EE 330
Lecture 29

Two-Port Amplifier Model
Thyristor Circuits
Thyristor Summary
Two-port representation of amplifiers

- Thevenin equivalent output port often more standard
- \( R_{\text{IN}}, A_v, \) and \( R_{\text{OUT}} \) often used to characterize the two-port of amplifiers
Amplifier input impedance, output impedance and gain are usually of interest.

Example 1: Assume amplifier is unilateral

\[ V_{IN} \]
\[ R_S \]
Amplifier
\[ R_L \]
\[ V_{OUT} \]

\[ V_{OUT} = \left( \frac{R_L}{R_L + R_{OUT}} \right) A_v \left( \frac{R_{IN}}{R_S + R_{IN}} \right) V_{IN} \]

\[ A_{VAMP} = \frac{V_{OUT}}{V_{IN}} = \left( \frac{R_L}{R_L + R_{OUT}} \right) \left( \frac{R_{IN}}{R_S + R_{IN}} \right) A_v \]

Can get gain without reconsdidering details about components internal to the Amplifier !!!

Analysis more involved when not unilateral
Amplifier input impedance, output impedance and gain are usually of interest.

**Why?**

**Example 2:** Assume amplifiers are unilateral.

Can get gain without reconsdidering details about components internal to the Amplifier !!!

Analysis more involved when not unilateral.
Two-port representation of amplifiers

- **Amplifier usually unilateral** (signal propagates in only one direction: wlog $y_{12}=0$)
- One terminal is often common
- “Amplifier” parameters often used

Amplifier parameters can also be used if not **unilateral**

- One terminal is often common

**Review from last lecture**
Determination of two-port model parameters

(One method will be discussed here)

A method of obtaining $R_{in}$

\[
\begin{align*}
    i_1 &= v_1 \left( \frac{1}{R_{in}} \right) + v_2 \left( -\frac{A_{VR}}{R_{in}} \right) \\
    i_2 &= v_1 \left( -\frac{A_{V0}}{R_0} \right) + v_2 \left( \frac{1}{R_0} \right)
\end{align*}
\]

\[
R_{in} = \frac{v_{\text{test}}}{i_{\text{test}}}
\]

Terminate the output in a short-circuit
Determination of two-port model parameters

A method of obtaining $A_{v0}$

\[ i_1 = v_1 \left( \frac{1}{R_{in}} \right) + v_2 \left( -\frac{A_{VR}}{R_{in}} \right) \]

\[ i_2 = v_1 \left( -\frac{A_{V0}}{R_0} \right) + v_2 \left( \frac{1}{R_0} \right) \]

Terminate the output in an open-circuit

\[ A_{V0} = \frac{v_{out-test}}{v_{test}} \]
Determination of two-port model parameters

A method of obtaining $R_0$

Terminate the input in a short-circuit

$$i_1 = v_1 \left( \frac{1}{R_{in}} \right) + v_2 \left( -\frac{A_{VR}}{R_{in}} \right)$$

$$i_2 = v_1 \left( -\frac{A_{V0}}{R_0} \right) + v_2 \left( \frac{1}{R_0} \right)$$

$v_1 = 0$

$R_0 = \frac{V_{test}}{i_{test}}$
Determination of two-port model parameters

A method of obtaining $A_{VR}$

Termination the input in an open-circuit

$$i_1 = v_1 \left( \frac{1}{R_{in}} \right) - v_2 \left( \frac{A_{VR}}{R_{in}} \right)$$

$$i_2 = v_1 \left( \frac{-A_{V0}}{R_0} \right) + v_2 \left( \frac{1}{R_0} \right)$$

$A_{VR} = \frac{v_{out\text{-}test}}{v_{test}}$
Determination of Amplifier Two-Port Parameters

- Input and output parameters are obtained in exactly the same way, only distinction is in the notation used for the ports.

- Methods given for obtaining amplifier parameters $R_{\text{in}}$, $R_{\text{OUT}}$, and $A_V$ for unilateral networks are a special case of the non-unilateral analysis by observing that $A_{VR}=0$.

- In some cases, other methods for obtaining the amplifier parameters are easier than what was just discussed.
Examples

Biasing Circuit

\[ V_{\text{CC}} = 12 \text{V} \]

\[ R_{B1} = 50 \text{K} \]

\[ C = 1 \mu\text{F} \]

\[ R_{B2} = 10 \text{K} \]

\[ R_1 = 0.5 \text{K} \]

\[ R_2 = 2 \text{K} \]

\[ V_{\text{IN}}(t) \]

\[ Q_1 \]

\[ V_{\text{OUT}} \]

Determine \( V_{\text{OUTQ}} \) and the SS voltage gain \( (A_V) \), assume \( \beta = 100 \)

\( (A_V \) is one of the small-signal model parameters for this circuit)
Examples

Determine $V_{OUTQ}$ and the SS voltage gain ($A_V$), assume $\beta=100$

($A_V$ is one of the small-signal model parameters for this circuit)
Examples

Determine $V_{OUTQ}$

This circuit is most practical when $I_B \ll I_{BB}$

With this assumption,

$$V_B = \left( \frac{R_{B2}}{R_{B1} + R_{B2}} \right) 12V$$

$$I_{CQ} = I_{EQ} = \left( \frac{V_B - 0.6V}{R_1} \right) = \frac{1.4V}{0.5K} = 2.8 mA$$

$$V_{OUTQ} = 12V - I_{CQ} R_1 = 6.4V$$

Note: This Q-point is nearly independent of the characteristics of the nonlinear BJT!
If $g_m R_1 >> 1$ this voltage gain is nearly independent of the characteristics of the nonlinear BJT!

This is such an attractive property that often design circuit so that $g_m R_1 >> 1$

This is a fundamentally different amplifier structure

It can be shown that this is slightly non-unilateral
Determine $V_{OUTQ}$, $R_{IN}$, $R_{OUT}$, and the SS voltage gain, assume $\beta=100$. 

\[ V_{CC} = 12V \]
\[ R_{B1} = 50K \]
\[ C_1 = 1uF \]
\[ V_{IN}(t) \]
\[ R_{B2} = 10K \]
\[ Q_1 \]
\[ R_2 = 2K \]
\[ V_{OUT} \]
\[ R_1 = 0.5K \]
\[ C_2 = 100uF \]
Examples

Determine $V_{\text{OUTQ}}$, $R_{\text{IN}}$, $R_{\text{OUT}}$, and the SS voltage gain, and $A_{\text{VR}}$; assume $\beta = 100$

($A_V$, $R_{\text{IN}}$, $R_{\text{OUT}}$, and $A_{\text{VR}}$ are the small-signal model parameters for this circuit)
Examples

Determine $V_{OUTQ}$

This is the same as the previous circuit!

$$V_{OUTQ} = 6.4V$$

$$I_{CQ} = \frac{5.6V}{2K} = 2.8mA$$

Note: This Q-point is nearly independent of the characteristics of the nonlinear BJT!

The dc equivalent circuit
Examples

Determine the SS voltage gain

This is the same as the previous-previous circuit!

\[ A_V \approx -g_m R_2 \]

\[ A_V \approx -\frac{I_{CQ} R_2}{V_t} \]

Note: This Gain is nearly independent of the characteristics of the nonlinear BJT!
Examples

Determine of $R_{IN}$

The SS equivalent circuit

$R_{IN} = R_{B1} // R_{B2} // r_\pi \simeq r_\pi$

$r_\pi = \left( \frac{I_{CQ}}{\beta V_t} \right)^{-1} = \left( \frac{2.8mA}{100 \cdot 26mV} \right)^{-1} = 928\Omega$

$R_{IN} = R_{B1} // R_{B2} // r_\pi \simeq r_\pi = 930\Omega$
Examples

Determine of $R_{OUT}$

The SS equivalent circuit

$$R_2 = 2K$$

$$Q_1$$

$$V_{IN(t)}$$

$$V_{CC} = 12V$$

$$R_{B1} = 50K$$

$$R_{B2} = 10K$$

$$C_1 = 1uF$$

$$R_1 = 0.5K$$

$$C_2 = 100uF$$

$\beta = 100$

$$v_{cc}$$

$$v_{in}$$

$\frac{v_{test}}{i_{test}}$ = $R_2 // r_o$

$$r_o = \left( \frac{I_{cq}}{V_{af}} \right)^{-1} = \left( \frac{2.8mA}{200V} \right)^{-1} = (1.4E-5)^{-1} = 71K\Omega$$

$$R_{OUT} = R_2 // r_o \approx R_2 = 2K$$
Examples

Determine $A_{VR}$

The SS equivalent circuit

$\beta = 100$

$V_{IN}(t)$ $\rightarrow$ $Q_1$ $\rightarrow$ $V_{OUT}$

$R_{B1} = 50K$ $C_1 = 1uF$

$R_{B2} = 10K$ $R_1 = 0.5K$ $C_2 = 100uF$

$V_{CC} = 12V$

$R_2 = 2K$

$\nu_{be}$ $\rightarrow$ $g_{m}$ $\rightarrow$ $\nu_{be}$ $\rightarrow$ $g_o$ $\rightarrow$ $\nu_{ce}$ $\rightarrow$ $R_2$

$\nu_{OUT} = 0$

$A_{VR} = 0$

$\nu_{OUT \_TEST} = 0$
Determination of small-signal two-port representation

\[ \begin{align*} 
V_{\text{IN}}(t) & \rightarrow Q_1 \\
V_{\text{OUT}} & \rightarrow V_{\text{CC}} = 12V \\
R_{B1} & = 50K \\
C_1 & = 1\text{uF} \\
R_{B2} & = 10K \\
R_1 & = 0.5K \\
C_2 & = 100\text{uF} \\
\end{align*} \]

\[ \begin{align*} 
A_v & \approx -215 \\
R_{\text{IN}} & \approx r_\pi = 930\Omega \\
R_{\text{OUT}} & \approx R_2 = 2K \\
\end{align*} \]

This is the same basic amplifier that was considered many times.
Review from last lecture

Identification of Quadrants of Operation in $I_T-V_{M21}$ plane

Curves may not be symmetric between $Q_1$ and $Q_3$ in the $I_T-V_{M21}$ plane

Turn on current may be large and variable in $Q_4$ (of the $V_{M21}-V_{GT1}$)

Generally avoid operation in $Q_4$ (of the $V_{M21}-V_{GT1}$ plane)

Most common to operate in $Q_2$-$Q_3$ quadrants or $Q_1$-$Q_3$ quadrants (of the $V_{M21}-V_{GT1}$ plane)
Some Basic Triac Application Circuits

Quad 1 : Quad 3

Quad 1 : Quad 3

Quad 1 : Quad 3

Review from last lecture
Some Basic Triac Application Circuits

Review from last lecture

Quad 1/ Quad 2 : Quad 3/Quad 4

Not real popular

Real popular
Thyristor Types

Some of the more major types:

- SCR
- Triac
- Bidirectional Phase-controlled thyristors (BCT)
- LASCR (Light activated SCR)
- Gate Turn-off thyristors (GTO)
- FET-controlled thyristors (FET-CTH)
- MOS Turn-off thyristors (MTO)
- MOS-controlled thyristors (MCT)
Thyristor Applications

Thyristors are available for working at very low current levels in electronic circuits to moderate current levels such as in incandescent light dimmers to very high current levels.

$I_{\text{TRIAC}}$ from under 1mA to 10000A

Applications most prevalent for moderate to high current thyristors
SCR, rated about 100 amperes, 1200 volts, 1/2 inch stud, photographed by C J Cowie. Uploaded on 4 April 2006.
PT40QPx45

Pulse Power Thyristor Switch
Preliminary Information

KEY PARAMETERS
- $V_{DRM} = 4500V$
- $I_{T(AV)} = 760A$
- $I_{TSM} = 13000A$
- $dl/dt = 5000A/\mu s$

APPLICATIONS
- Pulse Power
- Crowbars
- Ignitron Replacement

Thanks to Prof. Ajjarapu for providing the following slides:
From ABB Web Site

Bi-Directional Control Thyristor

5STB 13N6500

V_{RM} = 6500 V
I_{T(AN)M} = 1405 A
I_{T(RMS)} = 2205 A
I_{TSM} = 22 \times 10^3 A
V_{T0} = 1.2 V
r_T = 0.6 \text{ m\Omega}

Diameter = 140mm
Thanks to Prof. Ajjarapu for providing the following slides:

THE BIDIRECTIONAL CONTROL THYRISTOR (BCT)

by

Kenneth M. Thomas, Björn Backlund, Orhan Toker

*ABB Semiconductors AG, CH5600 Lenzburg, Switzerland*

Björn Thorvaldsson

*ABB Power Systems AB, S-721 64 Västerås, Sweden*

**ABSTRACT**

The Bidirectional Control Thyristor (BCT) is a new concept for high power thyristors integrated on a single silicon wafer with separate gate contacts. This unique design, based on free-floating silicon technology, successfully overcomes the traditional problems of interference experienced by bidirectional thyristors during dynamic operation which previously prevented the use of such devices. Such components are suitable for applications at high voltages like a normal thyristor but where triacs can no longer be used.
High Current, High Voltage Solid State Discharge
Switches for Electromagnetic Launch Applications

A. Welleman, R. Leutwyler, J. Waldmeyer
ABB Switzerland Ltd, Semiconductors - CH-5600 Lenzburg

Abstract—This presentation is about the work done on design, built-up, production and test of ready-to-use solid state switch assemblies using Thyristor- or IGCT technology. The presented thyristor switch assemblies, using 120 mm wafer size, are made to switch 3MJ stored energy into a load. The maximum charge voltage of the assembly is 12 kVdc, current capability more than 260kA@tp=3.3ms and a pulse repetition rate of up to 6 shots per minute with convection air cooling. New very large thyristors with 150 mm wafer diameter will be available from fall 2008. As second a 70 kA/21kVdc switch using IGCT technology will be presented. The switch is designed for fast discharge in the micro-second range and has a very high di/dt capability. Because for adapted standard products which can fulfill the requirements for pulsed applications. Beside the semiconductor devices, ABB is also in the position to supply complete custom made ready-to-use solid state switch assemblies including clamping, triggering, cooling and with application oriented testing. The presentation describes both, the loose semiconductor components as well as some custom made solid state switches for single pulse or low repetition rate pulsing.

II. DEVICE TECHNOLOGY

2008 Paper
Thanks to Prof. Ajjarapu for providing the following slides:

![Thyristor Switch Assembly A-STP 5742U-18-CC](image)

Fig. 3: Thyristor Switch Assembly A-STP 5742U-18-CC
Stud-Mounted SCR
110 Amp RMS Rating

Thanks to Prof. Ajjarapu for providing the following slides:

- **Auxiliary Cathode Lead** (Red)
  - Extends cathode potential to the control circuit.

- **Gate Lead** (White)

- **Cathode Lead**

- **Stud Anode**
Cross-section of a BCT wafer showing the antiparallel arrangement of the A and B component thyristors. The arrows indicate the convention of forward blocking for A and B.

Thanks to Prof. Ajjarapu for providing the following slides:
Thyristor Valve - 12 Pulse Converter (6.5kV, 1568 Amp, Water cooled)

Thanks to Prof. Ajjarapu for providing the following slides:
Thyristor Observations

Many different structures used to build thyristors

Range from low power devices to extremely high power devices

Often single-wafer solutions for high power applications

Usually formed by diffusions

Widely used throughout society but little visibility

Applications somewhat restricted
Thyristors

The good
- SCRs
- Triacs

The bad
Parasitic Device that can destroy integrated circuits
The Thyristor
A bipolar device in CMOS Processes

Consider a Bulk-CMOS Process

If this parasitic SCR turns on, either circuit will latch up or destroy itself.

Guard rings must be included to prevent latchup.

Design rules generally include provisions for guard rings.
Operating Point of Electronic Circuits

Often interested in circuits where a small signal input is to be amplified.

The electrical port variables where the small signal goes to 0 is termed the Operating Point, the Bias Point, the Quiescent Point, or simply the Q-Point.

By setting the small signal to 0, it means replacing small voltage inputs with short circuits and small current inputs with open circuits.

When analyzing small-signal amplifiers, it is necessary to obtain the Q-point.

When designing small-signal amplifiers, establishing of the desired Q-point is termed “biasing.”

Capacitors become open circuits (and inductors short circuits) when determining Q-points.

Simplified dc models of the MOSFET (saturation region) or BJT (forward active region) are usually adequate for determining the Q-point in practical amplifier circuits.
End of Lecture 29