 170	μA
C <sub>in</sub>	Input Capacitance		—	—	10	—	10	—	10	pF
V <sub>OL</sub>	Low-Level Output Voltage — OSC <sub>out</sub>	I <sub>out</sub> ≈ 0 μA V <sub>in</sub> = V <sub>DD</sub>	3	—	0.9	—	0.9	—	0.9	V
			5	—	1.5	—	1.5	—	1.5	
			9	—	2.7	—	2.7	—	2.7	
V <sub>OH</sub>	High-Level Output Voltage — OSC <sub>out</sub>	I <sub>out</sub> ≈ 0 μA V <sub>in</sub> = V <sub>SS</sub>	3	2.1	—	2.1	—	2.1	—	V
			5	3.5	—	3.5	—	3.5	—	
			9	6.3	—	6.3	—	6.3	—	
V <sub>OL</sub>	Low-Level Output Voltage — Other Outputs	I <sub>out</sub> ≈ 0 μA	3	—	0.05	—	0.05	—	0.05	V
			5	—	0.05	—	0.05	—	0.05	
			9	—	0.05	—	0.05	—	0.05	
V <sub>OH</sub>	High-Level Output Voltage — Other Outputs	I <sub>out</sub> ≈ 0 μA	3	2.95	—	2.95	—	2.95	—	V
			5	4.95	—	4.95	—	4.95	—	
			9	8.95	—	8.95	—	8.95	—	
V(BR)DSS	Drain-to-Source Breakdown Voltage — SW1, SW2	R <sub>pull-up</sub> = 4.7 kΩ	—	15	—	15	—	15	—	V
I <sub>OL</sub>	Low-Level Sinking Current — MC	V <sub>out</sub> = 0.3 V V <sub>out</sub> = 0.4 V V <sub>out</sub> = 0.5 V	3	1.30	—	1.10	—	0.66	—	mA
			5	1.90	—	1.70	—	1.08	—	
			9	3.80	—	3.30	—	2.10	—	
I <sub>OH</sub>	High-Level Sourcing Current — MC	V <sub>out</sub> = 2.7 V V <sub>out</sub> = 4.6 V V <sub>out</sub> = 8.5 V	3	- 0.60	—	- 0.50	—	- 0.30	—	mA
			5	- 0.90	—	- 0.75	—	- 0.50	—	
			9	- 1.50	—	- 1.25	—	- 0.80	—	
I <sub>OL</sub>	Low-Level Sinking Current — LD	V <sub>out</sub> = 0.3 V V <sub>out</sub> = 0.4 V V <sub>out</sub> = 0.5 V	3	0.25	—	0.20	—	0.15	—	mA
			5	0.64	—	0.51	—	0.36	—	
			9	1.30	—	1.00	—	0.70	—	
I <sub>OH</sub>	High-Level Sourcing Current — LD	V <sub>out</sub> = 2.7 V V <sub>out</sub> = 4.6 V V <sub>out</sub> = 8.5 V	3	- 0.25	—	- 0.20	—	- 0.15	—	mA
			5	- 0.64	—	- 0.51	—	- 0.36	—	
			9	- 1.30	—	- 1.00	—	- 0.70	—	
I <sub>OL</sub>	Low-Level Sinking Current — SW1, SW2	V <sub>out</sub> = 0.3 V V <sub>out</sub> = 0.4 V V <sub>out</sub> = 0.5 V	3	0.80	—	0.48	—	0.24	—	mA
			5	1.50	—	0.90	—	0.45	—	
			9	3.50	—	2.10	—	1.05	—	
I <sub>OL</sub>	Low-Level Sinking Current — Other Outputs	V <sub>out</sub> = 0.3 V V <sub>out</sub> = 0.4 V V <sub>out</sub> = 0.5 V	3	0.44	—	0.35	—	0.22	—	mA
			5	0.64	—	0.51	—	0.36	—	
			9	1.30	—	1.00	—	0.70	—	
I <sub>OH</sub>	High-Level Sourcing Current — Other Outputs	V <sub>out</sub> = 2.7 V V <sub>out</sub> = 4.6 V V <sub>out</sub> = 8.5 V	3	- 0.44	—	- 0.35	—	- 0.22	—	mA
			5	- 0.64	—	- 0.51	—	- 0.36	—	
			9	- 1.30	—	- 1.00	—	- 0.70	—	
I <sub>OZ</sub>	Output Leakage Current — PD <sub>out</sub>	V <sub>out</sub> = V <sub>DD</sub> or V <sub>SS</sub> Output in Off State	9	—	± 0.3	—	± 0.1	—	± 1.0	μA
I <sub>OZ</sub>	Output Leakage Current — SW1, SW2	V <sub>out</sub> = V <sub>DD</sub> or V <sub>SS</sub> Output in Off State	9	—	± 0.3	—	± 0.1	—	± 3.0	μA
C <sub>out</sub>	Output Capacitance — PD <sub>out</sub>	PD <sub>out</sub> — Three-State	—	—	10	—	10	—	10	pF



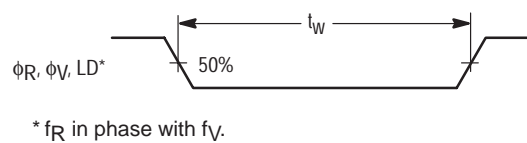
**AC ELECTRICAL CHARACTERISTICS** ( $C_L = 50$  pF, Input  $t_r = t_f = 10$  ns)

Symbol	Parameter	V <sub>DD</sub> V	Guaranteed Limit 25°C	Guaranteed Limit - 40 to 85°C	Unit
t <sub>PLH</sub> , t <sub>PHL</sub>	Maximum Propagation Delay, f <sub>IN</sub> to MC (Figures 1 and 4)	3 5 9	110 60 35	120 70 40	ns
t <sub>PHL</sub>	Maximum Propagation Delay, ENB to SW1, SW2 (Figures 1 and 5)	3 5 9	160 80 50	180 95 60	ns
t <sub>w</sub>	Output Pulse Width, φ <sub>R</sub> , φ <sub>V</sub> , and LD with f <sub>R</sub> in Phase with f <sub>V</sub> (Figures 2 and 4)	3 5 9	25 to 200 20 to 100 10 to 70	25 to 260 20 to 125 10 to 80	ns
t <sub>TLH</sub>	Maximum Output Transition Time, MC (Figures 3 and 4)	3 5 9	115 60 40	115 75 60	ns
t <sub>THL</sub>	Maximum Output Transition Time, MC (Figures 3 and 4)	3 5 9	60 34 30	70 45 38	ns
t <sub>TLH</sub> , t <sub>THL</sub>	Maximum Output Transition Time, LD (Figures 3 and 4)	3 5 9	180 90 70	200 120 90	ns
t <sub>TLH</sub> , t <sub>THL</sub>	Maximum Output Transition Time, Other Outputs (Figures 3 and 4)	3 5 9	160 80 60	175 100 65	ns

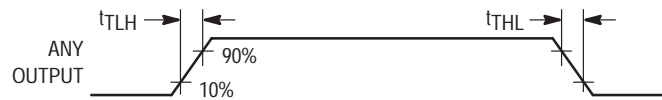
**SWITCHING WAVEFORMS**



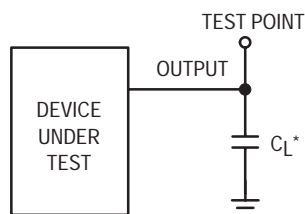
**Figure 1.**



**Figure 2.**

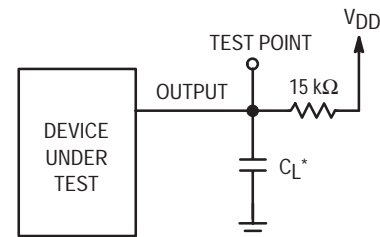


**Figure 3.**



\* Includes all probe and fixture capacitance.

**Figure 4. Test Circuit**



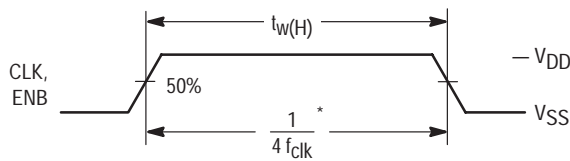
\* Includes all probe and fixture capacitance.

**Figure 5. Test Circuit**

**TIMING REQUIREMENTS** (Input  $t_r = t_f = 10$  ns unless otherwise indicated)

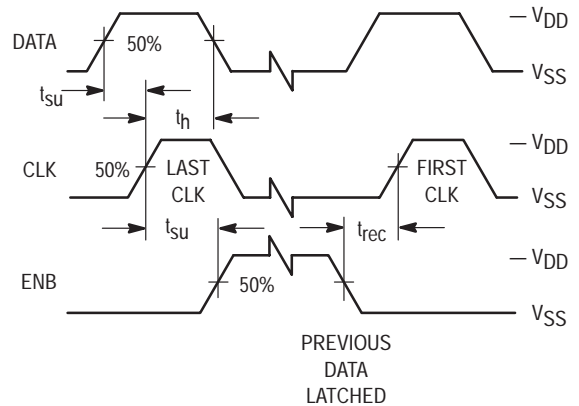
Symbol	Parameter	V <sub>DD</sub> V	Guaranteed Limit 25°C	Guaranteed Limit – 40 to 85°C	Unit
f <sub>clk</sub>	Serial Data Clock Frequency, Assuming 25% Duty Cycle NOTE: Refer to CLK $t_{w(H)}$ below (Figure 6)	3 5 9	dc to 5.0 dc to 7.1 dc to 10	dc to 3.5 dc to 7.1 dc to 10	MHz
t <sub>su</sub>	Minimum Setup Time, Data to CLK (Figure 7)	3 5 9	30 20 18	30 20 18	ns
t <sub>h</sub>	Minimum Hold Time, CLK to Data (Figure 7)	3 5 9	40 20 15	40 20 15	ns
t <sub>su</sub>	Minimum Setup Time, CLK to ENB (Figure 7)	3 5 9	70 32 25	70 32 25	ns
t <sub>rec</sub>	Minimum Recovery Time, ENB to CLK (Figure 7)	3 5 9	5 10 20	5 10 20	ns
t <sub>w(H)</sub>	Minimum Pulse Width, CLK and ENB (Figure 6)	3 5 9	50 35 25	70 35 25	ns
t <sub>r</sub> , t <sub>f</sub>	Maximum Input Rise and Fall Times — Any Input (Figure 8)	3 5 9	5 4 2	5 4 2	μs

**SWITCHING WAVEFORMS**

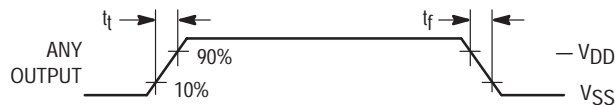


\*Assumes 25% Duty Cycle.

**Figure 6.**



**Figure 7.**

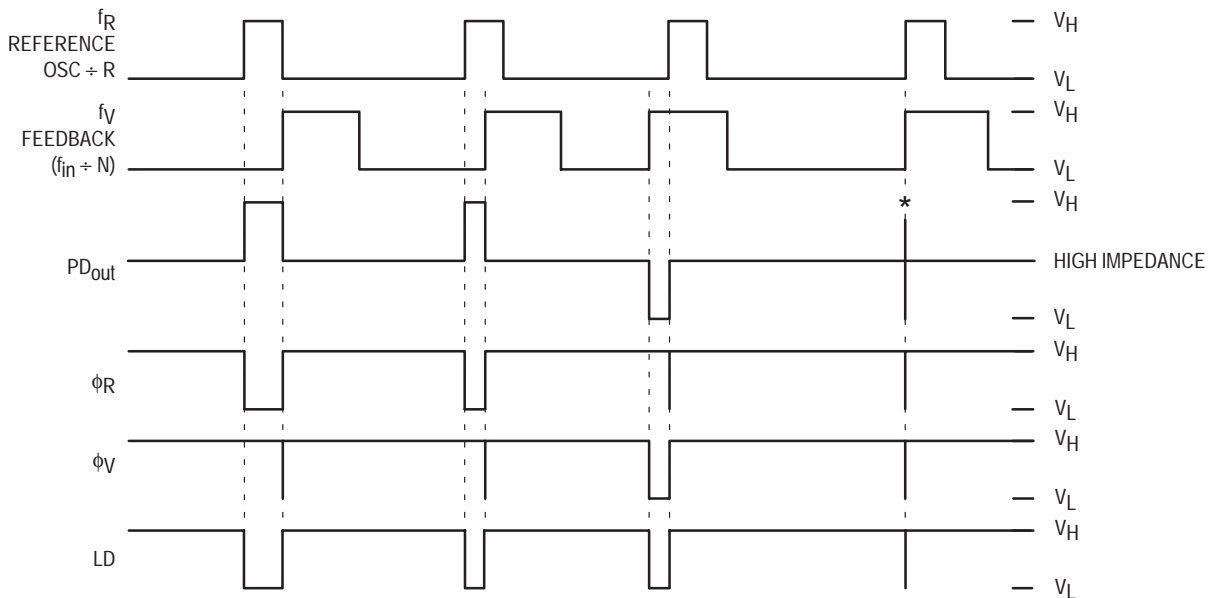


**Figure 8.**

**FREQUENCY CHARACTERISTICS** (Voltages References to  $V_{SS}$ ,  $C_L = 50$  pF, Input  $t_r = t_f = 10$  ns unless otherwise indicated)

Symbol	Parameter	Test Condition	$V_{DD}$ V	- 40°C		25°C		85°C		Unit
				Min	Max	Min	Max	Min	Max	
$f_i$	Input Frequency ( $f_{in}$ , $OSC_{in}$ )	$R \geq 8, A \geq 0, N \geq 8$ $V_{in} = 500$ mV p-p ac coupled sine wave	3	—	6	—	6	—	6	MHz
			5	—	15	—	15	—	15	
			9	—	15	—	15	—	15	
		$R \geq 8, A \geq 0, N \geq 8$ $V_{in} = 1$ V p-p ac coupled sine wave	3	—	12	—	12	—	7	MHz
			5	—	22	—	20	—	20	
			9	—	25	—	22	—	22	
		$R \geq 8, A \geq 0, N \geq 8$ $V_{in} = V_{DD}$ to $V_{SS}$ dc coupled square wave	3	—	13	—	12	—	8	MHz
			5	—	25	—	22	—	22	
			9	—	25	—	25	—	25	

NOTE: Usually, the PLL's propagation delay from  $f_{in}$  to MC plus the setup time of the prescaler determines the upper frequency limit of the system. The upper frequency limit is found with the following formula:  $f = P / (t_p + t_{set})$  where  $f$  is the upper frequency in Hz,  $P$  is the lower of the dual modulus prescaler ratios,  $t_p$  is the  $f_{in}$  to MC propagation delay in seconds, and  $t_{set}$  is the prescaler setup time in seconds. For example, with a 5 V supply, the  $f_{in}$  to MC delay is 70 ns. If the MC12028A prescaler is used, the setup time is 16 ns. Thus, if the 64/65 ratio is utilized, the upper frequency limit is  $f = P / (t_p + t_{set}) = 64 / (70 + 16) = 744$  MHz.



$V_H$  = High Voltage Level.

$V_L$  = Low Voltage Level.

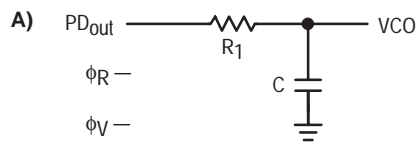
\* At this point, when both  $f_R$  and  $f_V$  are in phase, the output is forced to near mid-supply.

NOTE: The  $PD_{out}$  generates error pulses during out-of-lock conditions. When locked in phase and frequency the output is high and the voltage at this pin is determined by the low-pass filter capacitor.

**Figure 9. Phase Detector/Lock Detector Output Waveforms**

## DESIGN CONSIDERATIONS

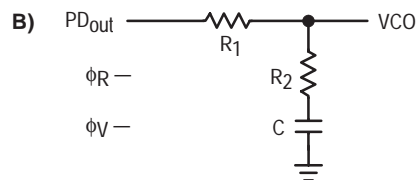
### PHASE-LOCKED LOOP — LOW-PASS FILTER DESIGN



$$\omega_n = \sqrt{\frac{K_\phi K_{VCO}}{NR_1 C}}$$

$$\zeta = \frac{N\omega_n}{2K_\phi K_{VCO}}$$

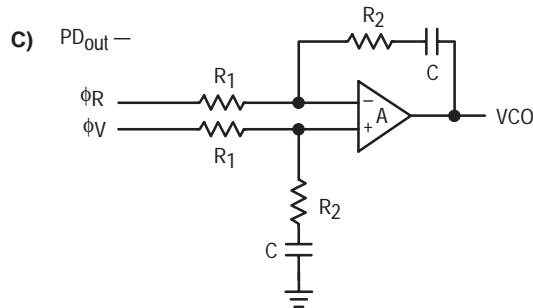
$$F(s) = \frac{1}{R_1 s C + 1}$$



$$\omega_n = \sqrt{\frac{K_\phi K_{VCO}}{NC(R_1 + R_2)}}$$

$$\zeta = 0.5 \omega_n \left( R_2 C + \frac{N}{K_\phi K_{VCO}} \right)$$

$$F(s) = \frac{R_2 s C + 1}{(R_1 + R_2) s C + 1}$$



$$\omega_n = \sqrt{\frac{K_\phi K_{VCO}}{NCR_1}}$$

$$\zeta = \frac{\omega_n R_2 C}{2}$$

ASSUMING GAIN A IS VERY LARGE, THEN:

$$F(s) = \frac{R_2 s C + 1}{R_1 s C}$$

NOTE: Sometimes  $R_1$  is split into two series resistors, each  $R_1 \div 2$ . A capacitor  $C_C$  is then placed from the midpoint to ground to further filter  $\phi_V$  and  $\phi_R$ . The value of  $C_C$  should be such that the corner frequency of this network does not significantly affect  $\omega_n$ . The  $\phi_R$  and  $\phi_V$  outputs swing rail-to-rail. Therefore, the user should be careful not to exceed the common mode input range of the op amp used in the combiner/loop filter.

#### DEFINITIONS:

$N$  = Total Division Ratio in feedback loop

$K_\phi$  (Phase Detector Gain) =  $V_{DD}/4\pi$  for  $PD_{out}$

$K_\phi$  (Phase Detector Gain) =  $V_{DD}/2\pi$  for  $\phi_V$  and  $\phi_R$

$K_{VCO}$  (VCO Gain) =  $\frac{2\pi\Delta f_{VCO}}{\Delta V_{VCO}}$

for a typical design  $\omega_n$  (Natural Frequency)  $\approx \frac{2\pi f_r}{10}$  (at phase detector input).

Damping Factor:  $\zeta \cong 1$

#### RECOMMENDED READING:

Gardner, Floyd M., *Phaselock Techniques (second edition)*. New York, Wiley-Interscience, 1979.

Manassewitsch, Vadim, *Frequency Synthesizers: Theory and Design (second edition)*. New York, Wiley-Interscience, 1980.

Blanchard, Alain, *Phase-Locked Loops: Application to Coherent Receiver Design*. New York, Wiley-Interscience, 1976.

Egan, William F., *Frequency Synthesis by Phase Lock*. New York, Wiley-Interscience, 1981.

Rohde, Ulrich L., *Digital PLL Frequency Synthesizers Theory and Design*. Englewood Cliffs, NJ, Prentice-Hall, 1983.

Berlin, Howard M., *Design of Phase-Locked Loop Circuits, with Experiments*. Indianapolis, Howard W. Sams and Co., 1978.

Kinley, Harold, *The PLL Synthesizer Cookbook*. Blue Ridge Summit, PA, Tab Books, 1980.

AN535, Phase-Locked Loop Design Fundamentals, Motorola Semiconductor Products, Inc., 1970.

AR254, Phase-Locked Loop Design Articles, Motorola Semiconductor Products, Inc., Reprinted with permission from *Electronic Design*, 1987.

## CRYSTAL OSCILLATOR CONSIDERATIONS

The following options may be considered to provide a reference frequency to Motorola's CMOS frequency synthesizers.

### Use of a Hybrid Crystal Oscillator

Commercially available temperature-compensated crystal oscillators (TCXOs) or crystal-controlled data clock oscillators provide very stable reference frequencies. An oscillator capable of sinking and sourcing 50  $\mu$ A at CMOS logic levels may be direct or dc coupled to OSC<sub>in</sub>. In general, the highest frequency capability is obtained utilizing a direct-coupled square wave having a rail-to-rail (V<sub>DD</sub> to V<sub>SS</sub>) voltage swing. If the oscillator does not have CMOS logic levels on the outputs, capacitive or ac coupling to OSC<sub>in</sub> may be used. OSC<sub>out</sub>, an unbuffered output, should be left floating.

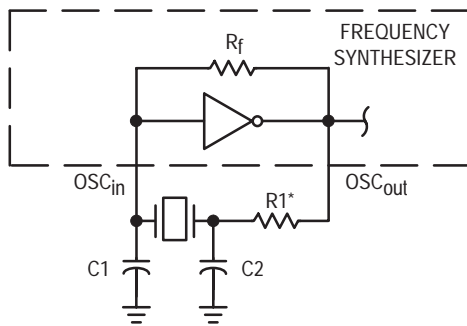
For additional information about TCXOs and data clock oscillators, please consult the latest version of the *eem Electronic Engineers Master Catalog*, the *Gold Book*, or similar publications.

### Design an Off-Chip Reference

The user may design an off-chip crystal oscillator using ICs specifically developed for crystal oscillator applications, such as the MC12061 MECL device. The reference signal from the MECL device is ac coupled to OSC<sub>in</sub>. For large amplitude signals (standard CMOS logic levels), dc coupling is used. OSC<sub>out</sub>, an unbuffered output, should be left floating. In general, the highest frequency capability is obtained with a direct-coupled square wave having rail-to-rail voltage swing.

### Use of the On-Chip Oscillator Circuitry

The on-chip amplifier (a digital inverter) along with an appropriate crystal may be used to provide a reference source frequency. A fundamental mode crystal, parallel resonant at the desired operating frequency, should be connected as shown in Figure 10.



\* May be deleted in certain cases. See text.

**Figure 10. Pierce Crystal Oscillator Circuit**

For V<sub>DD</sub> = 5.0 V, the crystal should be specified for a loading capacitance, C<sub>L</sub>, which does not exceed 32 pF for frequencies to approximately 8.0 MHz, 20 pF for frequencies in the area of 8.0 to 15 MHz, and 10 pF for higher frequencies. These are guidelines that provide a reasonable compromise between IC capacitance, drive capability, swamping variations in stray and IC input/output capacitance, and realistic

C<sub>L</sub> values. The shunt load capacitance, C<sub>L</sub>, presented across the crystal can be estimated to be:

$$C_L = \frac{C_{in}C_{out}}{C_{in} + C_{out}} + C_a + C_o + \frac{C_1 \cdot C_2}{C_1 + C_2}$$

where

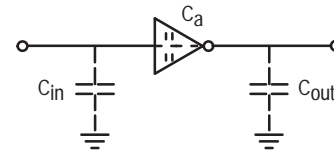
C<sub>in</sub> = 5 pF (see Figure 11)

C<sub>out</sub> = 6 pF (see Figure 11)

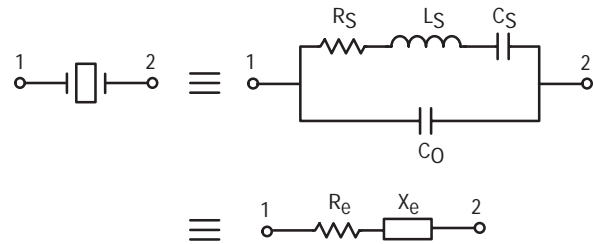
C<sub>a</sub> = 1 pF (see Figure 11)

C<sub>o</sub> = the crystal's holder capacitance (see Figure 12)

C1 and C2 = external capacitors (see Figure 10)



**Figure 11. Parasitic Capacitances of the Amplifier**



NOTE: Values are supplied by crystal manufacturer (parallel resonant crystal).

**Figure 12. Equivalent Crystal Networks**

The oscillator can be "trimmed" on-frequency by making a portion or all of C1 variable. The crystal and associated components must be located as close as possible to the OSC<sub>in</sub> and OSC<sub>out</sub> pins to minimize distortion, stray capacitance, stray inductance, and startup stabilization time. In some cases, stray capacitance should be added to the value for C<sub>in</sub> and C<sub>out</sub>.

Power is dissipated in the effective series resistance of the crystal, R<sub>e</sub>, in Figure 12. The drive level specified by the crystal manufacturer is the maximum stress that a crystal can withstand without damage or excessive shift in frequency. R1 in Figure 10 limits the drive level. The use of R1 may not be necessary in some cases (i.e., R1 = 0  $\Omega$ ).

To verify that the maximum dc supply voltage does not overdrive the crystal, monitor the output frequency as a function of voltage at OSC<sub>out</sub>. (Care should be taken to minimize loading.) The frequency should increase very slightly as the dc supply voltage is increased. An overdriven crystal will decrease in frequency or become unstable with an increase in supply voltage. The operating supply voltage must be reduced or R1 must be increased in value if the overdriven condition exists. The user should note that the oscillator start-up time is proportional to the value of R1.

Through the process of supplying crystals for use with CMOS inverters, many crystal manufacturers have developed expertise in CMOS oscillator design with crystals. Discussions with such manufacturers can prove very helpful (see Table 1).

**Table 1. Partial List of Crystal Manufacturers**

Motorola — Internet Address <i>http://motorola.com</i> (Search for resonators)
United States Crystal Corp.
Crystek Crystal
Statek Corp.
Fox Electronics

NOTE: Motorola cannot recommend one supplier over another and in no way suggests that this is a complete listing of crystal manufacturers.

**RECOMMENDED READING**

- Technical Note TN–24, Statek Corp.
- Technical Note TN–7, Statek Corp.
- E. Hafner, “The Piezoelectric Crystal Unit – Definitions and Method of Measurement”, *Proc. IEEE*, Vol. 57, No. 2 Feb., 1969.
- D. Kemper, L. Rosine, “Quartz Crystals for Frequency Control”, *Electro–Technology*, June, 1969.
- P. J. Ottowitz, “A Guide to Crystal Selection”, *Electronic Design*, May, 1966.

**DUAL–MODULUS PRESCALING**

**OVERVIEW**

The technique of dual–modulus prescaling is well established as a method of achieving high performance frequency synthesizer operation at high frequencies. Basically, the approach allows relatively low–frequency programmable counters to be used as high–frequency programmable counters with speed capability of several hundred MHz. This is possible without the sacrifice in system resolution and performance that results if a fixed (single–modulus) divider is used for the prescaler.

In dual–modulus prescaling, the lower speed counters must be uniquely configured. Special control logic is necessary to select the divide value P or P + 1 in the prescaler for the required amount of time (see modulus control definition). Motorola’s dual–modulus frequency synthesizers contain this feature and can be used with a variety of dual–modulus prescalers to allow speed, complexity and cost to be tailored to the system requirements. Prescalers having P, P + 1 divide values in the range of ÷ 3/÷ 4 to ÷ 128/÷ 129 can be controlled by most Motorola frequency synthesizers.

Several dual–modulus prescaler approaches suitable for use with the MC145152–2, MC145156–2, or MC145158–2 are:

MC12009	÷ 5/÷ 6	440 MHz
MC12011	÷ 8/÷ 9	500 MHz
MC12013	÷ 10/÷ 11	500 MHz
MC12015	÷ 32/÷ 33	225 MHz
MC12016	÷ 40/÷ 41	225 MHz
MC12017	÷ 64/÷ 65	225 MHz
MC12018	÷ 128/÷ 129	520 MHz
MC12028A	÷ 32/33 or ÷ 64/65	1.1 GHz
MC12052A	÷ 64/65 or ÷ 128/129	1.1 GHz
MC12054A	÷ 64/65 or ÷ 128/129	2.0 GHz

**DESIGN GUIDELINES**

The system total divide value, N<sub>total</sub> (N<sub>T</sub>) will be dictated by the application:

$$N_T = \frac{\text{frequency into the prescaler}}{\text{frequency into the phase detector}} = N \cdot P + A$$

N is the number programmed into the ÷ N counter, A is the number programmed into the ÷ A counter, P and P + 1 are the two selectable divide ratios available in the dual–modulus prescalers. To have a range of N<sub>T</sub> values in sequence, the ÷ A counter is programmed from zero through P – 1 for a particular value N in the ÷ N counter. N is then incremented to N + 1 and the ÷ A is sequenced from 0 through P – 1 again.

There are minimum and maximum values that can be achieved for N<sub>T</sub>. These values are a function of P and the size of the ÷ N and ÷ A counters.

The constraint N ≥ A always applies. If A<sub>max</sub> = P – 1, then N<sub>min</sub> ≥ P – 1. Then N<sub>Tmin</sub> = (P – 1) P + A or (P – 1) P since A is free to assume the value of 0.

$$N_{Tmax} = N_{max} \cdot P + A_{max}$$

To maximize system frequency capability, the dual–modulus prescaler output must go from low to high after each group of P or P + 1 input cycles. The prescaler should divide by P when its modulus control line is high and by P + 1 when its MC is low.

For the maximum frequency into the prescaler (f<sub>VCOmax</sub>), the value used for P must be large enough such that:

- f<sub>VCOmax</sub> divided by P may not exceed the frequency capability of f<sub>in</sub> (input to the ÷ N and ÷ A counters).
- The period of f<sub>VCO</sub> divided by P must be greater than the sum of the times:
  - Propagation delay through the dual–modulus prescaler.
  - Prescaler setup or release time relative to its MC signal.
  - Propagation time from f<sub>in</sub> to the MC output for the frequency synthesizer device.

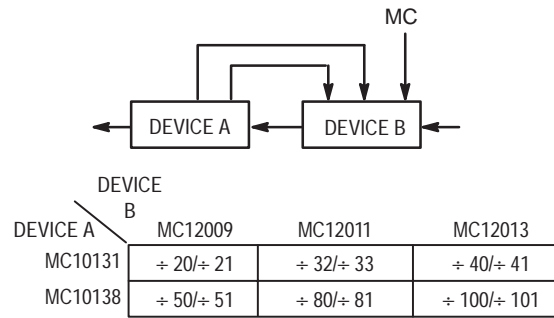
A sometimes useful simplification in the programming code can be achieved by choosing the values for P of 8, 16, 32, or 64. For these cases, the desired value of N<sub>T</sub> results when N<sub>T</sub> in binary is used as the program code to the ÷ N and ÷ A counters treated in the following manner:

- Assume the ÷ A counter contains “a” bits where 2<sup>a</sup> ≥ P.
- Always program all higher order ÷ A counter bits above “a” to 0.

3. Assume the  $\div N$  counter and the  $\div A$  counter (with all the higher order bits above “a” ignored) combined into a single binary counter of  $n + a$  bits in length ( $n =$  number of divider stages in the  $\div N$  counter). The MSB of this “hypothetical” counter is to correspond to the MSB of  $\div N$  and

the LSB is to correspond to the LSB of  $\div A$ . The system divide value,  $N_T$ , now results when the value of  $N_T$  in binary is used to program the “new”  $n + a$  bit counter.

By using the two devices, several dual-modulus values are achievable (shown in Figure 13).

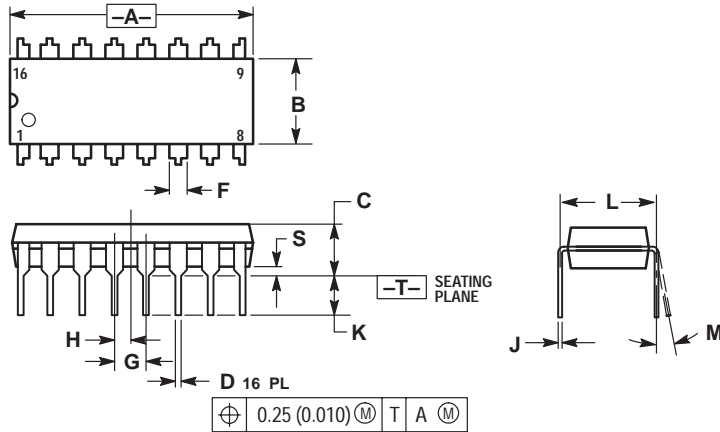


NOTE: MC12009, MC12011, and MC12013 are pin equivalent.  
MC12015, MC12016, and MC12017 are pin equivalent.

**Figure 13. Dual-Modulus Values**

## PACKAGE DIMENSIONS

### P SUFFIX PLASTIC DIP CASE 648-08 (MC145157-2, MC145158-D)

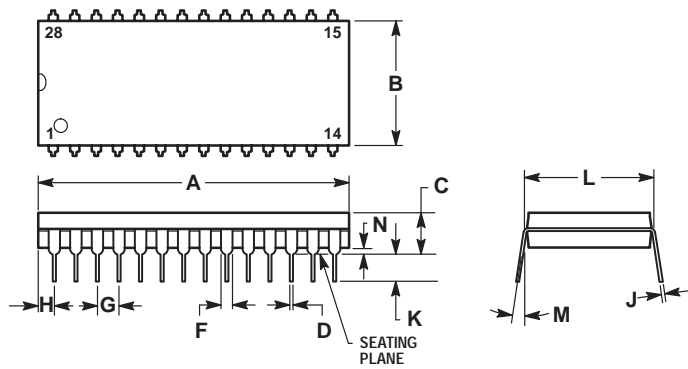


#### NOTES:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
4. DIMENSION B DOES NOT INCLUDE MOLD FLASH.
5. ROUNDED CORNERS OPTIONAL.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.740	0.770	18.80	19.55
B	0.250	0.270	6.35	6.85
C	0.145	0.175	3.69	4.44
D	0.015	0.021	0.39	0.53
F	0.040	0.70	1.02	1.77
G	0.100 BSC		2.54 BSC	
H	0.050 BSC		1.27 BSC	
J	0.008	0.015	0.21	0.38
K	0.110	0.130	2.80	3.30
L	0.295	0.305	7.50	7.74
M	0°	10°	0°	10°
S	0.020	0.040	0.51	1.01

### P SUFFIX PLASTIC DIP CASE 710-02 (MC145151-2, MC145152-2)



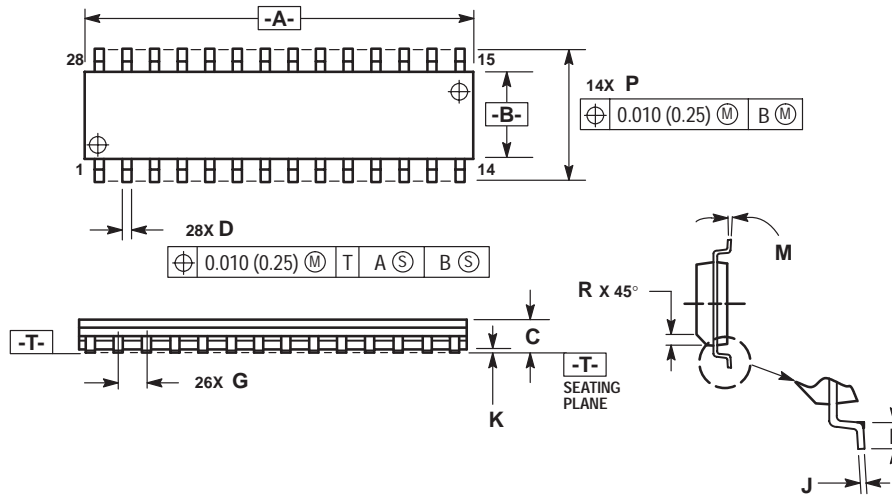
#### NOTES:

1. POSITIONAL TOLERANCE OF LEADS (D), SHALL BE WITHIN 0.25mm (0.010) AT MAXIMUM MATERIAL CONDITION, IN RELATION TO SEATING PLANE AND EACH OTHER.
2. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
3. DIMENSION B DOES NOT INCLUDE MOLD FLASH.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	36.45	37.21	1.435	1.465
B	13.72	14.22	0.540	0.560
C	3.94	5.08	0.155	0.200
D	0.36	0.56	0.014	0.022
F	1.02	1.52	0.040	0.060
G	2.54 BSC		0.100 BSC	
H	1.65	2.16	0.065	0.085
J	0.20	0.38	0.008	0.015
K	2.92	3.43	0.115	0.135
L	15.24 BSC		0.600 BSC	
M	0°	15°	0°	15°
N	0.51	1.02	0.020	0.040



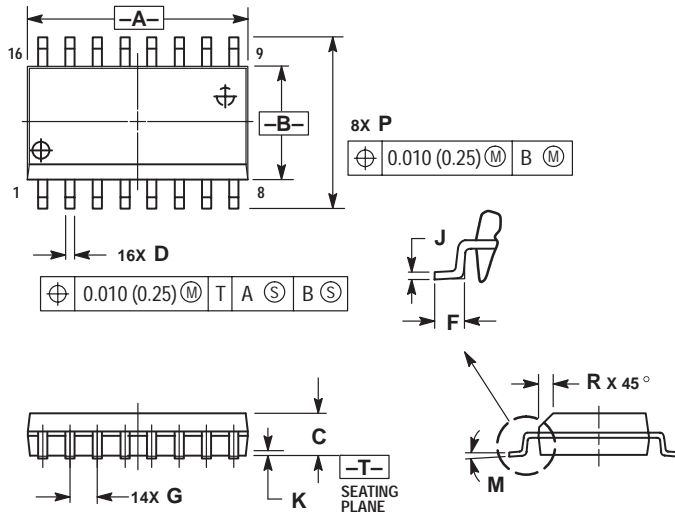
**DW SUFFIX  
SOG PACKAGE  
CASE 751F-04  
(MC145151-2, MC145152-2)**



- NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
  2. CONTROLLING DIMENSION: MILLIMETER.
  3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
  4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
  5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 (0.005) TOTAL IN EXCESS OF D DIMENSION AT MAXIMUM MATERIAL CONDITION.


DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	17.80	18.05	0.701	0.711
B	7.40	7.60	0.292	0.299
C	2.35	2.65	0.093	0.104
D	0.35	0.49	0.014	0.019
F	0.41	0.90	0.016	0.035
G	1.27 BSC		0.050 BSC	
J	0.23	0.32	0.009	0.013
K	0.13	0.29	0.005	0.011
M	0°	8°	0°	8°
P	10.05	10.55	0.395	0.415
R	0.25	0.75	0.010	0.029

**DW SUFFIX  
SOG PACKAGE  
CASE 751G-02  
(MC145157-2, MC145158-2)**



- NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
  2. CONTROLLING DIMENSION: MILLIMETER.
  3. DIMENSIONS A AND B DO NOT INCLUDE MOLD PROTRUSION.
  4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
  5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.13 (0.005) TOTAL IN EXCESS OF D DIMENSION AT MAXIMUM MATERIAL CONDITION.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	10.15	10.45	0.400	0.411
B	7.40	7.60	0.292	0.299
C	2.35	2.65	0.093	0.104
D	0.35	0.49	0.014	0.019
F	0.50	0.90	0.020	0.035
G	1.27 BSC		0.050 BSC	
J	0.25	0.32	0.010	0.012
K	0.10	0.25	0.004	0.009
M	0°	7°	0°	7°
P	10.05	10.55	0.395	0.415
R	0.25	0.75	0.010	0.029

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