Basic Principles of Sinusoidal Oscillators

- Linear oscillator
  - Linear region of circuit: linear oscillation
  - Nonlinear region of circuit: amplitudes stabilization
- Barkhausen criterion

\[
\text{loop gain } L(s) = \beta(s)A(s)
\]
\[
\text{characteristic equation } 1-L(s) = 0
\]
\[
\text{oscillation criterion } L(j\omega_0) = A(j\omega_0) \beta(j\omega_0) = 1
\]
at $\omega_0$, the phase of the loop should be zero and the magnitude of the loop gain should be unity. Oscillation frequency $\omega_0$ is determined solely by

$$\Delta\omega_0 = \frac{\Delta\phi}{d\phi/d\omega}$$

A steep phase response results in a small $\Delta\omega_0$ for a given change in phase $\Delta\phi$. 
Nonlinear Amplitude Control

- To sustain oscillation:\ $\beta A > 1$
  - a. overdesign for $\beta A$ variations
  - b. oscillation will grow in amplitude
    - poles are in the right half of the s-plane
  - c. Nonlinear network reduces $\beta A$ to 1 when the desired amplitude is reached
    - poles will be pulled to $j\omega$-axis
Nonlinear Amplitude Control (Cont.)

- Limiter circuit for amplitude control
  - linear region

\[ V_O = -(\frac{R_i}{R_1})V_i \]

\[ V_A = V \frac{R_3}{R_2 + R_3} + V_O \frac{R_2}{R_2 + R_3} \]

\[ V_B = -V \frac{R_4}{R_4 + R_5} + V_O \frac{R_5}{R_4 + R_5} \]
Nonlinear Amplitude Control (Cont.)

- **nonlinear region**

\[ V_O | V_A = -V_D = \left( -V \frac{R_3}{R_2 + R_3} \right) - V_D \]

\[ = -V \frac{R_3}{R_2} - V_D \left( 1 + \frac{R_3}{R_2} \right) \]

Similarly, \( L_+ = V \frac{R_4}{R_5} + V_D \left( 1 + \frac{R_4}{R_5} \right) \)

\[ \text{Slope} = -\frac{(R_f \parallel R_4)}{R_1} \]

\[ \text{Slope} = -\frac{R_f}{R_1} \]

\[ \text{Slope} = -\frac{(R_f \parallel R_3)}{R_1} \]
OPAMP-RC Oscillator Circuits

- Wien-bridge oscillator

\[ L(s) = \left[ 1 + \frac{R_2}{R_1} \right] \frac{Z_p}{Z_p + Z_s} \]

\[ = \frac{1 + \frac{R_2}{R_1}}{3 + SCR + \frac{1}{SCR}} \]

\[ L(j\omega) = \frac{1 + \frac{R_2}{R_1}}{3 + j\left(\omega RC - \frac{1}{\omega RC}\right)} \]

--- For phase = 0, \(\omega_0 RC = \frac{1}{\omega_0 RC}\)

\[ \Rightarrow \omega_0 = \frac{1}{RC} \]

--- \(L(s) = 1 \Rightarrow \frac{R_2}{R_1} = 2\)
OPAMP-RC Oscillator Circuits (Cont.)

- Wien-bridge oscillator with a limiter

![Diagram of Wien-bridge oscillator with a limiter]

- Circuit diagram with components labeled:
  - $R_3 = 3k$
  - $R_4 = 1k$
  - $R_5 = 1k$
  - $R_6 = 3k$
  - $V_1$, $V_o$
  - Diodes $D_1$, $D_2$
  - Capacitors $16nF$
  - Resistors $10k$
  - Analog circuit schematic
OPAMP-RC Oscillator Circuits (Cont.)

\[ + \quad \quad - \quad \quad 10k\Omega \quad 50k\Omega \quad b \quad a \quad v_o \]

\[ 16nF \quad 10k\Omega \]

\[ 16nF \quad 10k\Omega \]

Prof. Tai-Haur Kuo
12 - 8 Electronics(3), 2014
Phase-Shift Oscillator

- Without amplitude stabilization

\[ -K \]

\[ \begin{align*}
C & \quad C & \quad C \\
R & \quad R & \quad R \\
\end{align*} \]

------ phase shift of the RC network is 180 degrees.

\[ \implies \text{Total phase shift around the loop is 0 or 360 degrees.} \]
Phase-Shift Oscillator (Cont.)

- With amplitude stabilization
Quadrature Oscillator

- OP₁: inverting integrator with amplitude control
- OP₂: noninverting integrator

Equivalent circuit at the input of OP₂

Set \( R_f = 2R \)

\[ v = \frac{1}{C} \int_0^t \frac{v_{O1}}{2R} \, dt \]

(Nominally 2R)
Quadrature Oscillator (Cont.)

------ Break the loop at X, loop gain

\[ L(s) = \frac{V_{o2}}{V_x} = \frac{1}{S^2C^2R^2} \]

\[ \omega_0 = \frac{1}{RC} \]

------ \( V_{o2} \) is the integral of \( V_{o1} \)

\[ 90^\circ \text{ phase difference between } V_{o1} \text{ and } V_{o2} \]

\[ \Rightarrow \text{“quadrature” oscillator} \]
Active-Filter Tuned Oscillator

- Block diagram

- High-distortion $v_2$
- High-Q bandpass $\Rightarrow$ low-distortion $v_1$
Active-Filter Tuned Oscillator (Cont.)

- Practical implementation
A General Form of LC-Tuned Oscillator Configuration

- Many oscillator circuits fall into a general form shown below

\[ Z_1, Z_2, Z_3 : \text{capacitive or inductive} \]
A General Form of LC-Tuned Oscillator Configuration (Cont.)

\[ V_o = \frac{-A_v \hat{V}_{13} Z_L}{Z_L + R_O} \]

\[ V_{13} = \frac{Z_1}{Z_1 + Z_3} V_o \quad T = \frac{V_{13}}{\hat{V}_{13}} = \frac{-A_v Z_1 Z_2}{R_O (Z_1 + Z_2 + Z_3) + Z_2 (Z_1 + Z_3)} \]

if \( Z_1 = jX_1, \quad Z_2 = jX_2, \quad Z_3 = jX_3 \)

\[ X = \omega L \text{ for inductance} \quad X = -\frac{1}{\omega C} \text{ for capacitance} \]

\[ T = \frac{A_v X_1 X_2}{jR_O (X_1 + X_2 + X_3) - X_2 (X_1 + X_3)} \]

for oscillation, \( T = 1\angle 0^\circ \)

\[ \Rightarrow X_1 + X_2 + X_3 = 0 \]

\[ \Rightarrow T = \frac{A_v X_1 X_2}{-X_2 (X_1 + X_3)} = \frac{-A_v X_1}{X_1 + X_3} \]

\[ \Rightarrow T = \frac{A_v X_1}{X_2} \]
With oscillation
\[ |T| = 1 \text{ and } \angle T = 0, 360, 720, \ldots \text{ degree.} \]
i.e. \[ T = 1 \quad (X = \omega L \text{ or } X = -\frac{1}{\omega C}) \]
⇒ \[ X_1 \text{ and } X_2 \text{ must have the same sign if } A_v \text{ is positive} \]
⇒ \[ X_1 \text{ and } X_2 \text{ are } L, \quad X_3 = -(X_1 + X_2) \text{ is } C \]
or \[ X_1 \text{ and } X_2 \text{ are } C, \quad X_3 = -(X_1 + X_2) \text{ is } L \]

Transistor oscillators
1. Collpitts oscillator
   -- \( X_1 \) and \( X_2 \) are Cs, \( X_3 \) is L
2. Hartley oscillator
   -- \( X_1 \) and \( X_2 \) are Ls, \( X_3 \) is C
LC Tuned Oscillators

- Two commonly used configurations
  - Colpitts (feedback is achieved by using a capacitive divider)
LC Tuned Oscillators (Cont.)

- Two commonly used configurations
  - Hartley (feedback is achieved by using an inductive divider)
LC Tuned Oscillators (Cont.)

- Colpitts oscillator
  - Equivalent circuit

\[
\begin{align*}
\text{C} &= C_\pi \text{ of transistor input } + C_2 \\
\text{R} &= \text{loss of inductor } + \text{load resistance of oscillator } + \text{output resistance of transistor}
\end{align*}
\]
LC Tuned Oscillators (Cont.)

\[ V_O = V_\pi + sC_2V_\pi \cdot sL \]
\[ sC_2V_\pi + g_mV_\pi + \left(\frac{1}{R} + sC_1\right)(1 + s^2LC_2)V_\pi = 0 \]
\[ s^3LC_1C_2 + s^2\left(\frac{LC_2}{R}\right) + s(C_1 + C_2) + \left(g_m + \frac{1}{R}\right) = 0 \]
\[ \left(g_m + \frac{1}{R} - \frac{\omega^2LC_2}{R}\right) + j[\omega(C_1 + C_2) - \omega^3LC_1C_2] = 0 \]

\[ S = j\omega \]

◆ For oscillations to start, both the real and imaginary parts must be zero

◆ Oscillation frequency

\[ \omega_0 = \frac{1}{\sqrt{L\left(\frac{C_1C_2}{C_1 + C_2}\right)}} \]
LC Tuned Oscillators (Cont.)

◆ Gain

\[ g_m R = \frac{c_2}{c_1} \] (Actually, \( g_m R \geq \frac{c_2}{c_1} \))

◆ Oscillation amplitude

1. LC tuned oscillators are known as self – limiting oscillators. (As oscillations grown in amplitude, transistor gain is reduced below its small – signal value)

2. Output voltage signal will be a sinusoid of high purity because of the filtering action of the LC tuned circuit

◆ Hartley oscillator can be similarity analyzed
Crystal oscillators

- Symbol of crystal

- Circuit model of crystal
Crystal oscillators (Cont.)

- Reactance of a crystal assuming \( r = 0 \)

\[
Z(s) = \frac{1}{sC_p + \frac{1}{sL + \frac{1}{sC_s}}} = \frac{1}{sC_p} \left( s^2 + \frac{1}{LC_s} \right) \quad \left( \text{Crystal is high – Q device} \right)
\]

Let
\[
\begin{align*}
\omega_s^2 &= \frac{1}{LC_s} \\
\omega_p^2 &= \frac{1}{L} \left( \frac{1}{C_s} + \frac{1}{C_p} \right)
\end{align*}
\]

\[
Z(j\omega) = -j\frac{1}{\omega C_p} \left( \frac{\omega^2 - \omega_s^2}{\omega^2 - \omega_p^2} \right)
\]

If \( C_p \gg C_s \), then \( \omega_p \approx \omega_s \)
Crystal oscillators (Cont.)

- The crystal reactance is inductive over the narrow frequency band between $\omega_s$ and $\omega_p$

- Colpitts crystal oscillator
  - Configuration
  - Equivalent circuit

\[
C_S \ll C_P, C_1, C_2
\]

\[
\Rightarrow \omega_0 \approx \frac{1}{\sqrt{LC_S}} = \omega_s \approx \omega_p
\]
Crystal oscillators (Cont.)

- Pierce oscillator
  - Almost all digital clock oscillators are Pierce oscillators
  - Derived from Colpitts oscillator
    → Inverter with feedback resistor as an inverting amplifier
    → Replacement of the CE amplifier
Multivibrators

- Multivibrators (3 types)
  - bistable: two stable states
  - monostable: one stable state
  - astable: no stable state

- Bistable
  - Has two stable states
  - Can be obtained by connecting an amplifier in a positive-feedback loop having a loop gain greater than unity. I.e. $\beta A > 1$ where $\beta = R_1/(R_1+R_2)$
Bistable Multivibrators (Cont.)

◆ Bistable circuit with clockwise hysteresis

![Circuit Diagram]

◆ Clockwise hysteresis (or inverting hysteresis)

\[ L_+ : \text{positive saturation voltage of OPAMP} \]
\[ L_- : \text{negative saturation voltage of OPAMP} \]

\[ V_{TH} = \beta L_+ = \frac{R_1}{R_1 + R_2} L_+ \]

\[ V_{TL} = \beta L_- = \frac{R_1}{R_1 + R_2} L_- \quad \Rightarrow \text{Hysteresis width} = V_{TH} - V_{TL} \]
Noninverting Bistable Circuit

- Counterclockwise hysteresis
- Configuration

\[ v_+ = v_1 \frac{R_2}{R_1 + R_2} + v_o \frac{R_1}{R_1 + R_2} \]

For \( v_o = L_+ \), \( v_+ = 0 \), \( v_1 = V_{TL} \) \( \Rightarrow V_{TL} = -L_+ \left( \frac{R_1}{R_2} \right) \)

For \( v_o = L_- \), \( v_+ = 0 \), \( v_1 = V_{TH} \) \( \Rightarrow V_{TH} = -L_- \left( \frac{R_1}{R_2} \right) \)
Noninverting Bistable Circuit (Cont.)

- Comparator characteristics with hysteresis
  - Can reject interference

\[ V_{TL} \]  
\[ V_{TH} \]  
\[ R \]  
\[ V_0 \]

\[ t \]  
\[ V_R = 0 \]  
\[ V_{TH} \]  
\[ V_{TL} \]

Multiple Zero crossings
Signal corrupted with interference
Can reject interference
Generation of Square and Triangular Waveforms using Astable Multivibrators

- Can be done by connecting a bistable multivibrator with a RC circuit in a feedback loop.

\[ V_{TH} = \beta L_+ \]
\[ V_{TL} = \beta L_- \]
Generation of Square and Triangular Waveforms using Astable Multivibrators (Cont.)

\[ v_{O}(t) = \begin{cases} \beta L_+ & (0 < t < T_1) \\ \beta L_- & (T_1 < t < T_2) \end{cases} \]

Time constant \( \tau = RC \)
Generation of Square and Triangular Waveforms using Astable Multivibrators (Cont.)

- During T1

\[ V_- = L_+ - (L_+ - \beta L_-)e^{\frac{-t}{\tau}} \]

where \( \tau = RC \), \( \beta = \frac{R_1}{R_1 + R_2} \)

if \( V_- = \beta L_+ \) at \( t = T_1 \) \( \Rightarrow \) \( T_1 = \tau \ln \frac{1 - \beta (L_- / L_+)}{1 - \beta} \)

- During T2

\[ V_- = L_- - (L_- - \beta L_+)e^{\frac{-t}{\tau}} \]

if \( V_- = \beta L_- \) at \( t = T_2 \) \( \Rightarrow \) \( T_2 = \tau \ln \frac{1 - \beta (L_+ / L_-)}{1 - \beta} \)

\( T = T_1 + T_2 = 2\tau \ln \frac{1 + \beta}{1 - \beta}; (L_+ = -L_- \) is assumed)
Generation of Triangular Waveforms

\[ V_2 \]

\[ T_1 \rightarrow T_2 \]

\[ L_+ \]

0

\[ L_- \]

\[ T \]

\[ \text{Slope} = \frac{-L_+}{RC} \]

\[ \text{Slope} = \frac{-L_-}{RC} \]
Generation of Triangular Waveforms (Cont.)

- During $T_1$
  \[ V_{TL} - V_{TH} = -\frac{1}{C} \int_0^{T_1} i_C dt = \frac{L_+ T_1}{RC}; \quad \text{where } i_C = \frac{L_+}{R} \]
  \[ \Rightarrow T_1 = RC \frac{V_{TH} - V_{TL}}{L_+} \]

- During $T_2$
  Similarly
  \[ \Rightarrow T_2 = RC \frac{V_{TH} - V_{TL}}{-L_-} \]

- To obtain symmetrical waveforms
  \[ T_1 = T_2 \Rightarrow L_+ = -L_- \]
Monostable Multivibrators

- Its alternative name is “one shot”
- Has one stable state
- Can be triggered to a quasi-state

\[
\begin{align*}
\beta L_+ - V_{D_2} \rightarrow V_E(t) \\
L_+ \rightarrow V_A(t) \\
L_- \rightarrow T \\
\beta L_+ \rightarrow V_+(t) \\
\beta L_- \rightarrow V_-(t) \\
V_{D_1} \rightarrow V_B(t) \\
\beta L_- \rightarrow \text{To } L_- \\
\beta L_+ \rightarrow \text{To } L_+
\end{align*}
\]
Monostable Multivibrators (Cont.)

- During $T_1$

\[ V_B(t) = L_+ - (L_+ - V_{D1})e^{-\frac{t}{R_3C_1}} \]

\[ V_B(T) = \beta L_+ \Rightarrow \beta L_+ = L_+ - (L_+ - V_{D1})e^{-\frac{T}{R_3C_1}} \]

\[ \Rightarrow T = R_3C_1 \ln\left(\frac{V_{D1} - L_-}{\beta L_+ - L_-}\right) \]

For $V_{D1} \ll |L_-| \Rightarrow T \approx R_3C_1\left(\frac{1}{1-\beta}\right)$

- $\beta L_+$ is greater then $V_{D1}$

\[ \Rightarrow \text{Stable state is maintained} \]
Monostable Multivibrators (Cont.)

- Monostable multivibrator using NOR gates

\[ V_{in} \quad V_{o1} \quad V_{x} \quad V_{o2} \]

\[ V_{DD} \quad R \]

\[ V_{in} \quad V_{o1} \quad V_{x} \quad V_{o2} \]

\[ V_{DD} \quad V_{DD} + V_{T} = 3/2 \times V_{DD} \]

\[ V_{T} = V_{DD}/2 \]
Mono-stable Multivibrator (Cont.)

\[ v_c(0) = 0 \]

\[ v_x = V_{DD}(1 - e^{-\frac{t}{RC}}) \]

\[ v_x(T_1) = V_T = V_{DD}(1 - e^{-\frac{T_1}{RC}}) \]

\[ \Rightarrow T_1 = RC\ln\left(\frac{V_{DD}}{V_{DD} - V_T}\right) \approx RC\ln2 \approx 0.693RC \]

where \( V_T \approx \frac{V_{DD}}{2} \); \( V_T \) is NOR gate threshold voltage
Mono-stable Multivibrator (Cont.)

- Monostable multivibrator with catching diode

\[ \text{RC constant } T = \frac{V_{DD} - 5V}{V_D} \]

\[ \text{forward resistance of diode} \]

Time constant = \( R_C \)

Time constant = \( R_T \)

\[ V_x = 5.6V \]

\[ V_{in}, V_{01}, V_{o2} \]
Astable Multivibrator Using NOR(or Inverter) Gates

- Transient behavior
  (1) $0 < t < T_1$
  (i) $v_{o1} : V_{DD} \rightarrow 0$ when $t = 0$
  (ii) $v_{o2} : 0 \rightarrow V_{DD}$ when $t = 0$
  (iii) $v_x = (V_{DD} + V_T) e^{-\frac{t}{RC}}$
  (iv) $v_c = v_x - v_{o2} = -V_{DD} + (V_{DD} + V_T) e^{-\frac{t}{RC}}$
Astable Multivibrator Using NOR(or Inverter) Gates

(Cont.)

(2) $T_1 < t < (T_1 + T_2)$

(i) $v_{o1} : 0 \rightarrow V_{DD}$ when $t = T_1$

(ii) $v_{o2} : V_{DD} \rightarrow 0$ when $t = T_1$

(iii) $v_x = V_{DD} - (V_{DD} + V_T) e^{-\frac{(t-T_1)}{RC}}$

(iv) $v_c = v_x - V_{O2} = v_x = V_{DD} - (V_{DD} + V_T) e^{-\frac{(t-T_1)}{RC}}$
Astable Multivibrator Using NOR(or Inverter) Gates (Cont.)

- Oscillation frequency
  
  \[ v_x(T_1) = V_T \]
  
  \[ \Rightarrow (V_{DD} + V_T) e^{-\frac{t}{RC}} = V_T \]
  
  \[ \Rightarrow T_1 = RC \ln \frac{V_{DD} + V_T}{V_T} \]

  If \( V_T = \frac{V_{DD}}{2} \), then \( T_1 = RC \ln 3 \) and \( T_2 = RC \ln 3 \)

  Oscillation frequency \[ f_0 = \frac{1}{2RC \ln 3} \approx \frac{0.455}{RC} \]
Astable Multivibrator Using NOR(or Inverter) Gates (Cont.)

- With catching diode at $V_x$

- Asymmetrical square wave

\[ T_1 = T_2 = RC\ln 2 \]
\[ f_0 = \frac{1}{2RC\ln 2} \approx \frac{0.721}{RC} \]

- (i) $V_T \neq \frac{V_{DD}}{2}$
- (ii) $R_1 \neq R_2$
The 555 IC Timer

- Widely used as both a monostable and astable multivibrator
- Used as a monostable multivibrator

<table>
<thead>
<tr>
<th>$R_n$</th>
<th>$S_n$</th>
<th>$Q_{n+1}$</th>
<th>$V_{TH} = \frac{2}{3}V_{CC}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>$Q_n$</td>
<td>$V_{TL} = \frac{1}{3}V_{CC}$</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>N/A</td>
<td>$V_c \geq \frac{2}{3}V_{CC} \Rightarrow R_n = 1$</td>
</tr>
</tbody>
</table>

$V_{c}(t) = \frac{2V_{CC}}{3}$

$V_{CC}(1 - e^{-t/RC})$
The 555 IC Timer (Cont.)

◆ For $0 \leq t \leq T_1$

$$v_C(t) = V_{CC} - [V_{CC} - V_C(0)]e^{-\frac{t}{RC}} \quad (V_C(0) \approx V_{CE(sat)} \approx 0)$$

◆ For $t = T_1$, $v_C(T_1) = V_{TH} = \frac{2V_{CC}}{3}$

$$\Rightarrow T_1 = RC \ln \frac{V_{CC} - V_C(0)}{V_{CC}} \approx RC \ln 3 \quad (V_C(0) \approx 0)$$
The 555 IC Timer (Cont.)

- Used as an astable multivibrator

\[
\begin{align*}
V_{CC} &= (R_A + R_B)C \\
V_{TH} &= \frac{2V_{cc}}{3} \\
V_{TL} &= \frac{V_{cc}}{3}
\end{align*}
\]

\[
\begin{align*}
V_c &\geq \frac{2V_{cc}}{3} \Rightarrow S = 0, R = 1 \\
V_c &\leq \frac{V_{cc}}{3} \Rightarrow S = 1, R = 0 \\
\frac{V_{cc}}{3} &\leq V_c \leq \frac{2V_{cc}}{3} \Rightarrow S = R = 0 \\
T_1 &= R_B C \ln 2 \quad T_2 - T_1 = (R_A + R_B)C \ln 2
\end{align*}
\]

- Oscillation frequency

\[
f = \frac{1}{T_2} = \frac{1}{(R_A + 2R_B)C \ln 2}
\]
Appendix

- Sine-wave shaper
- Precision rectifier circuits
- Precision full-wave rectifiers
- Peak rectifier
- Crystal oscillators
Sine-Wave Shaper

- Shape a triangular waveform into a sinusoid
- Extensively used in function generators
- Note: linear oscillators are not cost-effective for low frequency application and not easy to time over wide frequency ranges
Sine-Wave Shaper (Cont.)

- Nonlinear-amplification method
  - For various input values, their corresponding output values can be calculated
  
  \[
  \text{Transfer curve can be obtained and is similar to}
  \]

![Circuit Diagram]
Sine-Wave Shaper (Cont.)

- Breakpoint method
  - Piecewise linear transfer curve
  - Low-valued R is assumed \( \Rightarrow V_1 \) and \( V_2 \) are constant

\[
V_1 < V_{in} < V_1 \Rightarrow V_{out} = V_{in}
\]

\[
V_1 < V_{in} < V_2 \Rightarrow D_2 \text{ is on (voltage drop } V_D) \\
\Rightarrow V_0 = V_1 + V_D + (V_{in} - V_D - V_1) \frac{R_5}{R_5 + R_4}
\]

\[
V_2 < V_{in} \Rightarrow D_1 \text{ is on } \Rightarrow \text{limit } V_0 \text{ to } V_2 + V_D
\]
Sine-Wave Shaper (Cont.)

\[ + V \]

\[ D_1 \]
\[ R_1 \]
\[ + V_2 \]
\[ D_2 \]
\[ R_2 \]
\[ + V_1 \]
\[ D_3 \]
\[ R_3 \]
\[ - V_1 \]
\[ D_4 \]
\[ R_3 \]
\[ - V_2 \]
\[ R_1 \]
\[ - V \]

\[ \text{in} \]
\[ \text{out} \]

\[ \text{in} \]
\[ \text{out} \]

\[ + V_2 \]
\[ + V_1 \]
\[ - V_1 \]
\[ - V_2 \]

\[ 1 \]
\[ 2 \]
\[ 3 \]
\[ 4 \]
\[ 5 \]
Precision Rectifier Circuits

- Precision half-wave rectifier --- “superdiode”

- An alternate circuit
Precision Rectifier Circuits (Cont.)

- Application: Measure AC voltages

Average $V_1 = \frac{V_p R_2}{\pi R_1}$; where $V_p$ is the peak amplitude of an input sinusoid
Precision Rectifier Circuits (Cont.)

If \( \frac{1}{R_4C} \ll \omega_{\text{min}} \); \( \omega_{\text{min}} \) is the lowest expected frequency of the input sine wave

\[ V_2 = -\frac{V_P}{\pi} \frac{R_2 R_4}{R_1 R_3} \]
Precision Full-Wave Rectifiers
Precision Full-Wave Rectifiers (Cont.)
Peak Rectifier

- With load

- buffered

Prof. Tai-Haur Kuo
Crystal oscillators

\[ L = 61 \text{ to } 122 \mu\text{H} \]

\[ C = 300 \text{ pF} \]

Bias circuit

(For AC, -22V and ground are the same = 0)
Since return ratio $T = \frac{A_v X_1}{X_2}$ then $X_1$ must be large for the loop gain to be greater than one.

$X_1$ is very large when \( \omega \) closes to $\omega_p$ and \( \omega_s < \omega < \omega_p \)

$X_1 + X_2 + X_3 = 0 \quad \& \quad X_3 = -\frac{1}{\omega C} \Rightarrow X_1 \& X_2$ are inductive

\[
Z_2 = \frac{1}{j\omega C + \frac{1}{j\omega L}} = \frac{j}{-\omega C + \frac{1}{\omega L}}
\]

\[
\Rightarrow X_2 = \frac{1}{-\omega C + \frac{1}{\omega L}} > 0 \Rightarrow \omega L > \frac{1}{\omega C} \Rightarrow \omega > \frac{1}{\sqrt{LC}}
\]

For 1MHz crystal,

\[
\begin{align*}
C &= 300\text{pF} \\
L &\approx 84.4\mu\text{H} \\
\frac{1}{2\pi \sqrt{LC}} &\approx 1\text{MHz}
\end{align*}
\]