EE 330
Lecture 23

Amplification with Transistor Circuits
Bi-directional switching with the Triac

- Has two cross-coupled SCRs!
- Manufactured by diffusions
- Single Gate Control
The Basic Triac Circuit

Assume ideal Triac

**Analysis:**

\[ V_{AC} = I_T R_L + V_{TR} \]

\[ I_{FI} = f(V_{TR}, V_{GT1}) \]

The solution of these two equations is at the intersection of the load line and the device characteristics.

Two stable operating points for both positive and negative \( V_{AC} \)

Review from Last Lecture
Review from Last Lecture

The Actual Triac

\[ I_T \quad V_{TR} \]

\[ I_{G4} > I_{G3} > I_{G2} > I_{G1} = 0 \]
The Actual Triac in Basic Circuit

Can turn on for either positive or negative $V_{AC}$ with single gate signal
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
Note: Not to vertical Scale
Area Comparison between BJT and MOSFET

• BJT Area = $3600 \lambda^2$
• n-channel MOSFET Area = $168 \lambda^2$
• Area Ratio = 21:1
Operating Point Analysis of MOS and Bipolar Devices

Determine $V_{\text{OUTQ}}$ and $V_{\text{CQ}}$
Operating Point Analysis of MOS and Bipolar Devices

Examples: Several Sample Circuits were Analyzed

Determine $V_{OUTQ}$ and $V_{CQ}$
Amplification with Transistors

From Wikipedia:

Generally, an **amplifier** or simply **amp**, is any **device** that changes, usually increases, the amplitude of a **signal**. The "signal" is usually voltage or current.

- It is difficult to increase the voltage or current very much with passive RC circuits.
- Voltage and current levels can be increased a lot with transformers but not practical in integrated circuits.
- Power levels can not be increased with passive elements (R, L, C, and Transformers).
- Often an amplifier is defined to be a circuit that can increase power levels.
- Transistors can be used to increase not only signal levels but power levels to a load.
- In transistor circuits, power that is delivered in the signal path is supplied by a biasing network.
Amplification with Transistors
Applications of Devices as Amplifiers

Typical Regions of Operation by Circuit Function

<table>
<thead>
<tr>
<th>MOS</th>
<th>Bipolar</th>
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<tbody>
<tr>
<td>Triode and Cutoff</td>
<td>Saturation and Cutoff</td>
</tr>
<tr>
<td>Saturation</td>
<td>Forward Active</td>
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</tbody>
</table>
Consider the following MOSFET and BJT Circuits

Assume BJT operating in FA region, MOSFET operating in Saturation
Assume same quiescent output voltage and same resistor $R_1$
One of the most widely used amplifier architectures
Consider the following MOSFET and BJT Circuits

- MOS and BJT Architectures often Identical
- Circuit are Highly Nonlinear
- Nonlinear Analysis Methods Must be used to analyze these and almost any other nonlinear circuit
Methods of Analysis of Nonlinear Circuits

KCL and KVL apply to both linear and nonlinear circuits

Superposition, voltage divider and current divider equations, Thevenin and Norton equivalence apply only to linear circuits!

Some other analysis techniques that have been developed may apply only to linear circuits as well
Methods of Analysis of Nonlinear Circuits

Will consider three different analysis requirements and techniques for some particularly common classes of nonlinear circuits:

1. **Circuits with continuously differential devices**
   Interested in obtaining transfer characteristics of these circuits or outputs for given input signals.

2. **Circuits with piecewise continuous devices**
   Interested in obtaining transfer characteristics of these circuits or outputs for a given input signals.

3. **Circuits with small-signal inputs that vary around some operating point**
   Interested in obtaining relationship between small-signal inputs and the corresponding small-signal outputs. Will assume these circuits operate linearly in some suitably small region around the operating point.

Other types of nonlinearities may exist and other types of analysis may be required but we will not attempt to categorize these scenarios in this course.
1. Nonlinear circuits with continuously differential devices

Analysis Strategy:

Use KVL and KCL for analysis

Represent nonlinear models for devices
either mathematically or graphically

Solve the resultant set of equations for the variables of interest
2. Circuits with piecewise continuous devices

\[ f(x) = \begin{cases} 
  f_1(x) & x < x_1 \quad \text{region 1} \\
  f_2(x) & x > x_1 \quad \text{region 2}
\end{cases} \]

Analysis Strategy:

Guess region of operation

Solve resultant circuit using the previous method

Verify region of operation is valid

Repeat the previous 3 steps as often as necessary until region of operation is verified

It helps to guess right the first time but a wrong guess will not result in an incorrect solution because a wrong guess cannot be verified.
3. Circuits with small-signal inputs that vary around some operating point

Interested in obtaining relationship between small-signal inputs and the corresponding small-signal outputs. Will assume these circuits operate linearly in some suitably small region around the operating point.

Analysis Strategy:

Use methods from previous class of nonlinear circuits.

More Practical Analysis Strategy:

Determine the operating point (using method 1 or 2 discussed above after all small signal independent inputs are set to 0).

Develop small signal (linear) model for all devices in the region of interest (around the operating point or “Q-point”).

Create small signal equivalent circuit by replacing all devices with small-signal equivalent.

Solve the resultant small-signal (linear) circuit.

Can use KCL, DVL, and other linear analysis tools such as superposition, voltage and current divider equations, Thevenin and Norton equivalence.

Determine boundary of region where small signal analysis is valid.
Small signal operation of nonlinear circuits

If $V_M$ is sufficiently small, then any nonlinear circuit operating at a region where there are no abrupt nonlinearities will have a nearly sinusoidal output and the variance of the magnitude of this output with $V_M$ will be nearly linear (could be viewed as “locally linear”)

This is termed the “small signal” operation of the nonlinear circuit

When operating with “small signals”, the nonlinear circuit performs linearly with respect to these small signals thus other properties of linear networks such as superposition apply provided the sum of all superimposed signals remains sufficiently small

Other types of “small signals”, e.g. square waves, triangular waves, or even arbitrary waveforms often are used as inputs as well but the performance of the nonlinear network also behaves linearly for these inputs

Many useful electronic systems require the processing of these small signals

Practical methods of analyzing and designing circuits that operate with small signal inputs are really important
Small signal operation of nonlinear circuits

$V_{IN} = V_M \sin \omega t$

$V_M$ is small

Practical methods of analyzing and designing circuits that operate with small signal inputs are really important

Two key questions:

How small must the input signals be to obtain locally-linear operation of a nonlinear circuit?

How can these locally-linear (alt small signal) circuits be analyzed and designed?
End of Lecture 23