AM Radio
Frequency encoding

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This illustrates the power of encoding a voltage in a frequency with the VCO.
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Modulate—vary the amplitude of—a carrier signal.

Carrier, $\cos(2\pi f t)$

Message, $m(t)$

Input binary sequence

ASK Modulated output wave
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\[ \omega_0 = \frac{1}{\sqrt{LC}} \]
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r(t) = [A_s \cos(\omega_s t) + 1] \cos(\omega_c t)
= \cos(\omega_c t) + A_s \cos(\omega_c t) \cos(\omega_s t)
\]

Use trig identity: \[\cos(A) \cos(B) = \frac{1}{2}[\cos(A+B) + \cos(A-B)]\]

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r(t) = \cos(\omega_c t) + \frac{1}{2}A_s \cos[(\omega_c + \omega_s)t] + \frac{1}{2}A_s \cos[(\omega_c - \omega_s)t]
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Signal is just above and below the carrier frequency.

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FCC regulates AM radio stations to be max signal frequency of 5 kHz and spaces them by 10 kHz. \( f_c \) ranges from 540 kHz - 1600 kHz.

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FM ranges from 88 - 108 MHz with 200 kHz wide bands

WiFi operates in channels at ~ 5 GHz or 2.4 GHz. (802.11a - 802.11n) with channel widths about 20 MHz and 5 MHz wide. (AKA bandwidth).

4G is around 2 GHz; 5G has many bands from 24 GHz to 47 GHz.

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AM radio circuit

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AM radio circuit: extracting the envelope

Extract the envelope with a “leaky peak detector”

\[ V_{IN} \rightarrow V_{OUT} \]

Choose RC to match the frequency of the signal, not the carrier.
\[ f_s = 10 \text{ kHz} \]
\[ RC = (1k\Omega)(100nF) = 100\mu s. \]
AM radio circuit: extracting the envelope

Now we have a signal, e.g., music, that we can amplify and drive a speaker.
To modulate the signal onto the carrier, you could use a simple switch, like morse code.
AM radio modulating circuit

To modulate the signal onto the carrier, you could use a MOSFET switch.
AM radio modulating circuit

To modulate the signal onto the carrier, you could use a variable resistance voltage divider.
AM radio modulating circuit

To modulate the signal onto the carrier, you could use a variable resistance voltage divider. We want a voltage-controlled variable resistance.

\[
R = \frac{1}{2k(V_{GS} - V_{\Theta})}
\]
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AM radio with LED TX/RX

In lab next week, you will build an AM transmitter and receiver, but use an LED & phototransistor to send and receive.

Rather than carefully tuning the LC resonator to your carrier, you can tune the carrier to the receiving channel.

You need two oscillators for this.
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It is important to factorize the stages to ease debugging.
Verify signal shape at each stage, e.g., measure LED output as current through R8.
This circuit is getting complex; how to simplify?

Careful layout and **stage-by-stage** debugging is key. Separate stages with easy probe points to recheck their behavior. Documentation is important to recheck previous behavior. Allow each stage to be self tested.

- Make a simple test circuit with just a morse-code modulator.
- Feed the LED a separately controlled signal.
- Measure LED output as current through R8.
- Feed the integrator a separately controlled signal.

ASICs often have a Built-In Self Test mode (BIST)
AM radio without power

Asymmetric conduction between a crystal and thin wire acted like a diode.

Crystal Radio Receiver from 1922

Galena (lead sulfide) was probably the most common crystal used in “cat's whisker” detectors.

Diagram from 1922 showing the circuit of a crystal radio. This common circuit did not use a tuning capacitor, but used the capacitance of the antenna to form the tuned circuit with the coil.
A modern AM radio

The AM band is rather low frequency: 540 kHz - 1600 kHz
Can just sample and process with DSP.

With digital electronics running at ~ 1GHz, even the FM range of 88 - 108 MHz is low enough to sample and process.

This is done with "software defined radio". Configurable filters, and ADC then process in real time. Very flexible, e.g., directional, data path, etc.