National Semiconductor

CD4046BM/CD4046BC Micropower Phase-Locked Loop

General Description

The CD4046B micropower phase-locked loop (PLL) consists of a low power, linear, voltage-controlled oscillator (VCO), a source follower, a zener diode, and two phase comparators. The two phase comparators have a common signal input and a common comparator input. The signal input can be directly coupled for a large voltage signal, or capacitively coupled to the self-biasing amplifier at the signal input for a small voltage signal.

Phase comparator I, an exclusive OR gate, provides a digital error signal (phase comp. I Out) and maintains 90° phase shifts at the VCO center frequency. Between signal input and comparator input (both at 50% duty cycle), it may lock onto the signal input frequencies that are close to harmonics of the VCO center frequency.

Phase comparator II is an edge-controlled digital memory network. It provides a digital error signal (phase comp. II Out) and lock-in signal (phase pulses) to indicate a locked condition and maintains a 0° phase shift between signal input and comparator input.

The linear voltage-controlled oscillator (VCO) produces an output signal (VCO Out) whose frequency is determined by the voltage at the VCO_{IN} input, and the capacitor and resistors connected to pin $C1_A$, $C1_B$, R1 and R2.

The source follower output of the VCO_{IN} (demodulator Out) is used with an external resistor of 10kΩ or more.

The INHIBIT input, when high, disables the VCO and source follower to minimize standby power consumption. The zener diode is provided for power supply regulation, if necessary.

Features

■ Wide supply voltage range	3.0V to 18V
■ Low dynamic power consumption	70μW (typ.) at f_o = 10kHz, V_{DD} = 5V
■ VCO frequency	1.3MHz (typ.) at V_{DD} = 10V
■ Low frequency drift with temperature	0.06%/°C at V_{DD} = 10V
■ High VCO linearity	1% (typ.)

Applications

- FM demodulator and modulator
- Frequency synthesis and multiplication
- Frequency discrimination
- Data synchronization and conditioning
- Voltage-to-frequency conversion
- Tone decoding
- FSK modulation
- Motor speed control

Block and Connection Diagrams

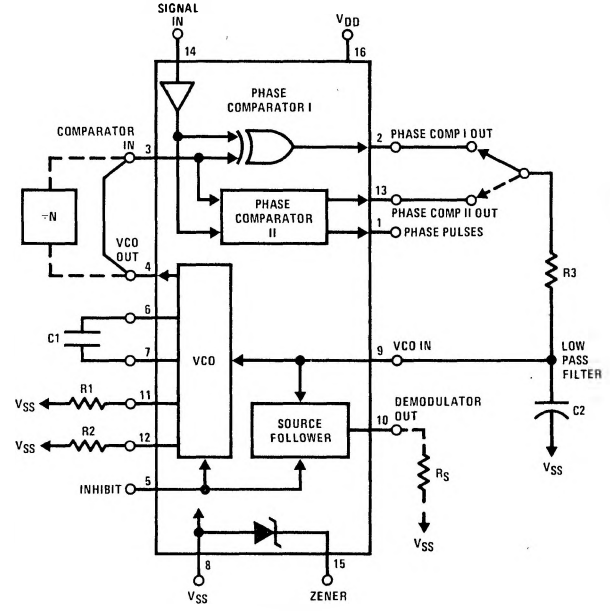
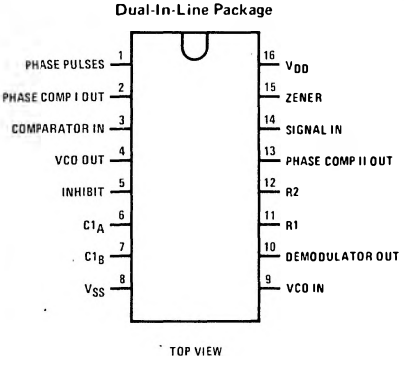


FIGURE 1



Absolute Maximum Ratings

(Notes 1 and 2)

V_{DD} DC Supply Voltage	−0.5 to +18 V_{DC}
V_{IN} Input Voltage	−0.5 to V_{DD} + 0.5 V_{DC}
T_S Storage Temperature Range	−65°C to +150°C
P_D Package Dissipation	500 mW
T_L Lead Temperature (Soldering, 10 seconds)	300°C

Recommended Operating Conditions

(Note 2)

V_{DD} DC Supply Voltage	3 to 15 V_{DC}
V_{IN} Input Voltage	0 to $V_{DD}V_{DC}$
T_A Operating Temperature Range	
CD4046BM	−55°C to +125°C
CD4046BC	−40°C to +85°C

DC Electrical Characteristics CD4046BM (Note 2)

Parameter	Conditions	−55°C		25°C			125°C		Units
		Min	Max	Min	Typ	Max	Min	Max	
I_{DD} Quiescent Device Current	PIN 5 = V_{DD}, PIN 14 = V_{DD}, PIN 3, 9 = V_{SS}								
	V_{DD} = 5V		5		0.005	5		150	μA
	V_{DD} = 10V		10		0.01	10		300	μA
	V_{DD} = 15V		20		0.015	20		600	μA
	PIN 5 = V_{DD}, PIN 14 = Open PIN 3,2 = V_{SS}								
	V_{DD} = 5V		45		5	35		185	μA
	V_{DD} = 10V		450		20	350		650	μA
	V_{DD} = 15V		1200		50	900		1500	μA
V_{OL} Low Level Output Voltage	V_{DD} = 5V		0.05		0	0.05		0.05	V
	V_{DD} = 10V		0.05		0	0.05		0.05	V
	V_{DD} = 15V		0.05		0	0.05		0.05	V
V_{OH} High Level Output Voltage	V_{DD} = 5V	4.95		4.95	5		4.95		V
	V_{DD} = 10V	9.95		9.95	10		9.95		V
	V_{DD} = 15V	14.95		14.95	15		14.95		V
V_{IL} Low Level Input Voltage Comparator and Signal In	V_{DD} = 5V, V_O = 0.5V or 4.5V		1.5		2.25	1.5		1.5	V
	V_{DD} = 10V V_O = 1V or 9V		3.0		4.5	3.0		3.0	V
	V_{DD} = 15V V_O = 1.5V or 13.5V		4.0		6.25	4.0		4.0	V
V_{IH} High Level Input Voltage Comparator and Signal In	V_{DD} = 5V, V_O = 0.5V or 4.5V	3.5		3.5	2.75		3.5		V
	V_{DD} = 10V, V_O = 1V or 9V	7.0		7.0	5.5		7.0		V
	V_{DD} = 15V, V_O = 1.5V or 13.5V	11.0		11.0	8.25		11.0		V
I_{OL} Low Level Output Current	V_{DD} = 5V, V_O = 0.4V	0.64		0.51	0.88		0.36		mA
	V_{DD} = 10V, V_O = 0.5V	1.6		1.3	2.25		0.9		mA
	V_{DD} = 15V, V_O = 1.5V	4.2		3.4	8.8		2.4		mA
I_{OH} High Level Output Current	V_{DD} = 5V, V_O = 4.6V	−0.64		−0.51	−0.88		−0.36		mA
	V_{DD} = 10V, V_O = 9.5V	−1.6		−1.3	−2.25		−0.9		mA
	V_{DD} = 15V, V_O = 13.5V	−4.2		−3.4	−8.8		−2.4		mA
I_{IN} Input Current	All Inputs Except Signal Input								
	V_{DD} = 14V, V_{IN} = 0V		−0.1		-10^{-5}	−0.1		−1.0	μA
	V_{DD} = 15V, V_{IN} = 15V		0.1		10^{-5}	0.1		1.0	μA
C_{IN} Input Capacitance	Any Input, (Note 3)							7.5	pF
P_T Total Power Dissipation	f_o = 10kHz, R1 = 1MΩ R2 = ∞, VCO_{IN} = $V_{DD}/2$								
	V_{DD} = 5V				0.07				mW
	V_{DD} = 10V				0.6				mW
	V_{DD} = 15V				2.4				mW

DC Electrical Characteristics CD4046BC (Note 2)

Parameter	Conditions	−40°C		25°C			85°C		Units
		Min	Max	Min	Typ	Max	Min	Max	
I_{DD} Quiescent Device Current	PIN 5 = V_{DD}, PIN 14 = V_{DD}, PIN 3,9 = V_{SS}								
	V_{DD} = 5V		20		0.005	20		150	μA
	V_{DD} = 10V		40		0.01	40		300	μA
	V_{DD} = 15V		80		0.015	80		600	μA
	PIN 5 = V_{DD}, PIN 14 = Open, PIN 3,9 = V_{SS}								
	V_{DD} = 5V		70		5	55		205	μA
	V_{DD} = 10V		530		20	410		710	μA
	V_{DD} = 15V		1500		50	1200		1800	μA
V_{OL} Low Level Output Voltage	V_{DD} = 5V		0.05		0	0.05		0.05	V
	V_{DD} = 10V		0.05		0	0.05		0.05	V
	V_{DD} = 15V		0.05		0	0.05		0.05	V
V_{OH} High Level Output Voltage	V_{DD} = 5V	4.95		4.95	5		4.95		V
	V_{DD} = 10V	9.95		9.95	10		9.95		V
	V_{DD} = 15V	14.95		14.95	15		14.95		V
V_{IL} Low Level Input Voltage Comparator and Signal In	V_{DD} = 5V, V_O = 0.5V or 4.5V		1.5		2.25	1.5		1.5	V
	V_{DD} = 10V V_O = 1V or 9V		3.0		4.5	3.0		3.0	V
	V_{DD} = 15V, V_O = 1.5V or 13.5V		4.0		6.25	4.0		4.0	V
V_{IH} High Level Input Voltage Comparator and Signal In	V_{DD} = 5V, V_O = 0.5V or 4.5V	3.5		3.5	2.75		3.5		V
	V_{DD} = 10V, V_O = 1V or 9V	7.0		7.0	5.5		7.0		V
	V_{DD} = 15V, V_O = 1.5V or 13.5V	11.0		1..0	8.25		1..0		V
I_{OL} Low Level Output Current	V_{DD} = 5V, V_O = 0.4V	0.52		0.44	0.88		0.36		mA
	V_{DD} = 10V, V_O = 0.5V	1.3		1.1	2.25		0.9		mA
	V_{DD} = 15V, V_O = 1.5V	3.6		3.0	8.8		2.4		mA
I_{OH} High Level Output Current	V_{DD} = 5V, V_O = 4.6V	−0.52		−0.44	−0.88		−0.36		mA
	V_{DD} = 10V, V_O = 9.5V	−1.3		−1.1	−2.25		−0.9		mA
	V_{DD} = 15V, V_O = 13.5V	−3.6		−3.0	−8.8		−2.4		mA
I_{IN} Input Current	All Inputs Except Signal Input								
	V_{DD} = 15V, V_{IN} = 0V		−0.3		-10^{-5}	−0.3		−1.0	μA
	V_{DD} = 15V, V_{IN} = 15V		0.3		10^{-5}	0.3		1.0	μA
C_{IN} Input Capacitance	Any Input, (Note 3)					7.5			pF
P_T Total Power Dissipation	f_o = 10 kHz, R1 = 1 MΩ R2 = ∞, VCO_{IN} = $V_{DD}/2$								
	V_{DD} = 5V				0.07				mW
	V_{DD} = 10V				0.6				mW
	V_{DD} = 15V				2.4				mW

Note 1: "Absolute Maximum Ratings" are those values beyond which the safety of the device cannot be guaranteed. They are not meant to imply that the devices should be operated at these limits. The table of "Recommended Operating Conditions" and "Electrical Characteristics" provides conditions for actual device operation.

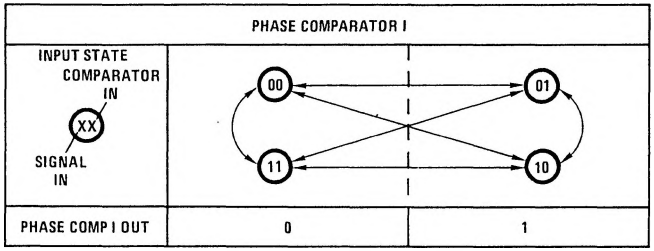
Note 2: V_{SS} = 0V unless otherwise specified.

Note 3: Capacitance is guaranteed by periodic testing.

AC Electrical Characteristics CD4046BM/CD4046BC $T_A = 25°C$, $C_L = 50\,pF$

Parameter	Conditions	Min	Typ	Max	Units
VCO Section					
Operating Current I_{DD}	f_o = 10 kHz, R1 = 1 MΩ				
	R2 = ∞, $VCO_{IN} = V_{DD}/2$				
	V_{DD} = 5 V		20		μA
	V_{DD} = 10 V		90		μA
	V_{DD} = 15 V		200		μA
f_{MAX} = Maximum Operating Frequency	C1 = 50 pF, 41 = 10 kΩ,				
	R2 = ∞, $VCO_{IN} = V_{DD}$				
	V_{DD} = 5 V	0.4	0.8		MHz
	V_{DD} = 10 V	0.6	1.2		MHz
	V_{DD} = 15 V	1.0	1.6		MHz
Linearity	VCO_{IN} = 2.5 V ∓0.3 V,				
	R1 ⩾ 10 kΩ, V_{DD} = 5 V		1		%
	VCO_{IN} = 5 V ±2.5 V,				
	R1⩾400 kΩ, V_{DD} = 10 V		1		%
	VCO_{IN} = 7.5 V ±5 V,				
	R1 ⩾ 1 MΩ, V_{DD} = 15 V		1		%
Temperature-Frequency Stability	%/°C∝1/f. V_{DD}				
No Frequency Offset, $f_{MIN} = 0$	R2 = ∞				
	V_{DD} = 5 V		0.12–0.24		%/°C
	V_{DD} = 10 V		0.04–0.08		%/°C
	V_{DD} = 15 V		0.015–0.03		%/°C
Frequency Offset, $f_{MIN} \neq 0$	V_{DD} = 5 V		0.06–0.12		%/°C
	V_{DD} = 10 V		0.05–0.1		%/°C
	V_{DD} = 15 V		0.03–0.06		%/°C
VCO_{IN} Input Resistance (VCO_{IN})	V_{DD} = 5 V		10^6		MΩ
	V_{DD} = 10 V		10^6		MΩ
	V_{DD} = 15 V		10^6		MΩ
VCO Output Duty Cycle	V_{DD} = 5 V		50		%
	V_{DD} = 10 V		50		%
	V_{DD} = 15 V		50		%
t_{THL} VCO Output Transition Time	V_{DD} = 5 V		90	200	ns
t_{THL}	V_{DD} = 10 V		50	100	ns
	V_{DD} = 15 V		45	80	ns
Phase Comparators Section					
R_{IN} Input Resistance					
Signal Input	V_{DD} = 5 V	1	3		MΩ
	V_{DD} = 10 V	0.2	0.7		MΩ
	V_{DD} = 15 V	0.1	0.3		MΩ
Comparator Input	V_{DD} = 5 V		10^6		MΩ
	V_{DD} = 10 V		10^6		MΩ
	V_{DD} = 15V		10^6		MΩ
AC-Coupled Signal Input Voltage Sensitivity	C_{SERIES} = 1000 pF				
	f = 50 kHz				
	V_{DD} = 5 V		200	400	mV
	V_{DD} = 10 V		400	800	mV
	V_{DD} = 15 V		700	1400	mV
Demodulator Output					
Offset Voltage ($VCO_{IN} - V_{DEM}$)	RS ⩾ 10 kΩ, V_{DD} = 5 V		1.50	2.2	V
	RS ⩾ 10 kΩ, V_{DD} = 10 V		1.50	2.2	V
	RS ⩾ 50 kΩ, V_{DD} = 15 V		1.50	2.2	V
Linearity	RS ⩾ 50 kΩ				
	VCO_{IN} = 2.5 ±0.3 V, V_{DD} = 5 V		0.1		%
	VCO_{IN} = 5 ±2.5 V, V_{DD} = 10 V		0.6		%
	VCO_{IN} = 7.5 ±5 V, V_{DD} = 15 V		0.8		%
Zener Diode					
V_Z Zener Diode Voltage					
CD4046BM	I_Z = 50 μA	6.7	7.0	7.3	V
CD4046BC		6.3	7.0	7.7	V
R_Z Zener Dynamic Resistance	I_Z = 1 mA		100		Ω

Phase Comparator State Diagrams



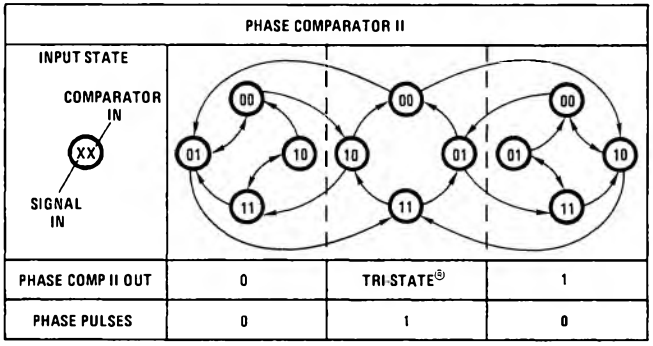


FIGURE 2

Typical Waveforms

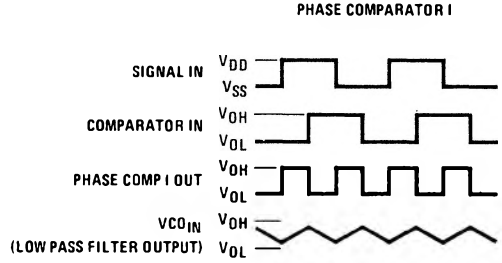


FIGURE 3. Typical Waveform Employing Phase Comparator I in Locked Condition

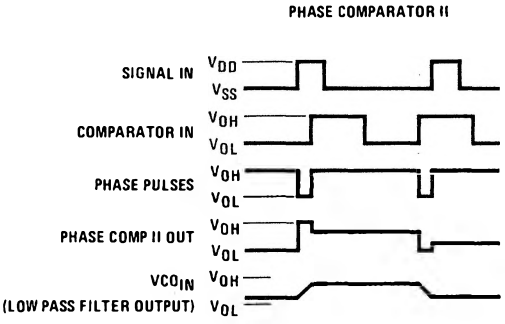


FIGURE 4. Typical Waveform Employing Phase Comparator II in Locked Condition

Typical Performance Characteristics

Typical Center Frequency vs C1 for R1 = 10 kΩ, 100 kΩ and 1 MΩ

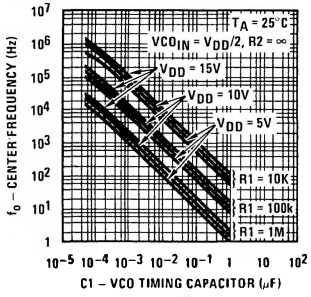


FIGURE 5a

Typical Frequency Offset vs C1 for R2 = 10 kΩ, 100 kΩ and 1 MΩ

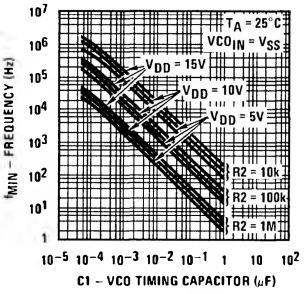


FIGURE 5b

Typical f_{MAX}/f_{MIN} vs R2/R1

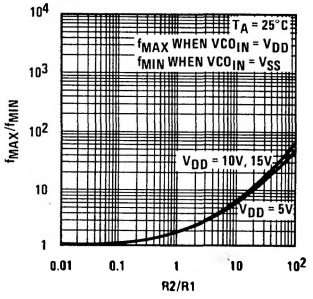


FIGURE 5c

Typical VCO Power Dissipation at Center Frequency vs R1

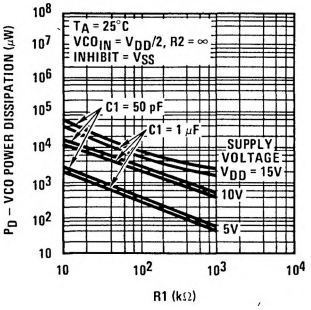


FIGURE 6a

Typical VCO Power Dissipation at f_{MIN} vs R2

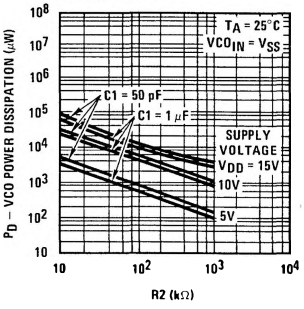


FIGURE 6b

Typical Source Follower Power Dissipation vs R_S

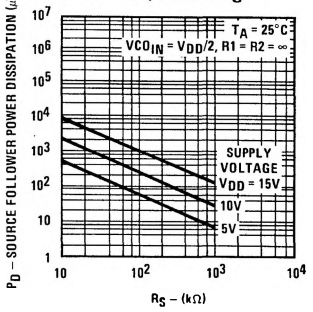


FIGURE 6c

Typical VCO Linearity vs R1 and C1

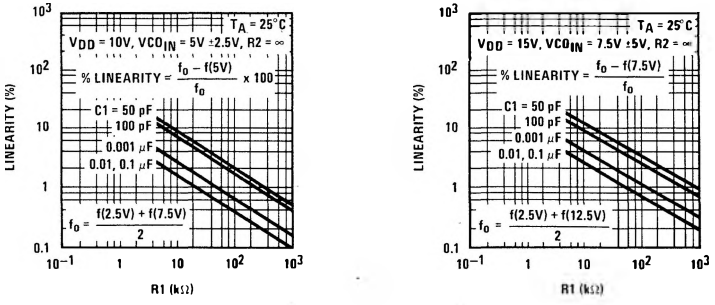


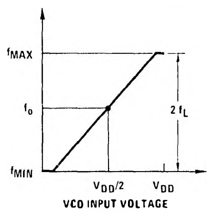
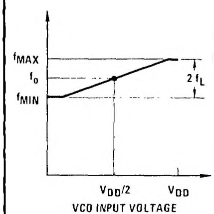
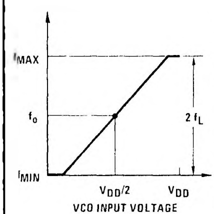
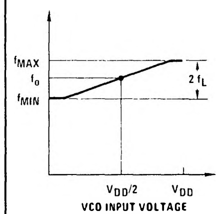
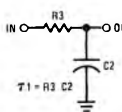
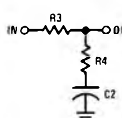
FIGURE 7

Note. To obtain approximate total power dissipation of PLL system for no-signal input: Phase Comparator I, P_D (Total) = P_D (f_o) + P_D (f_{MIN}) + P_D (R_S); Phase Comparator II, P_D (Total) = P_D (f_{MIN}).

Design Information

This information is a guide for approximating the value of external components for the CD4046B in a phase-locked-loop system. The selected external components must be within the following ranges: R1, R2 $\geq$ 10 kΩ, $R_S \geq$ 10 kΩ, C1 $\geq$ 50 pF.

In addition to the given design information, refer to *Figure 5* for R1, R2 and C1 component selections.

CHARACTERISTICS	USING PHASE COMPARATOR I		USING PHASE COMPARATOR II	
	VCO WITHOUT OFFSET $R2 = \infty$	VCO WITH OFFSET	VCO WITHOUT OFFSET $R2 = \infty$	VCO WITH OFFSET
VCO Frequency				
For No Signal Input	VCO in PLL system will adjust to center frequency, f_o		VCO in PLL system will adjust to lowest operating frequency, f_{min}	
Frequency Lock Range, $2 f_L$	$2 f_L$ = full VCO frequency range $2 f_L = f_{max} - f_{min}$			
Frequency Capture Range, $2f_C$		$2 f_C \approx \frac{1}{\pi}\sqrt{\frac{2\pi f_L}{\tau 1}}$	$f_C = f_L$	
Loop Filter Component Selection		For $2 f_C$, see Ref.		
Phase Angle Between Signal and Comparator	90° at center frequency (f_o), approximating 0° and 180° at ends of lock range ($2 f_L$)		Always 0° in lock	
Locks on Harmonics of Center Frequency	Yes		No	
Signal Input Noise Rejection	High		Low	
VCO Component Selection	–Given: f_o –Use f_o with *Figure 5a* to determine R1 and C1	–Given: f_o and f_L –Calculate f_{min} from the equation $f_{min} = f_o - f_L$ –Use f_{min} with *Figure 5b* to determine R2 and C1 –Calculate $\frac{f_{max}}{f_{min}}$ from the equation $\frac{f_{max}}{f_{min}} = \frac{f_o + f_L}{f_o - f_L}$ –Use $\frac{f_{max}}{f_{min}}$ with *Figure 5c* to determine ratio R2/R1 to obtain R1	–Given: f_{max} –Calculate f_o from the equation $f_o = \frac{f_{max}}{2}$ –Use f_o with *Figure 5a* to determine R1 and C1	–Given: f_{min} and f_{max} –Use f_{min} with *Figure 5b* to determine R2 and C1 –Calculate $\frac{f_{max}}{f_{min}}$ –Use $\frac{f_{max}}{f_{min}}$ with *Figure 5c* to determine ratio R2/R1 to obtain R1

REF. G.S. Moschytz, "Miniaturized RC Filters Using Phase-Locked Loop", BSTJ, May, 1965.
Floyd Gardner, "Phaselock Techniques," John Wiley & Sons, 1966.