Basic Principles of Sinusoidal Oscillators

- Linear oscillator
  - Linear region of circuit: linear oscillation
  - Nonlinear region of circuit: amplitudes stabilization
- Barkhausen criterion
  - Loop gain $L(s) = \beta(s)A(s)$
  - Characteristic equation: $1 - L(s) = 0$
  - Oscillation criterion: $L(j\omega_0) = A(j\omega_0)\beta(j\omega_0) = 1$
Basic Principles of Sinusoidal Oscillators (Cont.)

\[ \omega_0, \text{ the phase of the loop should be zero and the} \]
\[ \text{magnitude of the loop gain should be unity.} \]
\[ \text{Oscillation frequency } \omega_0 \text{ is determined solely by} \]
\[ \Delta \omega_0 = \frac{\Delta \phi}{d\phi/d\omega} \]

\[ \Delta \omega_0 \text{ for a} \]
\[ \text{given change in phase } \Delta \phi \]
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

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

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

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

- nonlinear region

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

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

Similarly, \( L_+ = V \frac{R_4}{R_5} + V_D \left( 1 + \frac{R_4}{R_5} \right) \)
OPAMP-RC Oscillator Circuits

- Wien-bridge oscillator

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

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

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

--- 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]
OPAMP-RC Oscillator Circuits (Cont.)
Phase-Shift Oscillator

- Without amplitude stabilization

\[ \text{----- phase shift of the RC network is 180 degrees.} \]
\[ \Rightarrow \text{Total phase shift around the loop is 0 or 360 degrees.} \]
Phase-Shift Oscillator (Cont.)

- With amplitude stabilization
Quadrature Oscillator

\[ V_+ \]

\[ V_- \]

\[ R_1 \]

\[ R_2 \]

\[ R_3 \]

\[ R_4 \]

\[ C \]

\[ 2R \]

\[ OP_1 \]

\[ OP_2 \]

\[ 2R \]

\[ 2R \]

\[ R_f \]

\[ (\text{Nominally } 2R) \]

\[ V_{o1} \]

\[ V_{o2} \]
Quadrature Oscillator (Cont.)

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

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

→ oscillation frequency

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

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

→ 90° phase difference between \( V_{o1} \) and \( V_{o2} \)

→ “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

- $Z_1, Z_2, Z_3$: capacitive or inductive
A General Form of LC-Tuned Oscillator Configuration (Cont.)

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

\[ V_{13} = \frac{Z_1}{Z_1 + Z_3} V_O \]

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

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

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

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

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

\[ X_1 + X_2 + X_3 = 0 \]

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

\[ T = \frac{A_v X_1}{X_2} \]
A General Form of LC-Tuned Oscillator Configuration (Cont.)

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

- Two commonly used configurations
  - 1. Collpitts (feedback is achieved by using a capacitive divider)
  - 2. Harley (feedback is achieved by using an inductive divider)

Configuration

1. Collpitts

2. Harley
LC Tuned Oscillators (Cont.)

- Collpitts oscillator
  - Equivalent circuit

\[ \pi \frac{V}{2} = \pi V_0 \left(1 + s^2 L C_2\right) \]

\[ sC_2 V_\pi \]

\[ \frac{-}{C_2} \quad + \quad \frac{V_\pi}{GmV_\pi} \quad \frac{R}{C_1} \quad \frac{L}{C} \]

- \( R = \) loss of inductor + load resistance of oscillator + output resistance of transistor
LC Tuned Oscillators (Cont.)

\[ SC_2 V + g_m v + \left( \frac{1}{R} + SC_1 \right) (1 + S^2 LC_2) V = 0 \]

\[ S^3 LC_1 C_2 + S^2 \left( \frac{LC_2}{R} \right) + S(C_1 + C_2) + \left( g_m + \frac{1}{R} \right) = 0 \]

\[ (g_m + \frac{1}{R} - \frac{w^2 LC_2}{R}) + j \left[ W(C_1 + C_2) - W^3 LC_1 C_2 \right] = 0 \]

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

- Oscillation frequency

\[ \omega_0 = \frac{1}{\sqrt{L \left( \frac{c_1 c_2}{c_1 + c_2} \right)}} \]
LC Tuned Oscillators (Cont.)

◆ Gain

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

◆ 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 \( r = 0 \)

\[
Z(s) = \frac{1}{sC_p + \frac{1}{sL + \frac{1}{sC_s}}} = \frac{1}{sC_p} \frac{s^2 + \left( \frac{1}{LC_s} \right)}{s^2 + \left( \frac{C_p + C_s}{LC_s C_p} \right)}
\]

(Crystal is high – Q device)

Let

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

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

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 $w_s$ and $w_p$

- Collpitts crystal oscillator
  - Configuration

![Collpitts Crystal Oscillator Circuit Diagram](image-url)
Crystal oscillators (Cont.)

- Equivalent circuit

\[ C_s \ll C_p, C_1, C_2 \]

\[ \Rightarrow \omega_0 \approx \frac{1}{\sqrt{LC_s}} = \omega_S \]
Crystal oscillators (Cont.)

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

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

\[ C_{gd} + C_{\text{stray}} \]

1MHz

XTAL

-22V

\[ 10 \text{M} \Omega \]

2.2kΩ

0.02μF

2N2608

\[ \equiv \]

Bias circuit

(For AC, -22V and ground are the same = 0)
Crystal oscillators (Cont.)

- 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 $\{\omega \text{ closes to } \omega_p \text{ and } \omega_s < \omega < \omega_p\}$

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

For 1MHz crystal, $C=300pF$, $L \approx 84.4\mu H$, $\frac{1}{2\pi \sqrt{LC}} \approx 1MHz$
Bistable 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 \( \beta = \frac{R_1}{(R_1 + R_2)} \)
Bistable Multivibrators (Cont.)

◆ Bistable circuit with clockwise hysteresis

◆ Clockwise hysteresis (or inverting hysteresis)
  
  \[ L_+ : \text{positive saturation voltage of OPAMP} \]
  
  \[ L_- : \text{negative saturation voltage of OPAMP} \]
Bistable Multivibrators (Cont.)

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

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

- Hysteresis width = \( V_{TH} - V_{TL} \)
Noninverting Bistable Circuit

- Counterclockwise hysteresis
- Configuration

\[ v_+ = v_l \frac{R_2}{R_1+R_2} + v_0 \frac{R_1}{R_1+R_2} \]

For \( v_0 = L_+ \), \( v_+ = 0 \), \( v_l = v_{TL} \) \( \Rightarrow v_{TL} = -L_+ \left( \frac{R_1}{R_2} \right) \)

For \( v_0 = L_- \), \( v_+ = 0 \), \( v_l = v_{TH} \) \( \Rightarrow v_{TH} = -L_- \left( \frac{R_1}{R_2} \right) \)
Noninverting Bistable Circuit (Cont.)

- Comparator characteristics with hysteresis
  - Can reject interference

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

Signal corrupted with interference

Multiple zero crossings
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.)

\[
V_{TH} = \beta L_+ \\
V_{TL} = \beta L_- \\
V_+ = \beta V_{TH} \\
V_- = \beta V_{TL}
\]

Time constant = 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 \( t = T_1 \) \( \Rightarrow T_1 = \tau \ln \frac{1 - \beta \left( \frac{L_-}{L_+} \right)}{1 - \beta} \)

- During T2
  \[ V_- = L_- - (L_- - \beta L_+)e^{\frac{t}{\tau}} \]
  
  if \( V_- = \beta L_- \) at \( t = T_2 \) \( \Rightarrow T_2 = \tau \ln \frac{1 - \beta \left( \frac{L_+}{L_-} \right)}{1 - \beta} \)

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

\[ V_2 \]

\[ L_+ \]

\[ 0 \]

\[ L_- \]

\[ T \]

\[ T_1 \]

\[ T_2 \]

\[ V_{TH} \]

\[ V_{TL} \]

\[ \text{Slope} = \frac{-L}{RC} \]

\[ \text{Slope} = \frac{-L}{RC} \]

Bistable

\[ V_1 \]

\[ V_2 \]

\[ t \]
Generation of Triangular Waveforms (Cont.)

- During T1
  \[ V_{TL} - V_{TH} = -\frac{1}{C} \int_0^{T_1} i_C dt = \frac{L_+ T_1}{RC} \; \text{ where } i_C = \frac{L_+}{R} \]
  \[ \Rightarrow T_1 = RC \frac{V_{TH} - V_{TL}}{L_+} \]

- During T2
  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

\[
\begin{align*}
V_E(t) &= (\beta L_+ - V_{D2}) \\
L_+ &= V_A(t) \\
L_- &= V_+(t) \\
\beta L_+ &= V_{D1} \\
\beta L_- &= V_{B}(t) \\
\end{align*}
\]
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

\[
\begin{align*}
V_{in} & \quad V_{o1} \quad V_{x} \quad V_{o2} \\
\text{NOR} & \quad C & \quad \text{NOR} \\
+V_{DD} & \quad R \\
\end{align*}
\]

- Timing Diagrams:
  - \( V_{in} \): \( V > V_T \) for \( 0 < t < T_1 \)
  - \( V_{o1} \): \( V_{DD} \) for \( 0 < t < T_1 \)
  - \( V_{x} \): \( V_{DD} + V_T = 3/2 V_{DD} \) for \( 0 < t < T_1 \)
  - \( V_{o2} \): \( V_{DD} \) for \( 0 < t < T_1 \)

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

\[ v_c(0) = 0 \]
\[ v_x = V_{DD}(1 - e^{-\frac{t}{RC}}) \]
\[ v_x(T_1) = V_T = V_{DD}(1 - e^{-\frac{T_1}{RC}}) \]

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

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

- Monostable multivibrator with catching diode

\[ t = R \cdot C \]

Forward resistance of diode

Time constant = \( R \cdot C \)

Time constant = \( R \cdot C \)
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

\[ v_x(T_1) = V_T \]

\[ \Rightarrow (V_{DD} + V_T) e^{-\frac{t}{RC}} = V_T \]

\[ \Rightarrow T_1 = R C \ln \frac{V_{DD} + V_T}{V_T} \]

If \[ V_T = \frac{V_{DD}}{2} \], then \[ T_1 = R C \ln 3 \] and \[ T_2 = R C \ln 3 \]

oscillation frequency \[ f_0 = \frac{1}{2 R C \ln 3} \approx \frac{0.455}{R C} \]
Astable Multivibrator Using NOR(or Inverter) Gates

(Cont.)

- With catching diode at $V_X$

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

- Asymmetrical square wave

(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 monostable multivibrator

\[ v(t) = \begin{cases} V_c & t < T \vspace{1cm} \\
0 & t \geq T 
\end{cases} \]

\[ V_c = \frac{2V_{cc}}{3} \]

\[ V_{th} = \frac{V_{cc}}{3} \]

\[ V_{cc}(1 - e^{-t/RC}) \]

\[ v(t) = \begin{cases} V_{th} & t < T_1 \vspace{1cm} \\
V_{cc} & t \geq T_1 
\end{cases} \]

\[ v(t) = \begin{cases} 0 & t < T_1 \vspace{1cm} \\
V_{cc} & t \geq T_1 
\end{cases} \]
The 555 IC Timer (Cont.)

◆ For $0 \leq t \leq T_1$

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

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

$$\Rightarrow T_1 = RC\ln\frac{V_{CC} - V(0)}{V_{CC}} \approx RC\ln3 \quad (V(0) \approx 0)$$
The 555 IC Timer (Cont.)

- **Used as an astable multivibrator**

\[
\begin{align*}
V_{th} &= \frac{2V_{cc}}{3} \\
V_{tl} &= \frac{V_{cc}}{3}
\end{align*}
\]

\[
T_2 = T_1 = \frac{(R_A + R_B)C \ln 2}{V_{cc}}
\]

\[
V_c \geq \frac{2V_{cc}}{3} \Rightarrow S = 0, R = 1
\]

\[
V_c \leq \frac{V_{cc}}{3} \Rightarrow S = 1, R = 0
\]

\[
\frac{V_{cc}}{3} \leq V_c \leq \frac{2V_{cc}}{3} \Rightarrow S = R = 0
\]

- **Oscillation frequency**

\[
f = \frac{1}{T_2} = \frac{1}{(R_A + 2R_B)C \ln 2}
\]
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
  - 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
  
  \[
  \text{Transfer curve can be obtained and is similar to}
  \]

\[
\begin{align*}
\text{Transfer curve can be obtained and is similar to} \\
\text{(Sine wave) and (Triangular wave)}
\end{align*}
\]
Sine-Wave Shaper (Cont.)

- Breakpoint method
  - Piecewise linear transfer curve
  - Low-valued R is assumed → V1 and V2 are constant

\[ V_1 < V_{in} < V_1 \implies V_{out} = V_{in} \]
\[ V_1 < V_{in} < V_2 \implies D_2 \text{ is on (voltage drop } V_D \text{)} \]

\[ \Rightarrow V_0 = V_1 + V_D + (V_{in} - V_D - V_1) \frac{R_5}{R_5 + R_4} \]

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

In

\[ \begin{align*}
&\text{D}_1 \quad \text{R}_1 \\
&\text{D}_2 \quad \text{R}_5 \\
&\text{D}_3 \quad \text{R}_5 \\
&\text{D}_4 \quad \text{R}_5 \\
&\text{R}_4 \\
&\text{out}
\end{align*} \]

\[ \begin{align*}
+V_2 & \quad +V_1 \\
-\quad \quad R_2 \\
-\quad \quad R_3 \\
-\quad \quad R_3 \\
-\quad \quad -V_1 \\
-\quad \quad -V_2 \\
-\quad \quad \text{out}
\end{align*} \]

\[ \begin{align*}
&\text{In} \\
&\text{out}
\end{align*} \]
Precision Rectifier Circuits

- Precision half-wave rectifier --- "superdiode"

- An alternate circuit
Precision Rectifier Circuits (Cont.)

- Application: Measure AC voltages

\[
V_1 = \frac{V_p R_2}{\pi R_1} \quad \text{where } V_p \text{ is the peak amplitude of an input sinusoid}
\]
Precision Rectifier Circuits (Cont.)

If \( \frac{1}{R_4 C} \ll \omega_{\text{min}} \); \( \omega_{\text{min}} \) is the lowest expected frequency of the input sine wave

\[ V_2 = -\frac{V_p}{\pi} \frac{R_2}{R_1} \frac{R_4}{R_3} \]
Precision Full-Wave Rectifiers

![Diagrams of full-wave rectifiers with waveforms and circuit symbols]
Precision Full-Wave Rectifiers (Cont.)

\[
\begin{align*}
&V_i \quad A \quad A_2 \quad D_1 \quad E \quad C \quad V_o \\
&R_1 \quad R_2 \quad R_L \\
&\quad F \quad D_2 \quad + \quad - \quad + \\
&\quad V_i \quad V_o \quad P
\end{align*}
\]
Peak Rectifier

- With load

\[ v_i \rightarrow + \rightarrow - \rightarrow + \rightarrow C \rightarrow R_L \rightarrow + \rightarrow v_o \]

- buffered

\[ v_i \rightarrow + \rightarrow - \rightarrow + \rightarrow \text{Buffer} \rightarrow + \rightarrow v_o \]