Active Devices for Amplifiers and Oscillators

Introduction

• Active electronic circuits is the focus of this chapter
• The outcomes from this chapter will be:
  – The use of a diode for envelope detection in AM receivers
  – Basic common emitter amplifier design for RF/IF/Audio applications
  – The use of LC feedback networks around an amplifier to create an RF oscillator to serve as
  – Creating a mixer in combination with an amplifier and oscillator for use in a superheterodyne receiver
  – An integrated circuit audio amplifier capable of driving a speaker or ear buds
Diodes

- A diode is a two terminal device that allows current to flow in just one direction

- A silicon diode is a sandwich of \( n \)-type and \( p \)-type silicon
  - Silicon doped to make a semiconductor
  - Doping with phosphorous creates \( n \)-type or negative-charge carrier (elect.)
  - Doping with boron creates \( p \)-type or positive-charge carrier (hole)
• Diodes take various forms depending upon the application
• The current versus voltage relationship for an ideal diode allows current flow in only one direction depending upon the polarity of the applied voltage

![Diode Diagram](image)

- In LTspice you can work with a diode model `.dc` and `.tran`
- Consider a DC sweep to obtain the I-V characteristic

![LTspice Circuit](image)

**Note:** The IN4148 is rated at 10mA; this sweep exceeds the maximum ratings!
Piecewise Diode Model Circuit Analysis

- In diode circuit analysis it is convenient to think of the diode as a switch that follows the piecewise model, only simplified even further
  - When the applied voltage (anode to cathode) is above $v_t$ the diode acts as a perfect conductor
  - When the applied voltage is below $v_t$ the diode acts as an open circuit

**Example 3.1: Simple Clipping Circuit**

- Consider the following:

![Simple Clipping Circuit Diagram]

- For silicon diodes, the threshold $v_t$ voltage where the diode begins to conduct is approximately 0.7 V (0.3 V for germanium and 0.2 V for Schottky)

- **Diode On:** Using the piecewise modeling approach you first consider $v_i \geq v_t$, which means the diode is on and conducting with current
and

\[ v_R(t) = v_i(t) - v_t \]  

- The voltage across the diode is held at \( v_t \)

• **Diode Off**: For \( v_i < v_t \) the diode acts like an open circuit, so no current flows, meaning there is no voltage drop across \( R \), thus

\[ v_d(t) = v_i(t) \]  

- In summary,

\[ v_o(t) = v_d(t) = \begin{cases} v_t, & v_i(t) \geq v_t \\ v_i(t), & \text{otherwise} \end{cases} \]

- Running an LTspice simulation produces

- The actual diode model makes the clipping *rounded*
**LTspice and the Parts Library:** When working with active devices you may not find a model in the LTspice library that you need

- For the radio circuits the 1N34a small signal germanium diode is a favorite because it has a 0.3 V threshold voltage
- This part is not in the LTspice library
- What to do?
  - Look for device models on the Internet
  - Learn how to work with external model files
- LTspice prefers that you place new models in the install folder of LTspice
  - On a shared machine with security this is a problem
  - We will keep models in the same folder as the schematic
- 1N34a model placed in same folder as the schematic that uses it
Example 3.2: Using an External Model Library

- The diode clipper revisited to compare the 1N4148 with the 1N34a

- In the above see that the clipping level drops from 0.6 to 0.3v with the 1N34a
  - This is good for use in an envelope detector (up next)

- There are many other configurations of diodes found in practical electronic circuit design [1]:

Device name needs to match the name in the model file exactly!
– Voltage dropper

- Step voltage in diode drops of $v_t$
- Adjust current with $R_L$

\[ I_L = \frac{5 - 1.8}{R_L} \]

– Voltage regulator

- Similar to dropper, but now you establish voltage from ground up
- $R_s$ sets the current flow to be split between the diodes and the load, e.g. a transistor base-emitter junction in a radio circuit

– Envelope detector (diode & resistor only)

- For $v_i \geq v_t$ the diode is on and the output is $v_o = v_i - v_t$
- For $v_i < v_t$ the diode is off and $v_o = 0$
- Summary

\[ v_o(t) = \begin{cases} v_i(t) - v_t, & v_i(t) \geq v_t \\ 0, & v_i(t) < v_t \end{cases} \]
– Transient Protection

– **Diode clamp** (DC restorer)
  - Also known as a *DC restorer* since the series capacitor allows the signal to float and bias voltage on the diode is used to set the clamp point
  - Here the diode connected to ground, clamps the bottom of the waveform to zero $-v_t v$
  - Reverse the diode to clamp the top

– **Diode clipper**, asymmetrical and symmetrical
  - Similar to the single diode clipper shown earlier
  - With two diodes clipping at $\pm v_t$ occurs on the positive and negative sides of a waveform

– Diode on/off switch
– Half-wave and full-wave rectifier
– Simple logic gates
Example 3.3: Diode clamping in LTspice

- In this example you will see a diode clamp in action

- To actually clamp the bottom of the waveform to zero you need to tie the diode to $-v_t \cdot V$

- Note here the input signal was arbitrarily biased to -2v
Envelop Detector

- To demodulate and amplitude modulated (AM) carrier signal (look back in Chapter 5 for a review) the envelope detector, including both $R$ and $C$ in parallel, is used
- In simple math terms the ideal envelope detector strips off the top or the bottom of the AM waveform and then lowpass filters the signal
- For an ideal diode all is well, but with $v_t$ present issues arise as shown (and demoed) in an Excel spreadsheet file
  
  ![Image](image.png)

- In the above I assume a 1N34a diode (0.3v threshold) and a 65% modulation index ($a = 0.65$)
- Increasing the carrier amplitude would help, but this more challenging under weak signal conditions
- **Note:** Broadcast AM can have modulation index up to 100%
Example 3.4: Envelope Detection with the 1N34a Diode

Consider the following LTspice schematic:

- The AM signal is fed directly into the envelope detector:

  - The above results look nice, but the modulation index (again recall from Chapter 5) is set to 50% \(a = 0.5\)
  - AM broadcasting pushes this up to 100% \(a = 1\)

Two key design considerations are:

- Is the AM signal large enough to turn on the diode with only minimal distortion/clipping of the message signal \(m(t)\)?
\( v_{\text{AM}}(\text{valley peak}) \approx v_t \) or higher \hspace{1cm} (7.5)

- Is the time constant \( \tau \) of the RC lowpass filter circuit formed by placing \( R \) and \( C \) in parallel following the diode able to pass the message signal and filter out the carrier signal components?

\[
W \ll \frac{1}{2\pi R_4 C_1} \ll f_c \quad (7.6)
\]

- Testing on the Analog Discovery
• Using the fixed resistor the waveforms are:

![Waveform diagram]

• Notice from the orange trace of the AM signal the height of the valley at 80% modulation depth falls short of reaching 0.3v to fully turn on the 1N34a (this is a challenge)
  – The larger input signal would help

---

**Transistors**

• A transistor is a three terminal device that can be used to control or amplify a signal

• A voltage or current applied to the *control terminal* of the device allows you to control the flow of current between the remaining to terminals

• The two major families of transistors are: *bipolar* and *field-effect* (FET)
- In integrated circuit (IC) design FETs are the dominant transistor in use.
- For single (to a few) device amplifier circuits, of primary interest in this course, bipolar devices are however preferred as they offer greater voltage gain and greater current to the load.
- Six types and their symbols:

  - With the NPN device a sandwich is formed with a thin layer of $p$-type material between two $n$-type layers.
  - With a positive bias of about 0.6v on the base-emitter junction current can flow from the collector to the emitter, such that
    \[ i_c = \beta i_b \] (7.7)
    where $\beta$ is the current gain.
• **Note**: For the above equation to hold the voltage from collector to emitter, $v_{ce}$ must be at least 0.2V and the diode formed between base and emitter must be *turned on*, meaning the base to emitter voltage is $v_{be} \approx 0.6-0.7V$

• Also note that although the collector-emitter junction when viewed as a diode is back-biased, current however flows once the base-emitter junction is turned on

• Finally note: Kirchoff’s current law (KCL) also tells you that

$$i_e = i_c + i_b = (1 + \beta)i_b \quad (7.8)$$

• To put the BJT to work you need DC biasing circuitry plus a way to superimpose an input signal and later extract it

**A BJT Voltage Amplifier [2]**

• At the systems level a voltage amplifier takes input $v_s(t)$ and returns output $v_o(t)$, such that

$$v_o(t) = A_v v_s(t) \quad (7.9)$$

where $A_v$ is the voltage gain

– **Note**: $A_v$ is typically also a function of the operating frequency, but here for simplicity I assume it is a constant

– In the above $R_s$ is part of the source signal generator and $R_L$ is part of the load where $v_o(t)$ is received
• The three basic amplifier topologies of the BJT (simplified form, no biasing shown) are shown below

![Diagrams of amplifier topologies: Common Emitter (CE), Common Collector (CC), Common Base (CB)]

• The common emitter (CE) is the most popular and the one explored in Lab 4
• The common base (CB) is shows up in radio circuits, and in fact is found in the oscillator/mixer problem of Lab 4

**Biasing and Coupling [2, 1]**

• To make a bipolar device into an amplifier you need to bias the device into the *active region*, then connect input and output terminals
• The significance of the active region and how to make a CE voltage amplifier is explored next
• More detailed BJT terminal equations are

\[
V_{CE} = V_{cc} - R_c I_s e^{V_{BE}/V_T} \\
I_C = I_s e^{V_{BE}/V_T}
\] (7.10)
where $V_T$ is the thermal voltage (~25mv at room temperature), $I_s$ is the saturation current (device specific), and $V_{cc}$ is the collector supply voltage.

- **Using a DC sweep** LTspice produces the following:

  - The blue curve is $V_{CE}$ versus $V_{BE}$, which shows the BJT has three distinct operating regions:
    - **Cutoff** (no current flow)
    - **Active** (controlled current flow via $V_{BE}$ or $I_B$)
    - **Saturation** (maximum current flow)

  - **Bias device to quiescent/operating point Q**
  - **Amplify small signal input**
  - **Simplified input bias network**
  - **Separate amplified signal at collector from DC bias using coupling capacitor**
• For amplifiers of interest in this course, you want to stay in the active region at all times (known as class A)

• With DC bias only the device sits at the quiescent point $Q$

• When the input signal, $v_{be}$, is also present, i.e., *super imposed* along with bias, both $v_{BE}$ and $v_{CE}$ deviate about $Q$ and an output/input voltage gain exists

• The slope of the $v_{CE}$ versus $v_{BE}$ curve at $Q$ is the small signal voltage gain (here ~92) as alluded to in (7.9)
  – **Note**: You can show [2] that $A_v = -(I_C/V_T)R_c$

• Biasing is generally provided using a resistor network surrounding the device, and the use of *coupling* (series) *capacitors* to superimpose the input and extract the output

• Consider a CE voltage amplifier:

• Here the four resistors of the bias network are chosen to set the quiescent point $Q$
  – **Note**: The emitter resistor is needed to make biasing stable
over temperature

- DC circuit analysis, equations (7.7) and (7.8), the $V_{BE}$ threshold, e.g., 0.6 or 0.7 V, and $\beta$ enable the design

---

**Example 3.5**: A small signal biasing analysis example

- Let $C_1 = C_2 = 1\, \mu\text{F}$ and $R_1 = 30\, \text{k}\Omega$, $R_2 = 10\, \text{k}\Omega$, $R_e = 470\, \Omega$, and $R_c = 2.4\, \text{k}\Omega$

- Assume that $\beta = 100$

- Find the voltages and currents around the NPN device

- From ohms law

  $$I_{R_1} = I_{R_2} + I_B \quad (7.11)$$

- Assume the current through the bias network $R_1 - R_2$ is large compared with the base current, thus $I_{R_1} \approx I_{R_2}$

- With this assumption you can easily write using ohm’s law that

  $$I_{R_1} = \frac{V_{cc}}{R_1 + R_2} = \frac{5}{(10 + 30)k} = 0.125\, \text{mA} \quad (7.12)$$

- The base voltage, from the voltage divider relationship is just

  $$V_B = 5 \cdot \frac{10}{10 + 30} = 1.25\, \text{V} \quad (7.13)$$
Transistors

- Assuming the base-emitter junction is biased on, with a 0.6V $V_{BE}$ drop, $V_E = 1.25 - 0.6 = 0.65$V and

$$I_E = \frac{V_E}{R_e} = \frac{0.65}{470} = 1.38 \text{mA} \quad (7.14)$$

- Since $I_E = I_B + I_C$ and $I_C = \beta I_B$ a little algebra yields

$$I_E = \left(\frac{1}{\beta} + 1\right)I_C \Rightarrow I_C = \frac{I_E}{1/\beta + 1} = \frac{\beta}{1 + \beta}I_E \quad (7.15)$$

so

$$I_C = \frac{100}{101} \cdot 1.38 = 1.37 \text{mA} \quad (7.16)$$

and

$$V_C = V_{cc} - R_c I_C = 5 - (1.1k \cdot 1.37 \text{mA}) = 3.49 \text{V} \quad (7.17)$$

- **Note:** $V_{CE} = 3.49 - 0.65 = 2.84 > 0.2$V

- An exact analysis of the bias circuit is possible using a Thevenin equivalent (notes Chapter 4 p. 4–10) of the $R_1 - R_2$ base biasing network
• With some algebra

\[ I_E = \frac{V_{BB} - V_{BE}}{R_e + \left[ R_{BB}/(1 + \beta) \right]} \]

\[ V_B = V_{BE} + I_E R_e \]

\[ I_C = I_E \cdot \frac{\beta}{1 + \beta} \]

\[ V_C = V_{cc} - I_C R_c \]

(7.18)

• A practical design consideration is to choose \( V_C \) to be about \( V_{cc}/2 \)

Example 3.6: Interactive CE Biasing Using Excel

• In this example I use the Excel spreadsheet `CommonEmitter.xlsx` to interactively explore biasing options

• Start with the resistor values used in Example 3.5
- Suppose you want to raise the $V_C$ up to $V_{cc}/2 = 2.5\, \text{V}$
- Interactively increase $R_2$ in small steps corresponding to the standard 5% resistors values (see Appendix A)

**Small Signal Characteristics**
- With biasing set the small signal characteristics of the amplifier are now of interest
- You know the voltage gain $A_v$ is of interest, but there are other amplifier attributes of interest:
  - $R_{in}$ = the input resistance
  - $R_o$ = the output resistance
  - $A_{vo}$ = the open circuit voltage gain
– $G_v$ = the voltage gain from source to load

• To focus on just the small signal model of the CE amplifier consider the following [2]:

$$\alpha = \frac{\beta}{1 + \beta}$$

\[\text{Note: The above circuit contains a current controlled current source (CCCS) to represent the flow of collector current in terms of emitter current using gain } \alpha = \beta/(1 + \beta)\]

• The internal emitter resistor $r_e$ is a function of the quiescent emitter current $I_E$ and the thermal voltage $V_T$

$$r_e = \frac{V_T}{I_E} \quad (7.19)$$

• Summarizing the results (see [2] for more details)

$$R_{in} = (1 + \beta)(r_e + R_e) \quad (7.20)$$

and
where $g_m = I_C / V_T$, the BJT transconductance, is the slope of the $I_C$ versus $v_{BE}$ curve at the operating point $Q$

- Observe that the gain $G_v$ contains $(1 + \beta)(r_e + R_e)$ is the denominator
  - The internal emitter resistance is typically small, 20Ω
  - For bias stability reasons the external emitter resistor can range from say 470Ω up to 4700Ω, thus serious gain reduction can occur
  - To combat gain degeneration it is common to employ a bypass capacitor or a resistor in series with a capacitor
  - Bias stability is maintained yet the superimposed small signal is then shunted to ground allowing $R_e$ to be replaced by $R_{eb}$ or even 0Ω
- All of the math modeling details above are brought into an Excel worksheet to allow easy analysis of the CE amplifier, both with and without the emitter bypass capacitor
Example 3.7: Interactive CE Bias and Gain Using Excel

- Beyond the equations, the a small signal input sinusoid can be applied and saturation and device saturation and cutoff effects represented in the waveform as clipping
- Use the same starting point resistor values as in Example 3.7 apply a 10mV sinusoid at 2kHz
- The gain is only -4.61 or in dB $20\log_{10}(4.61) = 13.28\text{dB}$

- To invoke a bypass capacitor you reduce $R_{eb}$ to say 0Ω
- The gain increases to 41dB (very good), however the input
If the input signal level goes up clipping on the waveform bottom will become a problem, yet the top has plenty of headroom.

Adjusting the bias resistor $R_2$ from 10k to 8.2k (a 5% standard value) works well to center the waveform.

The input level is increased to 25mV and the output is filling the min to max voltage range nicely.

A third tab of the Excel workbook (not shown here) shows the output after the coupling capacitor, hence the output is centered about 0V.
Oscillators

- The subject of oscillators means circuit design for waveform generation
- In radio receiver circuits the need for an oscillator most often arises in a superheterodyne receiver where a local oscillator is needed to convert $f_{RF}$ to $f_{IF}$ via a mixing operation (see notes Chapter 5 for more details)
- For a fixed frequency oscillator using a quartz crystal as a resonator is a popular option

With $R2 = 8.2k$ an input of 25mv is OK
A crystal oscillator in combination with a phase-locked loop (PLL) frequency synthesizer chip is used to create a digitally programmable local oscillator.

- In this course a variable frequency oscillator design with an analog interface is needed, hence an $LC$ resonator, with $C$ being the primary adjustable element, is the objective here.

- An oscillator begins as an amplifier with feedback:

\[ x_s(t) \rightarrow \sum x_i(t) \rightarrow \text{Amplifier Gain } A(s) \rightarrow x_o(t) \]

\[ \begin{array}{c}
    x_f(t) \\
    \downarrow \\
    \text{Feedback Network } B_f(s)
\end{array} \]

- Using block diagram algebra in the $s$-domain you can write that [2]

\[ X_o(s) = X_s(s) \cdot \frac{A(s)}{1 - A(s)B_f(s)} \quad (7.22) \]

- The condition for oscillation to occur is making the denominator zero, that is

\[ A(s)B_f(s) = 1 \]

\[ \text{or } A(j2\pi f_0)B_f(j2\pi f_0) = 1 \angle 0^\circ \quad (7.23) \]

- If the oscillator circuit satisfies (7.23) then without any applied input oscillations can begin (a little bit of noise will help) and be sustained.

---

• A single BJT Colpitts (1918 patent) oscillator

- For tuning using a single capacitor, the Colpitts oscillator is not appropriate; using a single inductor yes but that will not work with the available components
- In the Colpitts circuit above, resonance corresponds to the LC tank formed by \( L_1 \) in parallel with the series capacitor combination of \( C_1 \) and \( C_5 \), thus you expect the oscillation frequency to be about:
\[ f_0 = \frac{1}{2\pi \sqrt{\frac{C_1 C_5}{L_1 (C_1 + C_5)}}} \]

\[ = \frac{1}{2\pi \sqrt{150 \times 10^{-5} \cdot 100 \times 10^{-12}}} = 1.838 \text{ MHz} \] (7.24)

• A tapped inductor form of LC oscillator, invented by Hartley in 1915, is an option that uses a single tuning capacitor.

- The tapped inductor is evident and in this case the coils are coupled so mutual inductance comes into play, that is
\[ L_{\text{total}} = L_1 + L_2 + k\sqrt{L_1 L_2} \]  \hspace{1cm} \text{(7.25)}

where \( k \) is the coupling coefficient

- Here the total inductance is

\[ L = 50 + 50 + 1 \cdot \sqrt{50 \cdot 50} = 3 \cdot 50 = 150\mu\text{H} \]  \hspace{1cm} \text{(7.26)}

- Excluding other loading capacitance in the circuit, you expect

\[ f_0 = \frac{1}{2\pi \sqrt{LC}} \]

\[ = \frac{1}{2\pi \sqrt{100 \times 10^{-12} \cdot 150 \times 10^{-6}}} = 1.84 \text{ MHz} \]  \hspace{1cm} \text{(7.27)}

- The simulated oscillator has an \( f_0 \) of only 956 kHz

- For Lab 4 and the AM superheterodyne receiver, a common base oscillator using transformer feedback is employed:
– Unfortunately this circuit does not (yet) work in LTspice simulation, but it works very well on the breadboard!
– Note the 60pF fixed capacitor next to the tapped inductor is replaced with a 0–360 variable cap

**Mixer and 1st IF Amplifier**

- In a superheterodyne receiver the local oscillator and mixer are connected together, with the mixer output driving a band-pass filter (IF filter)

- The intent of the mixer is to take as inputs

  \[ x_{RF}(t) = A \cos[2\pi f_{RF}t] \]
  \[ x_{LO}(t) = B \cos[2\pi f_{LO}t] \]  

  and produce the frequency difference signal

  \[ x_{IF}(t) = \frac{AB}{2} \cos[2\pi (f_{LO} \pm f_{RF})t] = \frac{AB}{2} \cos[2\pi f_{IF}t] \]  

- Here you choose \( f_{LO} - f_{RF} = f_{IF} \) so \( f_{LO} = f_{RF} + f_{IF} \)
- A practical mixer produces many more terms than just the sum and difference, but the IF bandpass filter can fortunately extract the term of interest
A simple yet practical mixer can be an amplifier that combines (sums) two inputs and then via non-ideal characteristics, such as clipping, is able to form output terms that are the sum of the input raised to an integer power, i.e.,

$$x_{\text{mixer}}(t) = \sum_{n=1}^{\infty} g_n (A \cos[2\pi f_{RF}t] + B \cos[2\pi f_{LO}t])^n,$$  \hspace{1cm} (7.30)

where $g_n$ is a gain scale factor that applies to each of the terms in the summation.

As long as $g_2 \neq 0$ proper mixing action occurs, that is

$$[\cos(\theta) + \cos(\phi)]^2 = [\cos(\theta)]^2 + [\cos(\phi)]^2 + 2\cos(\theta)\cos(\phi)$$  \hspace{1cm} (7.31)

The last line above contains the term of interest, namely

$$2\cos(\theta)\cos(\phi) = \cos(\theta + \phi) + \cos(\theta - \phi)$$  \hspace{1cm} (7.32)

The real proof of this will be in the lab when you see the mixing action in real-time using the Analog Discovery scope-based spectrum analyzer.
• Putting it all together, oscillator + mixer + IF BPF yields:

• The breadboard circuit:

Notice: Red and yellow tuning slug tops for ‘100’ and ‘101’ respectively
• Oscillator Test:

![Image of oscilloscope and FFT analysis]

- The test point signal amplitude does vary over frequency, with it becoming smaller at the low end, just before the oscillator stops working.

• To test the mixer and oscillator together you input an AM modulated carrier at 1 MHz.
• Then observe the mixer output at the test point:

- The mixer output is working as expected
  - With $f_c = 1.0$ MHz high-side tuning of the LO needs to be at $f_c + f_{IF} = 1455$ kHz to give difference at 455kHz
  - Note the tuning slug on the 42IF101 (yellow) is adjustable, so the IF center frequency may not be exactly 455 kHz
- For this test the AM signal amplitude is 200mv and the modulation index is just 40%

- In a complete superheterodyne design one or two (better) additional IF amplification and filtering stages are required

- The output of the final IF stage will then have signal amplitude large enough to turn on an envelope detection diode

**Integrated Devices**

- The invention of the transistor in 1947 eventually led to the integrated circuit in 1958
  - The inventor, Jack Kilby of Texas Instruments, was awarded the Nobel Prize in Physics for his invention in 2000

- Integrated circuits for analog and digital circuit applications abound

- One integrated circuit is utilized in the TRF and superheterodyne receivers considered in this course

**LM386 Headphone Amplifier**

- The LM386 is a low voltage audio power amplifier originally created by National Semiconductor, now part of Texas Instruments

- The device can drive an 8Ω load to with greater than 500mW of audio power
• The voltage gain is adjustable from 20 (26 dB) to 200 (46 dB)
• The quiescent current is around 4mA with a 6V supply and no input
• The equivalent circuit and the pin out is shown below:

![8-Pin DIP Pinout](image)

![Equivalent Schematic](image)

• Application circuits from the data sheet

![Amplifier with Gain = 20 Minimum Parts](image)

![Amplifier with Gain = 50](image)

![Amplifier with Gain = 200](image)

![AM Radio Power Amplifier](image)

3 turns on small bead to suppress RF feedback

Added lowpass at $f_c \sim 7$ kHz

magnet wire
• An LTspice compatible model is available for the LM386:

- The LM386 model is composed of (1) a library subcircuit model **LM386.lib** and (2) a schematic symbol **lm386.asy**
- Place both of the model files in the folder where your schematic is located
- To place the LM386 component navigate the Select Component Symbol dialog to the local folder where you have place the ***.lib** and ***.asy** files

![Select Component Symbol](image)
• The pin connection 8 to 1, which contains $R_1$ and $C_1$, sets the amplifier gain:
  – No connection or $R_1 \to \infty$ provides a gain of 20 or 26dB, while $R_1 \to 0$ sets the gain to 200 or 46dB (at 47Ω the gain is less)

• The frequency response from LTspice is:

• In the time domain, with a 10mV 1kHz sinusoid you expect a voltage gain of about $10^{\frac{43}{20}} = 141$, so the peak output should be 1.41V or 2.82V p-p:
  – It is close at 1.39V peak
– Note also that the DC current from the 9V supply is reported at ~16mA (hover over voltage source to see DC)
– Getting this circuit run off the Analog Discovery power supply due to a current spike when power is applied; a powered USB hub might be the solution to this problem
  • If the input rises to just 30mV, the output is already clipping

![Graph](image)

• A ZIP package can be found on the Web Site containing the LTspice amplifier schematic, the two files for the LM386 model, and the data sheet pdf

**Case Study: Tuned Radio Frequency Receiver**

• To conclude this chapter I consider the tuned radio frequency (TRF) receiver and its implementation for AM broadcasting
• Building and testing this receiver on a solderless breadboard is a lab task that lies ahead for you
MK484\textsuperscript{1} Radio IC

- A complete TRF receiver can be assembled with very few components by starting with an integrated device such as the MK484 radio chip:

**Description**

The MK484 is a monolithic integrated circuit designed in a TO92 package for use as a one chip radio solution, high sensitivity and high quality AM radio is possible with very few external components.

Special features of the circuit include low supply voltage operation, the device is particularly suited to small hand-held radios.

**Features**

- Stable operation with 1.1V
- Low Drain Current
- Small and light weight (TO92 Package)
- Wide AGC Ranging

**Maximum Ratings**

<table>
<thead>
<tr>
<th>Item</th>
<th>Symbol</th>
<th>Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temp</td>
<td>$T_{\text{op}}$</td>
<td>-30 to +80</td>
<td>°C</td>
</tr>
<tr>
<td>Storage Temp</td>
<td>$T_{\text{st}}$</td>
<td>-40 to +125</td>
<td>°C</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>$V_{\text{CC}}$</td>
<td>1.5</td>
<td>V</td>
</tr>
</tbody>
</table>

**Electrical Characteristics**

- From the above we see that this device more than covers the AM broadcast band (150 kHz to 3 MHz)
- Has very high input impedance (4 meg) so as not to lower the $Q$ of an antenna coil – tuning capacitor tank circuit

\[ V_{\text{CC}} = 1.4V, \, R_{\text{AGC}} = 1.5K\Omega, \, = 1,000\text{kHz} \]
Modulation 1,000Hz 40%, $V_{\text{in}} = 1\text{mV (RMS)}$

---

\textsuperscript{1}Rapid Electronics Ltd, Severalls Lane, Colchester, Essex, England, CO4 5JS.
- Specifically this insures good frequency band selectivity for accepting the signal of interest and rejecting nearby strong signals

- Has very high gain (70 dB) to bring weak AM signal to an amplitude level suitable for driving a headphone amplifier with no additional gain stages required

- What’s inside?

- A simple TRF design that uses a 1.5V battery for power:
References


Appendix A: Standard R and C Values

**Standard 5% Resistors Values**

<table>
<thead>
<tr>
<th>Standard Resistor Values (±5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
</tr>
<tr>
<td>1.1</td>
</tr>
<tr>
<td>1.2</td>
</tr>
<tr>
<td>1.3</td>
</tr>
<tr>
<td>1.5</td>
</tr>
<tr>
<td>1.6</td>
</tr>
<tr>
<td>1.8</td>
</tr>
<tr>
<td>2.0</td>
</tr>
<tr>
<td>2.2</td>
</tr>
<tr>
<td>2.4</td>
</tr>
<tr>
<td>2.7</td>
</tr>
<tr>
<td>3.0</td>
</tr>
<tr>
<td>3.3</td>
</tr>
<tr>
<td>3.6</td>
</tr>
<tr>
<td>3.9</td>
</tr>
<tr>
<td>4.3</td>
</tr>
<tr>
<td>4.7</td>
</tr>
<tr>
<td>5.1</td>
</tr>
<tr>
<td>5.6</td>
</tr>
<tr>
<td>6.2</td>
</tr>
<tr>
<td>6.8</td>
</tr>
<tr>
<td>7.5</td>
</tr>
<tr>
<td>8.2</td>
</tr>
<tr>
<td>9.1</td>
</tr>
</tbody>
</table>

**Standard 10% Capacitor Values**

<table>
<thead>
<tr>
<th>Standard Capacitor Values (±10%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10pF</td>
</tr>
<tr>
<td>12pF</td>
</tr>
<tr>
<td>15pF</td>
</tr>
<tr>
<td>18pF</td>
</tr>
<tr>
<td>22pF</td>
</tr>
<tr>
<td>27pF</td>
</tr>
<tr>
<td>33pF</td>
</tr>
<tr>
<td>39pF</td>
</tr>
<tr>
<td>47pF</td>
</tr>
<tr>
<td>56pF</td>
</tr>
<tr>
<td>68pF</td>
</tr>
<tr>
<td>82pF</td>
</tr>
</tbody>
</table>

---

1. [http://ecee.colorado.edu/~mcclurel/resistorsandcaps.pdf](http://ecee.colorado.edu/~mcclurel/resistorsandcaps.pdf)