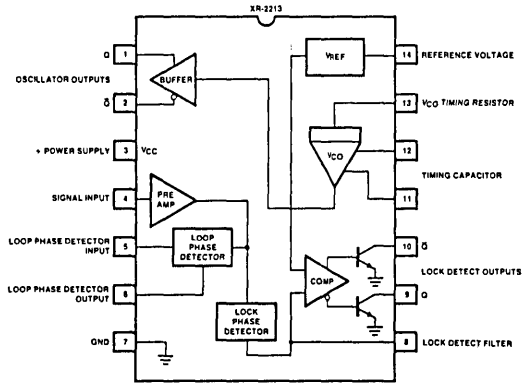
Precision Phase-Locked Loop/Tone Decoder

GENERAL DESCRIPTION

The XR-2213 is a highly stable phase-locked loop (PLL) system designed for control systems and tone detection applications. It combines the features of the XR-2211 and XR-2212 into a single monolithic IC. The circuit consists of a high stability VCO, input preamplifier, phase detector, quadrature phase detector, and high gain voltage comparator. Initial VCO frequency accuracy and supply rejection are an order of magnitude better than industry standards like the 567 decoder. An on board reference contributes to reliable operation and complementary outputs aid applicability.

FUNCTIONAL BLOCK DIAGRAM



FEATURES

Wide Frequency Range	0.01 Hz to 300 kHz
Wide Supply Voltage Range	4.5 V to 15 V
Uncommitted V_{CO} Q and $\overline{Q}$ Outputs	
Wide Dynamic Input Voltage Range	2mV to 3 V RMS
Excellent V_{CO} Stability	20 PPM/°C Typ.

ORDERING INFORMATION

Part Number	Package	Operating Temperature
XR-2213CN	Ceramic	0°C to + 70°C
XR-2213CP	Plastic	0°C to + 70°C
XR-2213N	Ceramic	−40°C to + 85°C
XR-2213P	Plastic	−40°C to + 85°C

APPLICATIONS

Tone Detection
Frequency Synthesis
FM Detection
Tracking Filters

ABSOLUTE MAXIMUM RATINGS

Power Supply	15 V
Input Signal Level	3 V RMS
Power Dissipation	
Ceramic Package:	750 mW
Derate Above T_A = +25°C	6 mW/°C
Plastic Package:	625 mW
Derate Above T_A = +25°C	5 mW/°C
Storage Temperature	−55°C to +150°C

SYSTEM DESCRIPTION

The XR-2213 is a complete PLL system including circuitry enabling dedicated tone detection capability over a frequency range of 0.01 Hz to 300 kHz. Supply voltage may range from 4.5 V to 15 V.

The input preamplifier has a dynamic range of 2 mV to 3 Vrms. The high stability VCO, with buffered complementary outputs, typically features better than 20 ppm/°C temperature drift and 0.05%/V supply rejection. An on board voltage reference is provided, and can sink 2 mA. The complementary lock detect outputs are each capable of sinking more than 7 mA. All system parameters are independantly determined by external components.

ELECTRICAL CHARACTERISTICS

Test Conditions: V_{CC} = +12V, T_A = +25°C, R_0 = 10 kΩ, C_0 = 0.1 μF, unless otherwise specified. See Figure 2 for component designation.

PARAMETERS	XR-2213/2213M			XR-2213C			UNITS	CONDITIONS
	MIN	TYP	MAX	MIN	TYP	MAX		
GENERAL								
Supply voltage	4.5		15	4.5		15	V	
Supply current		9	11		9	12	mA	$R_O \geq 10K\Omega$
OSCILLATOR SECTION								
Frequency accuracy		±1	±3		±1		%	Deviation from $f_O = \frac{1}{R_O C_O}$ $R_1 = x$
Frequency stability								
Temperature		20	50		20		PPM/°C	
Power supply		0.05	0.5		0.05		%/V	V^+ = 12V ± 1V
Upper frequency limit	100	300			300		kHz	R_O = 8.2KΩ, C_O = 400pF
Timing resistor R_O								
operating range	5		2000				KΩ	
Recommended range	10		100				KΩ	
OSCILLATOR OUTPUT								
Voltage output								
Positive swing	9.5	11.5		2.5	4.5		V	$I_L \leq 100\mu A$
Negative swing		0.4	0.8		0.4	0.8	V	I_L = 2mA
LOOP PHASE DETECTOR SECTION								
Peak output current	±150	±200		±100	±200		μA	
Output offset current		±1			±2		μA	
Output impedance		1			1		MΩ	
Maximum swing	±4	±5		±4	±5		V	Referenced to V_{REF}
INPUT PREAMP SECTION								
Input impedance		20			20		KΩ	
Input signal to cause limiting		2	10		2		MV_{RMS}	
Internal Reference								
Voltage level	4.9	5.3	5.7	4.75	5.3	5.85	V	
Output impedance		100			100		Ω	

PRINCIPLES OF OPERATION

Figure 2 shows the standard connection for tone detection. The input signal at Pin 4 is amplified and squared-up by the preamp before it is fed to the loop phase detector. The V_{CO} Q output provides the other loop phase detector input. The V_{CO} provided in the XR-2213 is actually a current controlled oscillator, ICO. The input to the ICO, Pin 13, is internally biased at V_{REF}, with the current drawn from this pin controlling the frequency of operation of the ICO. The resistor R_0 from Pin 13 to ground will provide a constant current which will be made up of the current from Pin 13 and the current from R_1 or the phase detector output. The phase detector output, filtered by C_1, will provide a voltage to R_1, which is proportional to the phase difference between the input frequency and the ICO frequency. The relationship between this voltage and phase difference is shown in Figure 3. If the phase difference is 90°, Pin 6 will be at V_{REF}, and therefore there will be no current flow in R_1 with all of the current in R_0 coming from Pin 13. This point is defined as the center frequency, f_0, of the PLL and is calculated by:

$$*f_0 = \frac{1}{R_0 C_0}$$

If the input frequency is increased, the phase shift will decrease causing the voltage at Pin 6 to decrease. Current will now flow from Pin 13 to both R_0 and R_1, causing an increase in ICO input current and thus an output frequency increase. If the phase detector swings all the way to 0 volts, the current in R_1, will be:

$$I_{R_1} = \frac{V_{REF}}{R_1}$$

*This condition will also occur if no input signal is applied to Pin 4.

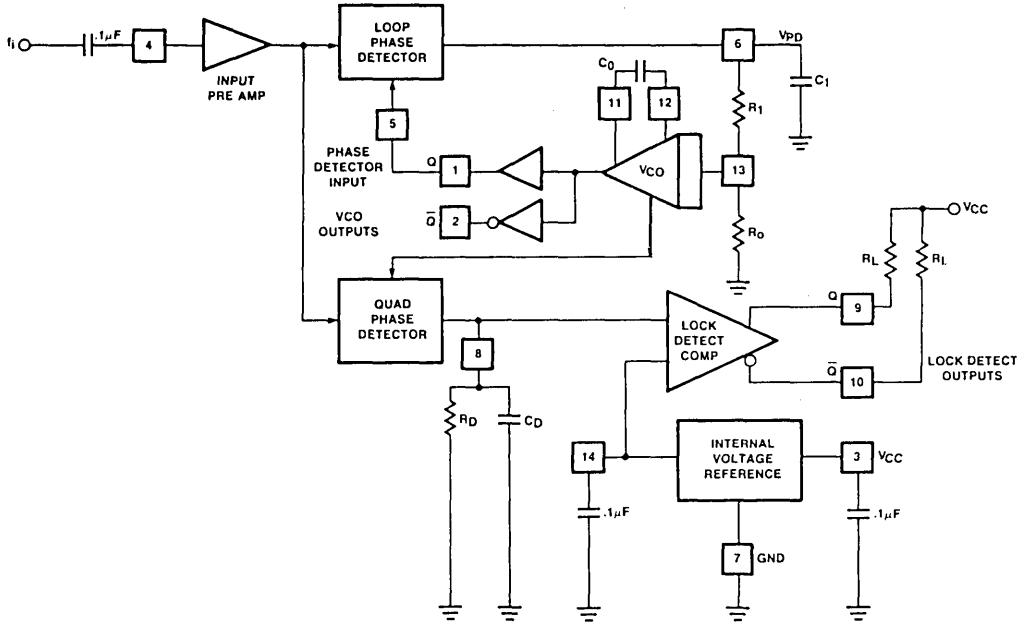


Figure 2. Generalized Circuit Connection for Tone Detection

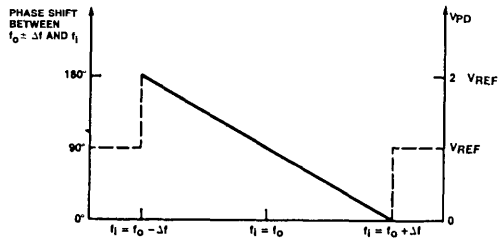


Figure 3. PLL Input/Output Relationships

At f_0, the current from Pin 13 was:

$$I_{13} = \frac{V_{REF}}{R_0}$$

If the ratio of Pin 13 current at f_0 and the change, Δ, from f_0 is written, the tracking range can be determined:

$$\frac{\Delta f_L}{f_0} = \frac{\frac{V_{REF}}{R_1}}{\frac{V_{REF}}{R_0}} = \frac{R_0}{R_1} \text{ or } \Delta f_L = \frac{R_0}{R_1}$$

If the input frequency was decreased, Δf will have the same magnitude in the opposite direction. The tracking range of the PLL will then be:

$$f_0 \pm \Delta f$$

The capture range of the PLL, which is always less than the tracking range, is described by:

$$\Delta W_C = 2\pi\Delta f_C = \sqrt{\frac{\Delta W_L}{\tau}}$$

$\tau = R_1C_1$ loop time constant
f_C = capture range

$$\Delta f_C = \sqrt{\frac{\Delta f_L}{2\pi R_1 C_1}}$$

The internal voltage reference provides a voltage equal to:

$$V_{REF} = \frac{V_{CC}}{2} - .7\ V$$

This reference can sink up to 2 mA, but source only 100 μA.

The quadrature phase detector will provide a high level, $-V_{CC}$, at Pin 8 whenever a frequency within the PLL capture range is present at Pin 4. This will drive the lock-detect outputs for a tone-detection indication. The response of the lock-detect section can be controlled by the capacitor, C_D, from Pin 8 to ground. The minimum value of C_D is calculated by the formula:

$$C_D\ (\mu F) \geq \frac{16}{f_c} \quad f_c = \text{capture range in Hz}$$

R_D = 470 K_Q is suitable for most applications.

The input to the phase detector may be directly connected to the V_{CO} output in the stand-alone connection. If the V_{CO} is not connected to the phase detector, the signal driving this pin must have sufficient amplitude to drive the pin above and below a voltage equal to V_{REF}. For low level signals, Pin 5 should be connected to V_{REF} through a 10 KΩ resistor and the signal capacitively coupled to Pin 5. The impedance into Pin 5 is approximately 100 KΩ and this pin is clamped for swings above V_{REF} +2 V.

DESIGN EQUATIONS

Refer to Figure 2 for component definitions.

1. V_{CO} center frequency, f_0:

$$f_0 = \frac{1}{R_0 C_0} \text{ Hz}$$

2. Internal voltage reference, V_{REF}:

$$V_{REF} = \frac{V_{CC}}{2} - .7 \text{ V} \quad \text{V}$$

3. Loop tracking range, $\pm \Delta f_L$:

$$\Delta f_L = f_0 \frac{R_0}{R_1} \text{ Hz}$$

4. Loop low-pass filter time constant, τ:

$$\tau = R_1 C_1 \text{ sec.}$$

5. Loop damping, ζ:

$$\zeta = \frac{1}{4}\sqrt{\frac{C_0}{C_1}}$$

6. Loop phase detector conversion gain, K_ϕ:

$$K_\phi = -\frac{2\,V_{REF}}{\pi} \frac{\text{volts}}{\text{radian}}$$

7. V_{CO} conversion gain, K_0:

$$K_0 = -\frac{1}{V_{REF}\, C_0 R_1} \frac{\text{Hz}}{\text{volt}}$$

8. Total loop gain, K_T:

$$K_T = K_0 K_\phi = \frac{4}{C_0 R_1} \text{ Hz}$$

9. Loop capture range, $\pm \Delta f_C$:

$$\Delta f_C = \sqrt{\frac{\Delta f_L}{2\pi R_1 C_1}} \text{ Hz}$$

10. Lock detect filter capacitor:

$$C_D = \frac{16}{f_C} \mu\text{F}$$

APPLICATIONS INFORMATION

Figure 2 shows the XR-C453 connected for tone detection. The input signal is capacitively coupled to Pin 4 and may range from 2 mV to 3 V RMS. The V_{CO} Q output is directly connected to the phase detector input, Pin 5. The detection bandwidth is set by the ratio of R_0 and R_1 and the loop time constant, τ. This corresponds to the capture range of the PLL. The lock-detect output, Pins 9 and 10, will give an active high and low indication when a tone in the detection bandwidth is present.

DESIGN EXAMPLE:

20 kHz tone detector with a ±1 kHz detection band.

A. Choose R_0 = 15 KΩ, 12 KΩ resistor plus 5Ω potentiometer.

B. Calculate $C_0 = \frac{1}{f_0 R_0} .0033\ \mu\text{F}$

C. Calculate $C_1 = \frac{C_0}{4} \simeq .001\ \mu\text{F}$

D. Calculate $R_1 = f_0 \frac{R_0}{\Delta f_C} = 300\ \text{K}\Omega$

E. Calculate $C_D = \frac{16}{f_C} \simeq 0.01\ \mu\text{F}$

F. Fine tune f_0 with R_X, 5 K potentiometer.

The complete circuit is shown in Figure 4.

Figure 5 shows the connection for a frequency synthesizer. Here an input frequency of 10 kHz produces an output frequency of 40 kHz. The V_{CO} center frequency, f_0, is set for 40 kHz. The divide by four will then provide the phase detector input with 10 kHz. The lock range is set to approximately 10% of f_0. For larger divider ratios, C_1 should be increased to minimize phase jitter.

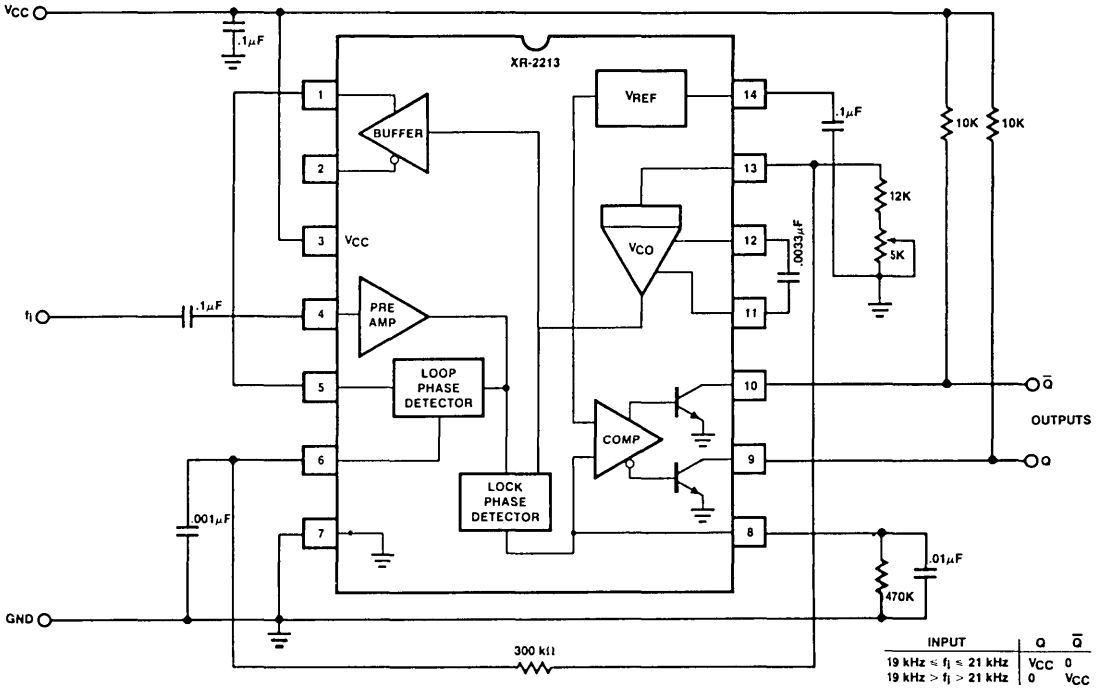


Figure 4. Tone Detector

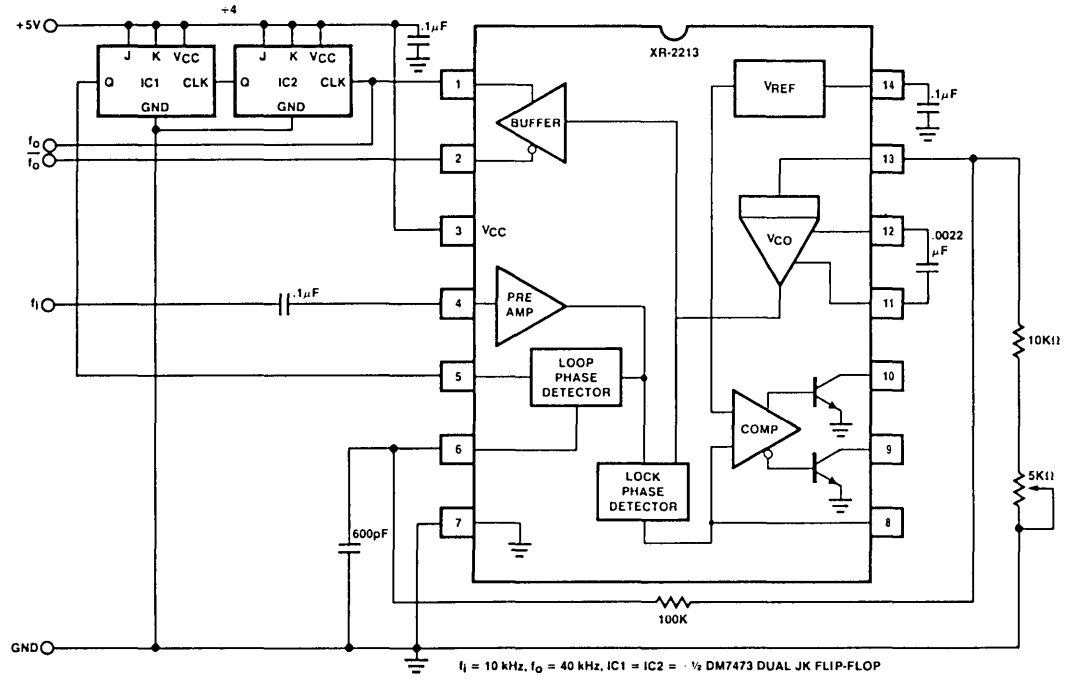


Figure 5. Frequency Synthesizer