LM565/LM565C Phase Locked Loop

General Description
The LM565 and LM565C are general purpose phase locked loops containing a stable, highly linear voltage controlled oscillator for low distortion FM demodulation, and a double balanced phase detector with good carrier suppression. The VCO frequency is set with an external resistor and capacitor, and a tuning range of 10:1 can be obtained with the same capacitor. The characteristics of the closed loop system—bandwidth, response speed, capture and pull in range—may be adjusted over a wide range with an external resistor and capacitor. The loop may be broken between the VCO and the phase detector for insertion of a digital frequency divider to obtain frequency multiplication.

The LM565H is specified for operation over the −55°C to +125°C military temperature range. The LM565CN is specified for operation over the 0°C to +70°C temperature range.

Features
- 200 ppm/°C frequency stability of the VCO
- Power supply range of ±5 to ±12 volts with 100 ppm/% typical
- 0.2% linearity of demodulated output
- Linear triangle wave with in phase zero crossings available
- TTL and DTL compatible phase detector input and square wave output
- Adjustable hold in range from ±1% to > ±60%

Applications
- Data and tape synchronization
- Modems
- FSK demodulation
- FM demodulation
- Frequency synthesizer
- Tone decoding
- Frequency multiplication and division
- SCA demodulators
- Telemetry receivers
- Signal regeneration
- Coherent demodulators

Connection Diagrams

Metal Can Package
Order Number LM565H
See NS Package Number H10C

Dual-In-Line Package
Order Number LM565CN
See NS Package Number N14A
Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
<th>LM565H</th>
<th>LM565CN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temperature Range</td>
<td></td>
<td>−55°C to +125°C</td>
<td>0°C to +70°C</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>±12V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Dissipation (Note 1)</td>
<td>1400 mW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differential Input Voltage</td>
<td>±1V</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Electrical Characteristics

AC Test Circuit, \( T_A = 25°C, V_{CC} = ±6V \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>LM565</th>
<th>LM565C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Supply Current</td>
<td></td>
<td>8.0, 12.5 mA</td>
<td>8.0, 12.5 mA</td>
</tr>
<tr>
<td>Input Impedance (Pins 2, 3)</td>
<td>(-4V &lt; V_2, V_3 &lt; 0V)</td>
<td>7, 10 kΩ</td>
<td>5, 30 kΩ</td>
</tr>
<tr>
<td>VCO Maximum Operating Frequency</td>
<td>( C_0 = 2.7 \text{ pF} )</td>
<td>300 kHz</td>
<td>500 kHz</td>
</tr>
<tr>
<td>VCO Free-Running Frequency</td>
<td>( C_0 = 1.5 \text{ nF} ) ( R_0 = 20 \text{ kΩ} ) ( f_0 = 10 \text{ kHz} )</td>
<td>(-10, 0 ) +10 (-30, 0 ) +30 %</td>
<td></td>
</tr>
<tr>
<td>Operating Frequency Temperature Coefficient</td>
<td>(-100, 200 ) ppm/°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency Drift with Supply Voltage</td>
<td>( V_2, V_3 )</td>
<td>0.1, 1.0 %/V</td>
<td>0.2, 1.5 %/V</td>
</tr>
<tr>
<td>Triangle Wave Output Voltage</td>
<td>( V_{pp} )</td>
<td>2, 2.4 V</td>
<td>2, 3.3 V</td>
</tr>
<tr>
<td>Triangle Wave Output Linearity</td>
<td>( % )</td>
<td>0.2, 0.5 %</td>
<td>0.5, 30 %</td>
</tr>
<tr>
<td>Square Wave Output Level</td>
<td>( V_{pp} )</td>
<td>4.7, 5.4 V</td>
<td>5.4, 6.5 V</td>
</tr>
<tr>
<td>Output Impedance (Pin 4)</td>
<td>( kΩ )</td>
<td>5, 5 kΩ</td>
<td>5, 5 kΩ</td>
</tr>
<tr>
<td>Square Wave Duty Cycle</td>
<td>( % )</td>
<td>45, 55 %</td>
<td>60, 70 %</td>
</tr>
<tr>
<td>Square Wave Rise Time</td>
<td>( \text{ns} )</td>
<td>20 ns</td>
<td>20 ns</td>
</tr>
<tr>
<td>Square Wave Fall Time</td>
<td>( \text{ns} )</td>
<td>50 ns</td>
<td>50 ns</td>
</tr>
<tr>
<td>Output Current Sink (Pin 4)</td>
<td>( mA )</td>
<td>0.8, 1 mA</td>
<td>0.8, 1 mA</td>
</tr>
<tr>
<td>VCO Sensitivity ( f_0 = 10 \text{ kHz} )</td>
<td>( \text{Hz/V} )</td>
<td>6600 Hz/V</td>
<td>6600 Hz/V</td>
</tr>
<tr>
<td>Demodulated Output Voltage (Pin 7)</td>
<td>( \pm 10% \text{ Frequency Deviation} )</td>
<td>250, 400 mV/V</td>
<td>300, 450 mV/V</td>
</tr>
<tr>
<td>Total Harmonic Distortion</td>
<td>( \pm 10% \text{ Frequency Deviation} )</td>
<td>0.2, 0.75 %</td>
<td>0.2, 1.5 %</td>
</tr>
<tr>
<td>Output Impedance (Pin 7)</td>
<td>( \text{kΩ} )</td>
<td>3.5, 3.5 kΩ</td>
<td>3.5, 3.5 kΩ</td>
</tr>
<tr>
<td>DC Level (Pin 7)</td>
<td>( \text{V} )</td>
<td>0.25, 0.5 V</td>
<td>4.0, 0.5 V</td>
</tr>
<tr>
<td>Output Offset Voltage ( V_7 - V_6 )</td>
<td>( \mu\text{V} )</td>
<td>30, 100 μV</td>
<td>50, 200 μV</td>
</tr>
<tr>
<td>Temperature Drift of (</td>
<td>V_7 - V_6</td>
<td>)</td>
<td>( \mu\text{V/°C} )</td>
</tr>
<tr>
<td>AM Rejection</td>
<td>( \text{dB} )</td>
<td>30, 40 dB</td>
<td>40, 50 dB</td>
</tr>
<tr>
<td>Phase Detector Sensitivity ( K_D )</td>
<td>( \text{V/°C} )</td>
<td>0.68, 0.68 V/°C</td>
<td>0.68, 0.68 V/°C</td>
</tr>
</tbody>
</table>

Note 1: The maximum junction temperature of the LM565 and LM565C is +150°C. For operation at elevated temperatures, devices in the TO-5 package must be derated based on a thermal resistance of +150°C/W junction to ambient or +45°C/W junction to case. Thermal resistance of the dual-in-line package is +85°C/W.
Typical Performance Characteristics

- **Power Supply Current as a Function of Supply Voltage**
- **Lock Range as a Function of Input Voltage**
- **VCO Frequency**
- **Oscillator Output Waveforms**
- **Phase Shift vs Frequency**
- **VCO Frequency as a Function of Temperature**
- **Loop Gain vs Load Resistance**
- **Hold in Range as a Function of \( R_{6-7} \)**
AC Test Circuit

Note: S1 open for output offset voltage ($V_7 - V_6$) measurement.

Typical Applications

2400 Hz Synchronous AM Demodulator
Typical Applications (Continued)

**FSK Demodulator (2025–2225 cps)**

![Circuit Diagram]

**FSK Demodulator with DC Restoration**

![Circuit Diagram]
Typical Applications (Continued)

Frequency Multiplier ($\times 10$)

IRIG Channel 13 Demodulator
Applications Information

In designing with phase locked loops such as the LM565, the important parameters of interest are:

FREE RUNNING FREQUENCY

\[ f_0 = \frac{0.3}{R_D C_D} \]

LOOP GAIN: relates the amount of phase change between the input signal and the VCO signal for a shift in input signal frequency (assuming the loop remains in lock). In servo theory, this is called the "velocity error coefficient."

Loop gain = \( K_o K_D \left( \frac{1}{\text{sec}} \right) \)

\( K_o \) = oscillator sensitivity \( \left( \frac{\text{radians/sec}}{\text{volt}} \right) \)

\( K_D \) = phase detector sensitivity \( \left( \frac{\text{volts}}{\text{radian}} \right) \)

The loop gain of the LM565 is dependent on supply voltage, and may be found from:

\[ K_o K_D = 33.6 f_0 \]

\( f_0 \) = VCO frequency in Hz

\( V_c \) = total supply voltage to circuit

Loop gain may be reduced by connecting a resistor between pins 6 and 7; this reduces the load impedance on the output amplifier and hence the loop gain.

HOLD IN RANGE: the range of frequencies that the loop will remain in lock after initially being locked.

\[ f_H = \frac{8 f_0}{V_c} \]

\( f_0 \) = free running frequency of VCO

\( V_c \) = total supply voltage to the circuit

THE LOOP FILTER

In almost all applications, it will be desirable to filter the signal at the output of the phase detector (pin 7); this filter may take one of two forms:

Simple Lag Filter

![Simple Lag Filter Diagram](TL/H/7853-11)

A simple lag filter may be used for wide closed loop bandwidth applications such as modulation following where the frequency deviation of the carrier is fairly high (greater than 10%), or where wideband modulating signals must be followed.

The natural bandwidth of the closed loop response may be found from:

\[ f_n = \frac{1}{2\pi} \sqrt{\frac{K_o K_D}{R_1 C_1}} \]

Associated with this is a damping factor:

\[ \delta = \sqrt{\frac{1}{2 R_1 C_1 K_o K_D}} \]

For narrow band applications where a narrow noise bandwidth is desired, such as applications involving tracking a slowly varying carrier, a lead lag filter should be used. In general, if \( 1/R_1 C_1 < K_o K_D \), the damping factor for the loop becomes quite small resulting in large overshoot and possible instability in the transient response of the loop. In this case, the natural frequency of the loop may be found from

\[ f_n = \frac{1}{2\pi} \sqrt{\frac{K_o K_D}{\tau_1 + \tau_2}} \]

\( \tau_1 + \tau_2 = (R_1 + R_2) C_1 \)

\( R_2 \) is selected to produce a desired damping factor \( \delta \), usually between 0.5 and 1.0. The damping factor is found from the approximation:

\[ \delta = \pi \tau_2 f_n \]

These two equations are plotted for convenience.

Filter Time Constant vs Natural Frequency

![Filter Time Constant vs Natural Frequency](TL/H/7853-13)

Damping Time Constant vs Natural Frequency

![Damping Time Constant vs Natural Frequency](TL/H/7853-14)

Capacitor \( C_2 \) should be much smaller than \( C_1 \) since its function is to provide filtering of carrier. In general \( C_2 \leq 0.1 C_1 \).
Physical Dimensions inches (millimeters)

Metal Can Package (H)
Order Number LM565H
NS Package Number H10C
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