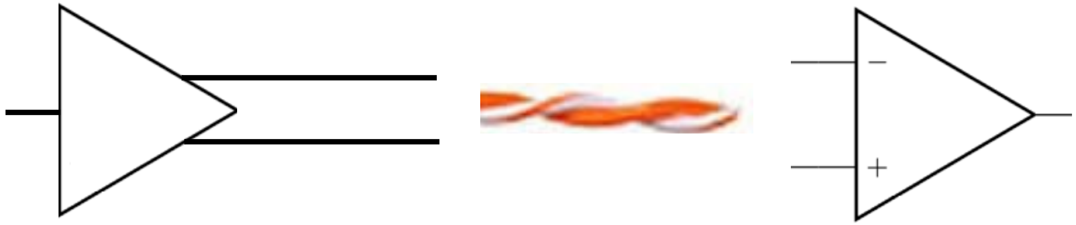
PHYS127AL Lecture 14

David Stuart, UC Santa Barbara

AM Radio

Frequency encoding

We saw how to send signals over long cables with LVDS.



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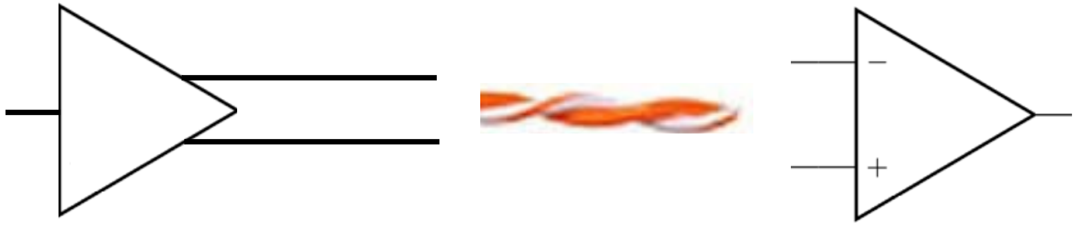

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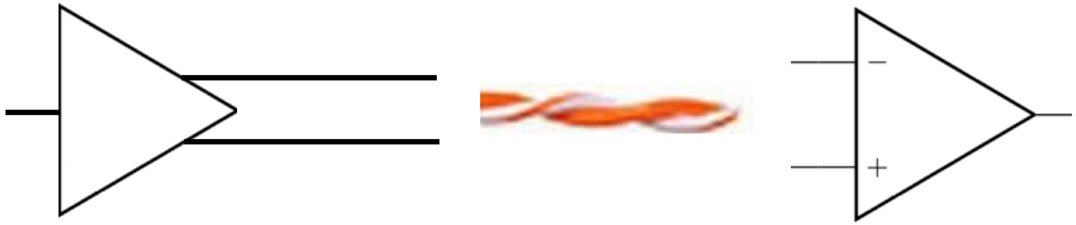

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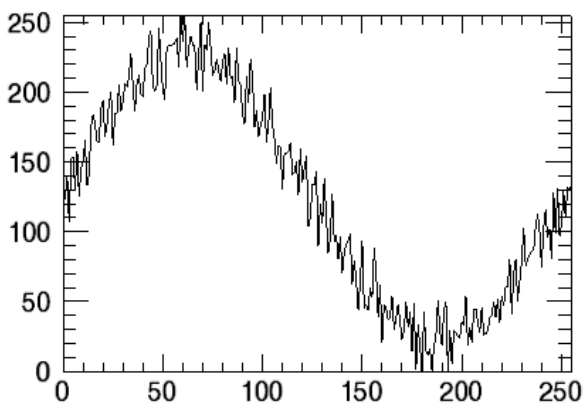

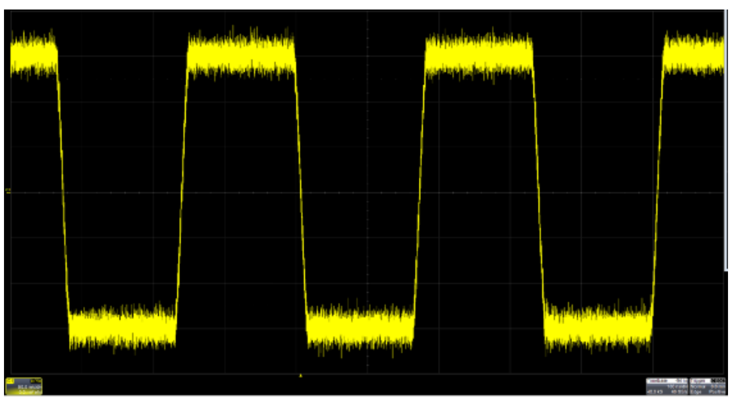

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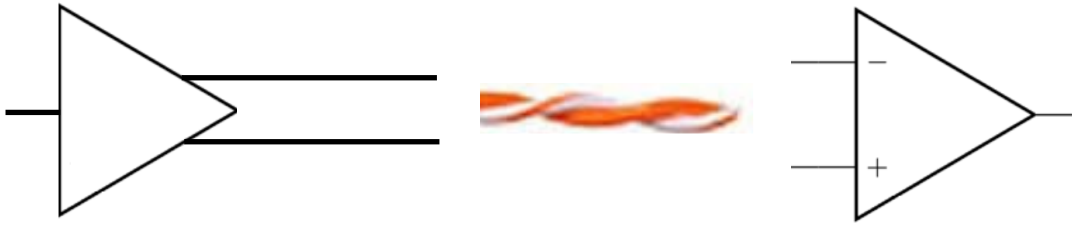

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This illustrates the power of encoding a voltage in a frequency with the VCO.

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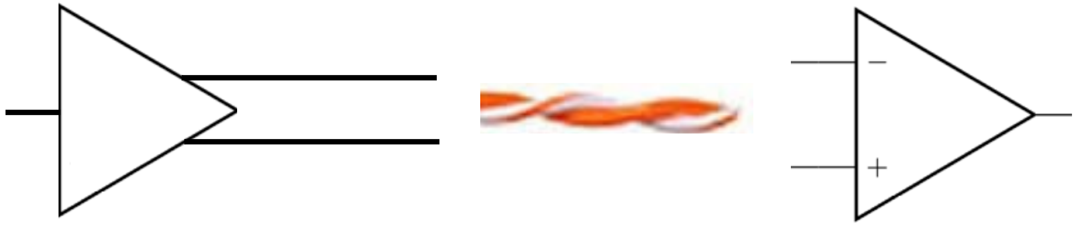

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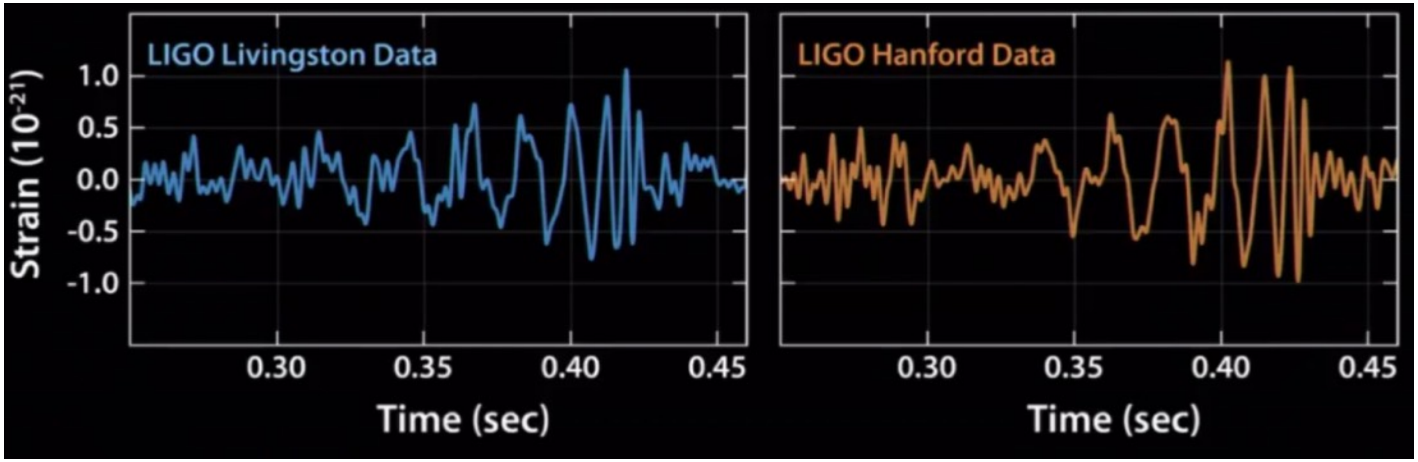

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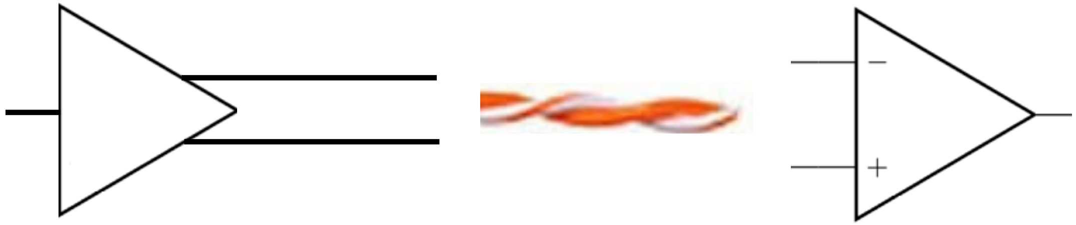

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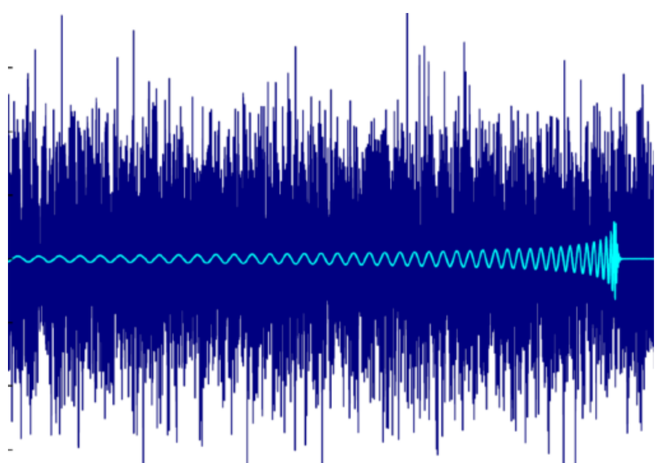
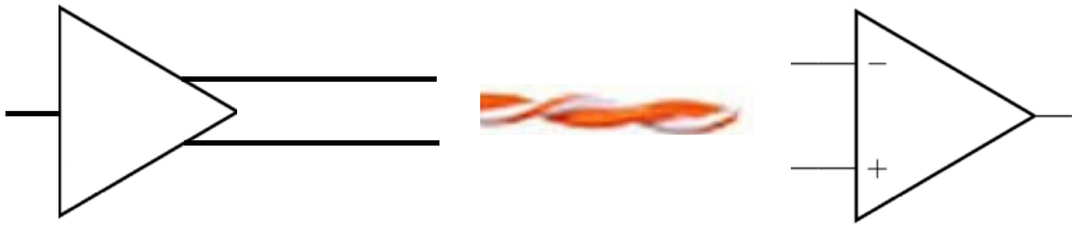
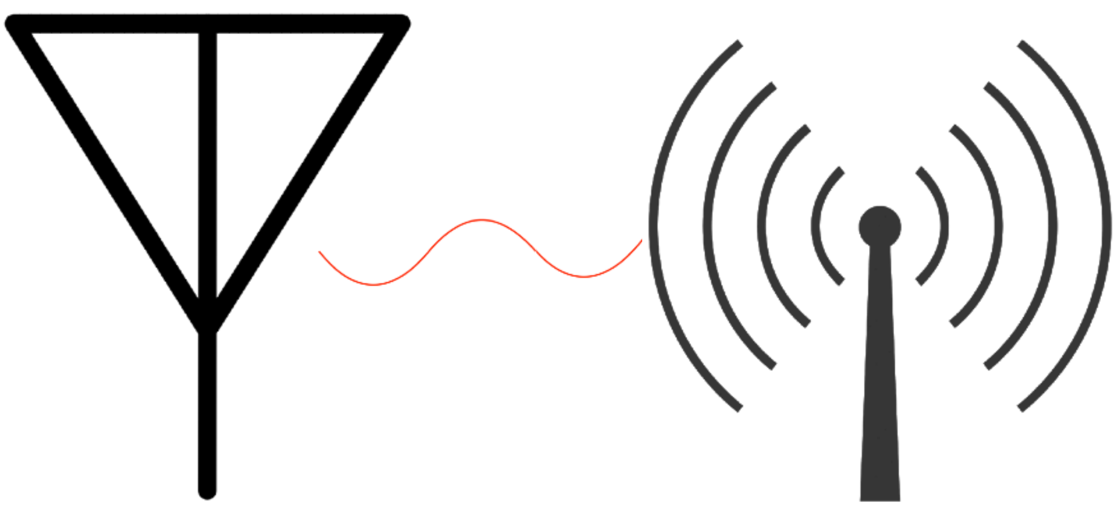


AM (amplitude modulation) radio

AM radio encodes information within a narrow frequency band (range).
It can operate over wires or wireless.





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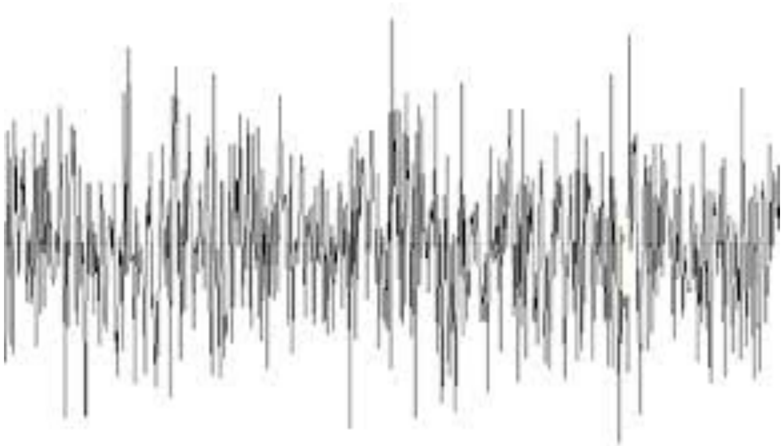
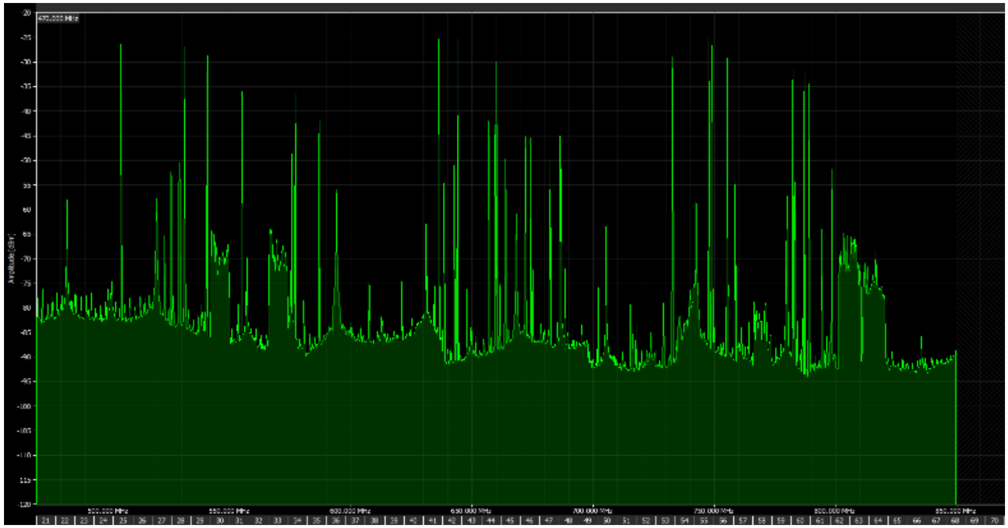
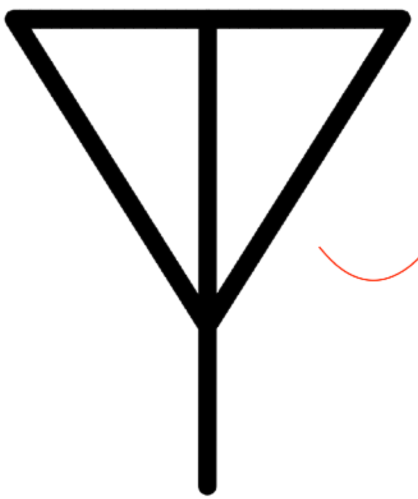
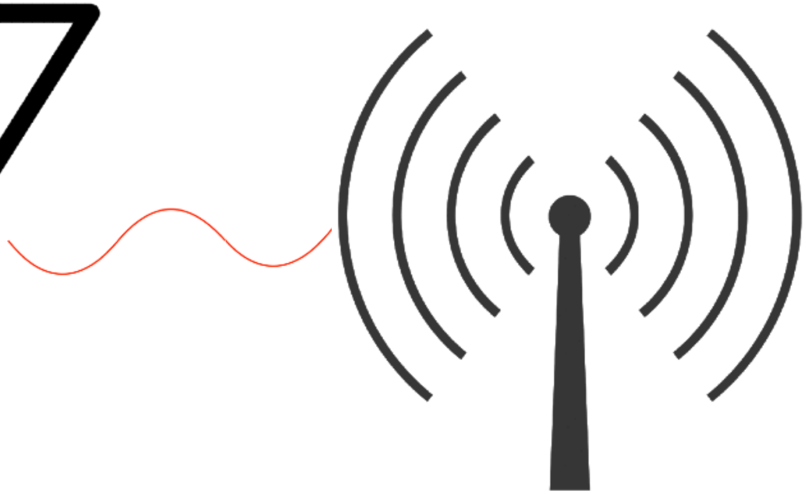


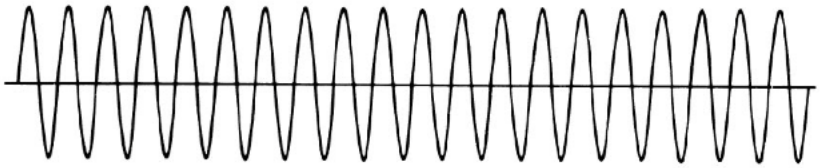






AM (amplitude modulation) radio

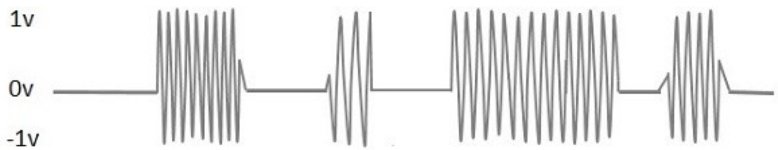
Modulate—vary the amplitude of—a carrier signal.



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

Message, m(t)

Input binary sequence



ASK Modulated output wave

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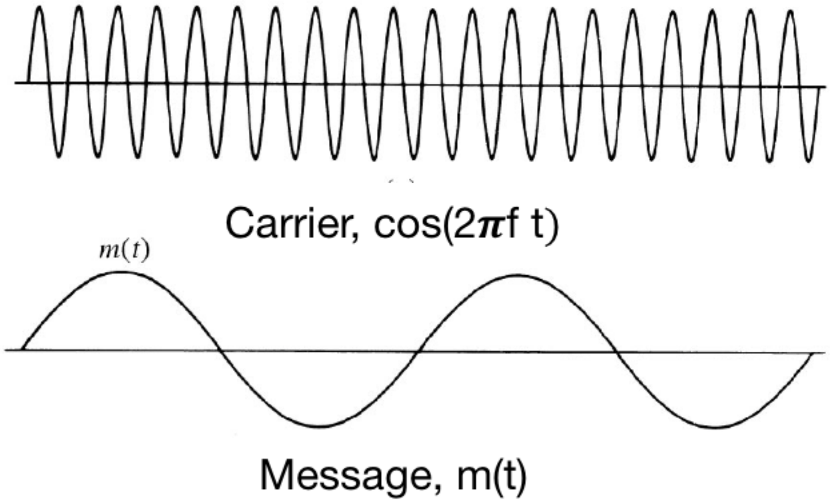

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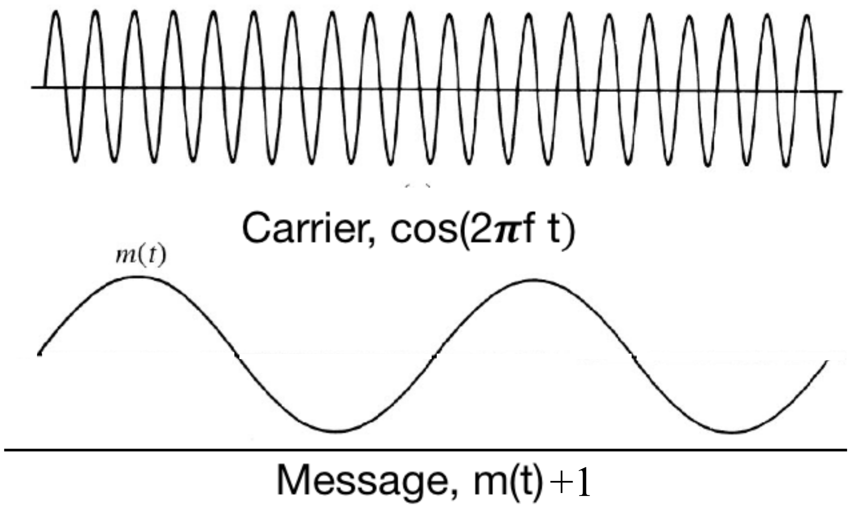

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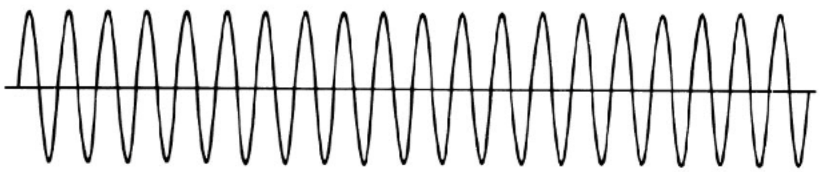

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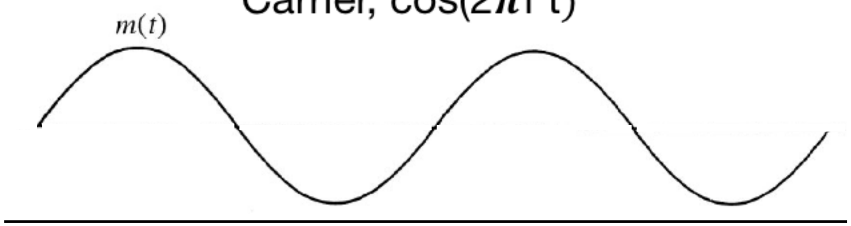
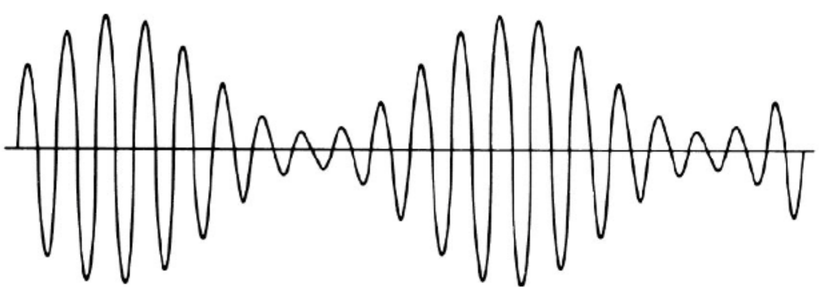


Message, $m(t)+1$



AM Signal, $(m(t)+1)\cos(2\pi f\, t)$

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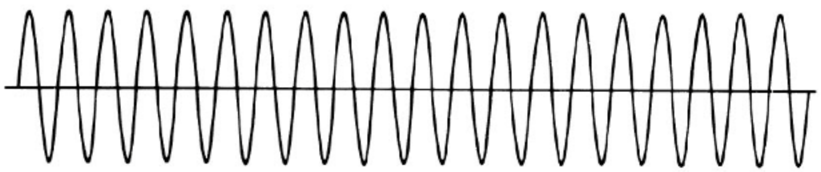

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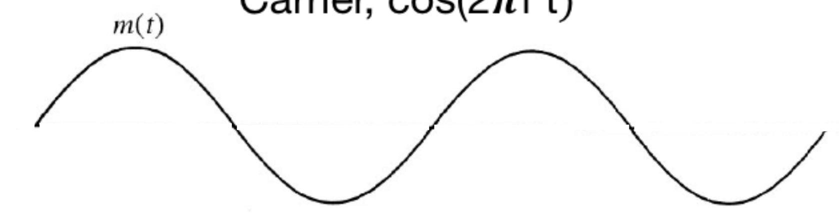

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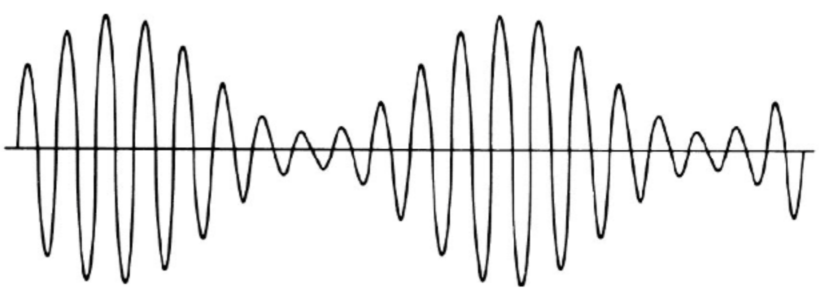

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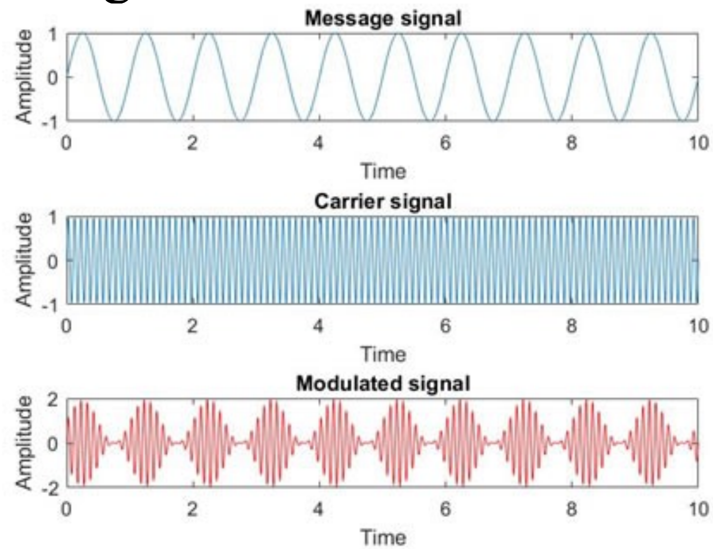
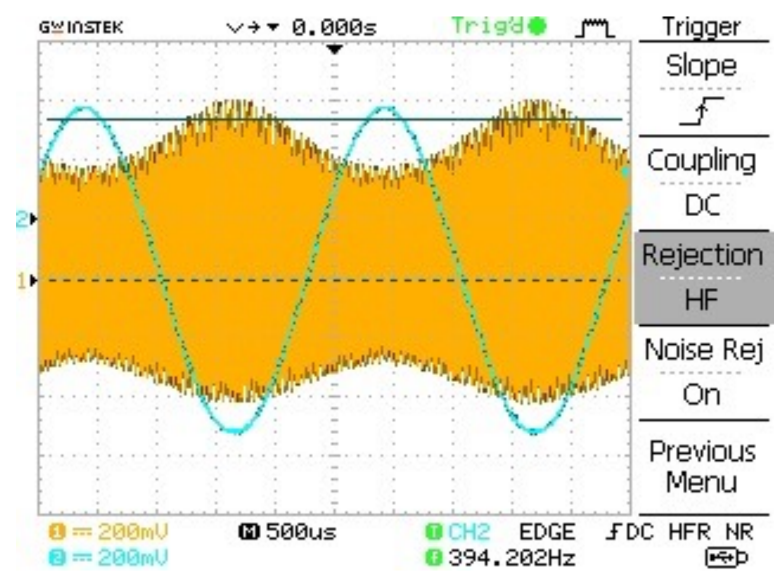
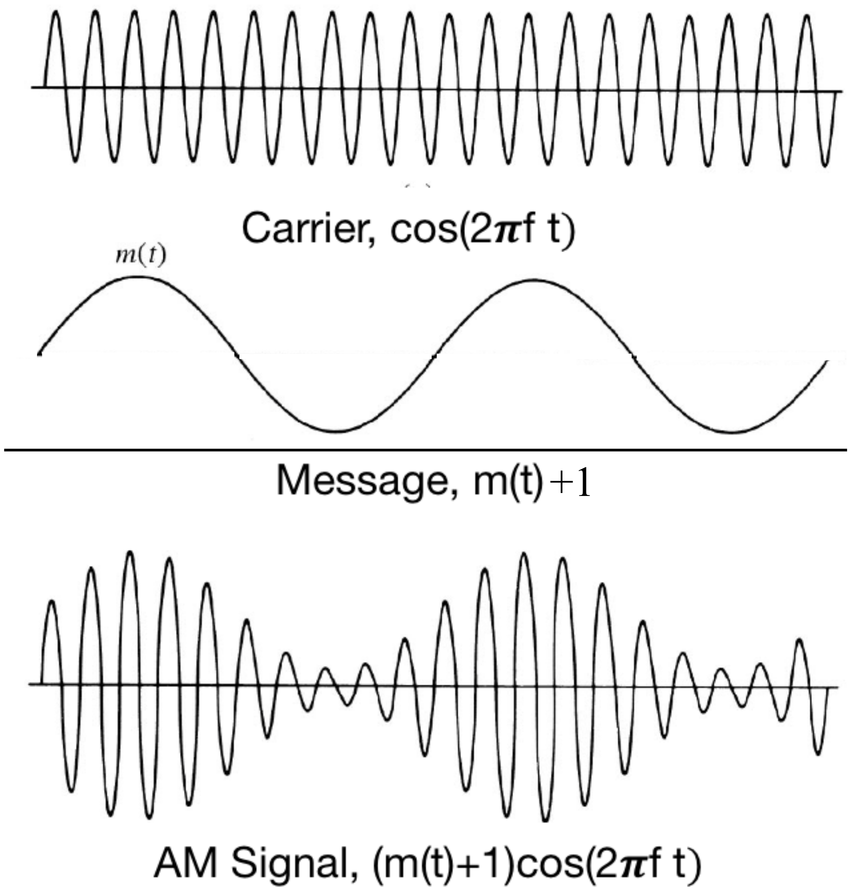


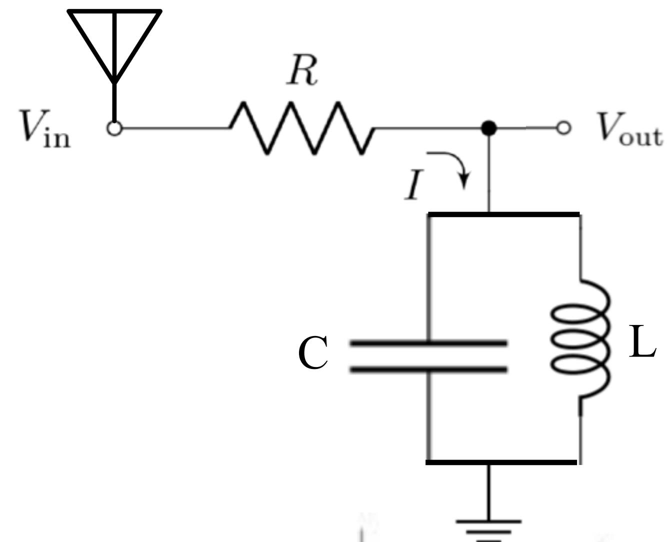


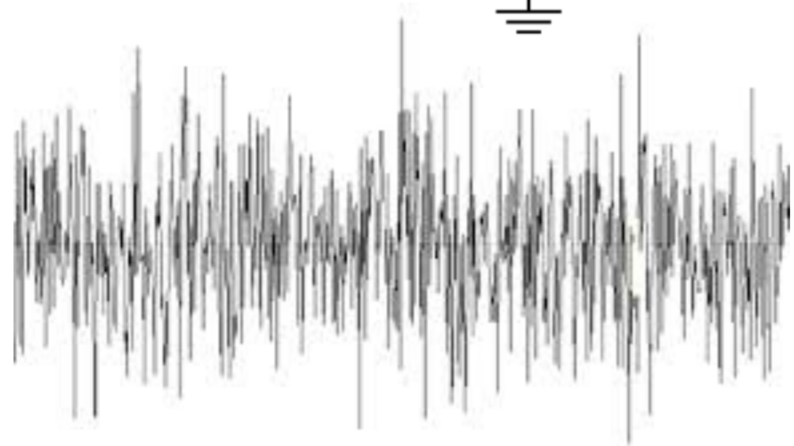
AM (amplitude modulation) radio

Modulate—vary the amplitude of—a carrier signal.

We can select only the “station” of interest with a band-pass filter.







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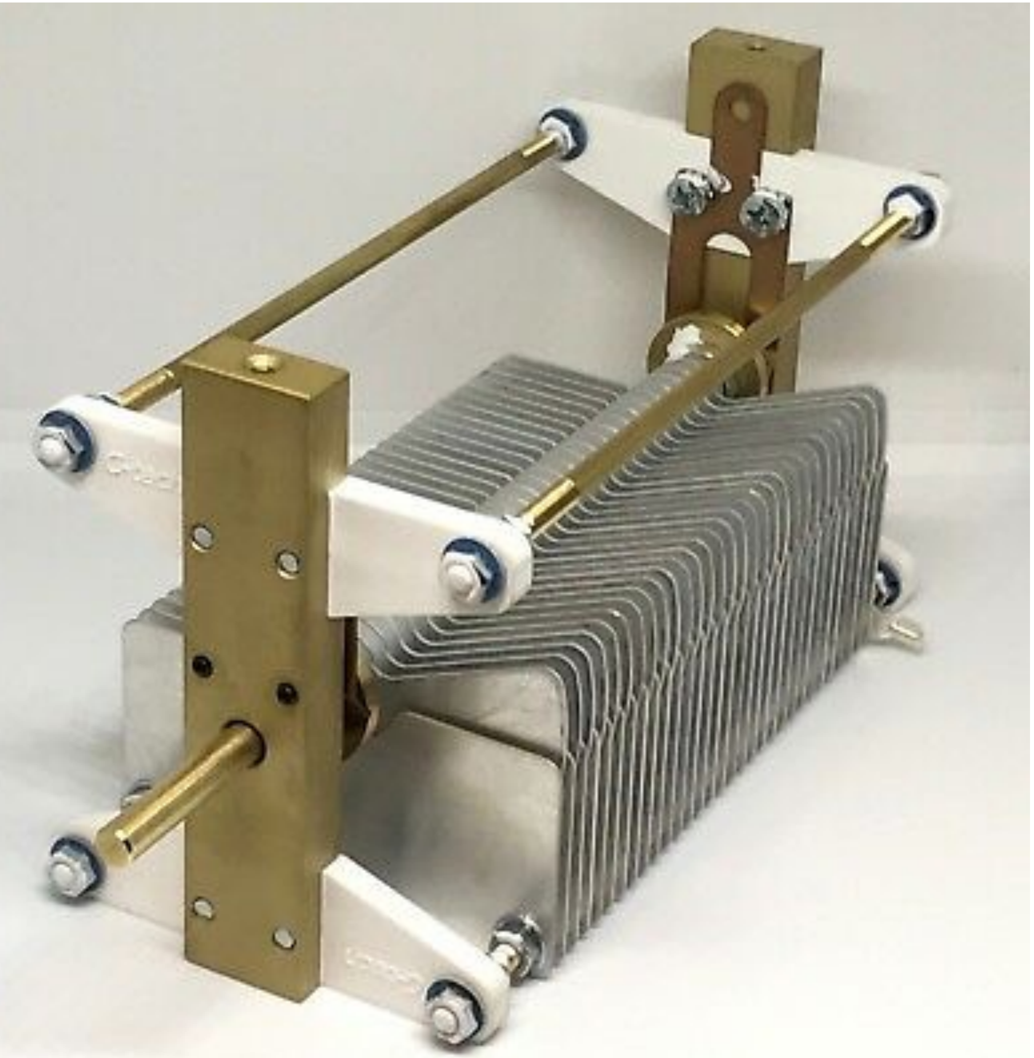

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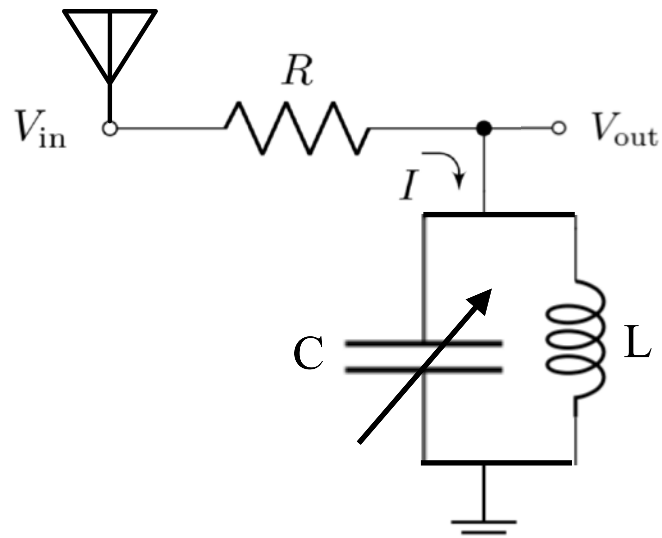

$$\omega_0 = 1/\sqrt{LC}$$

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Modulate—vary the amplitude of—a carrier signal.
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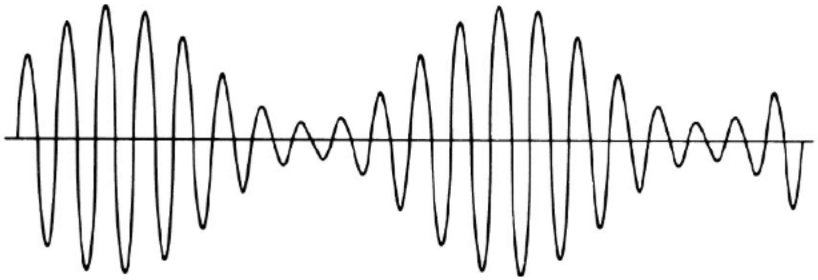
The low frequency message can still get through the band-pass.



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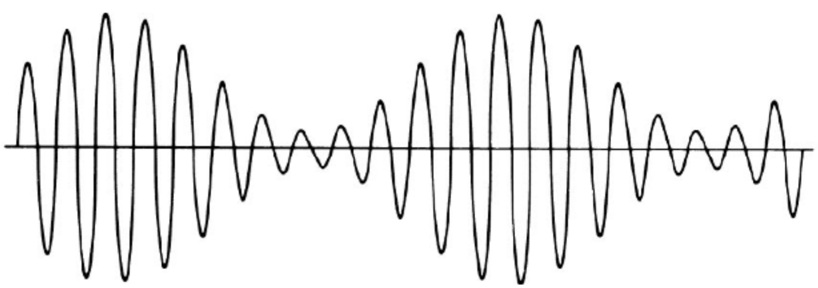
$$= \cos(\omega_c t) + A_s \cos(\omega_c t) \cos(\omega_s t)$$

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

$$r(t) = \cos(\omega_c t) + \frac{1}{2} A_s \cos[(\omega_c + \omega_s)t] + \frac{1}{2} A_s \cos[(\omega_c - \omega_s)t]$$

Signal is just above and below the carrier frequency.



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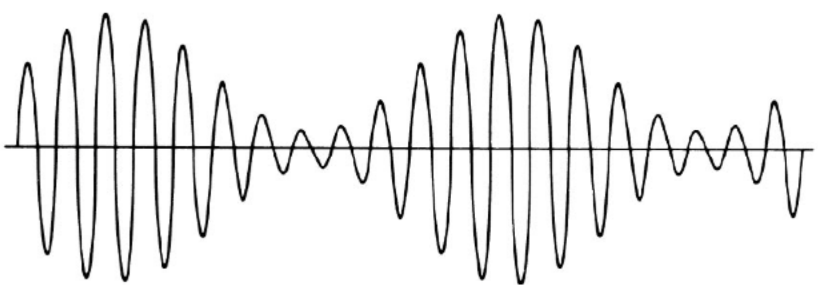
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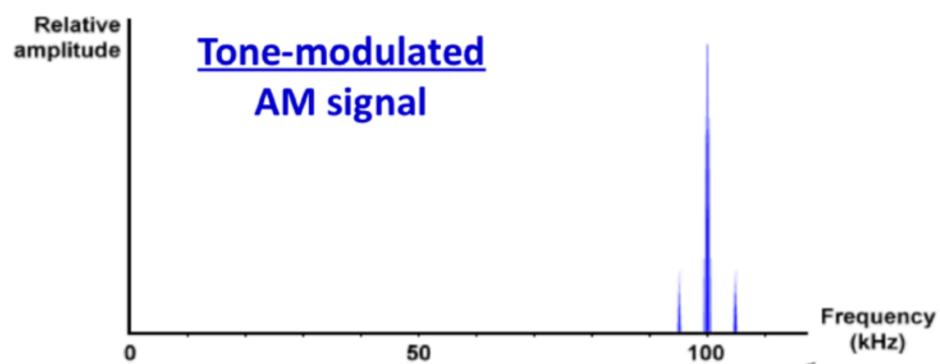

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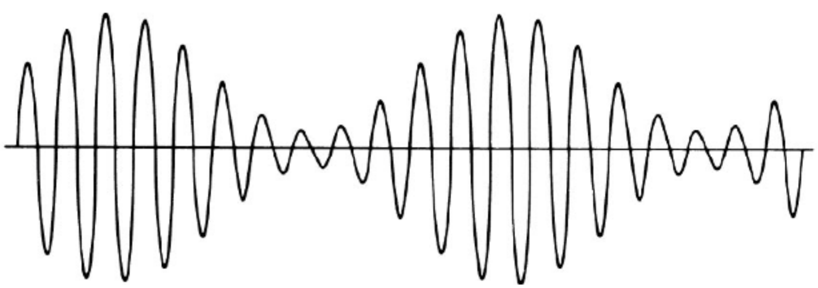

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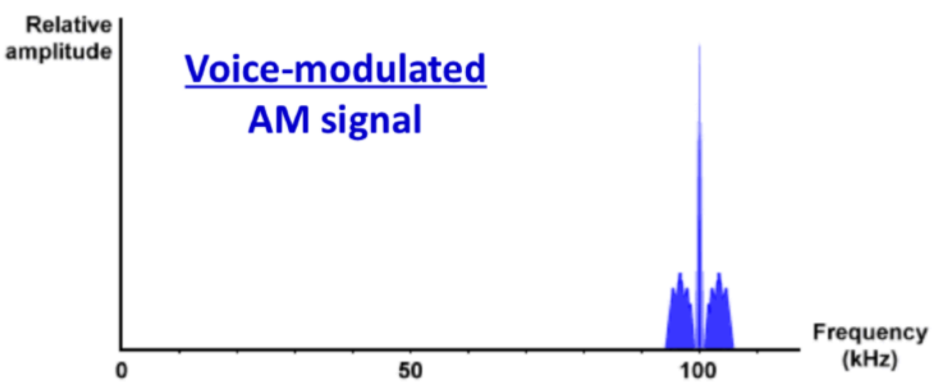

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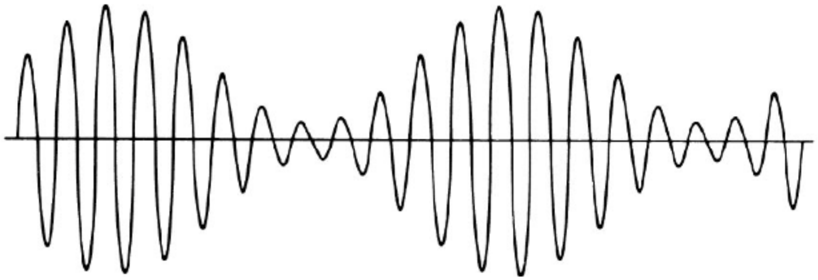

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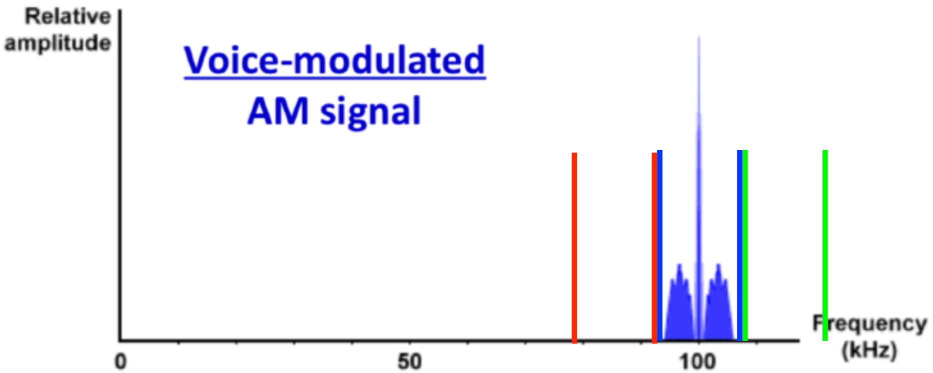

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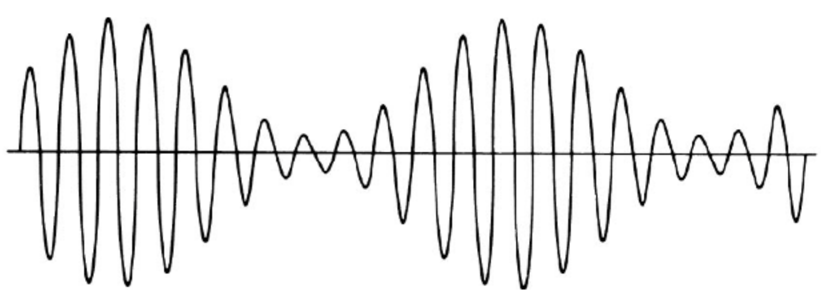
FM ranges from 88 - 108 MHz with 200 kHz wide bands

WiFi operates in channels at ~ 5 GHz or 2.4 GHz. (802.11a - 802.11n) with channel <u>widths</u> 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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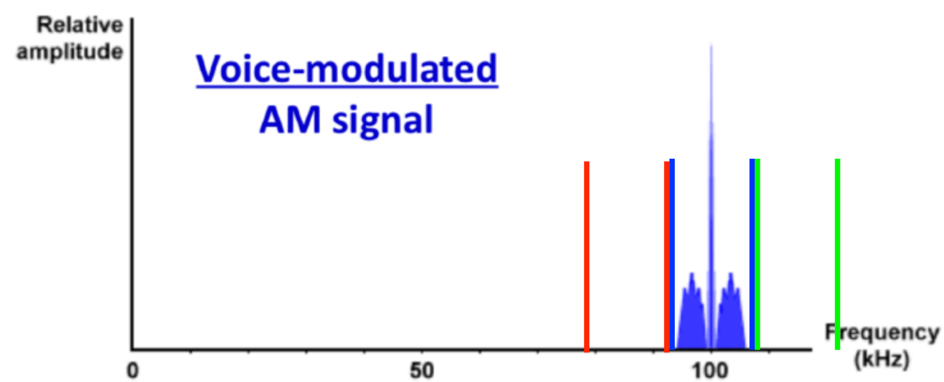
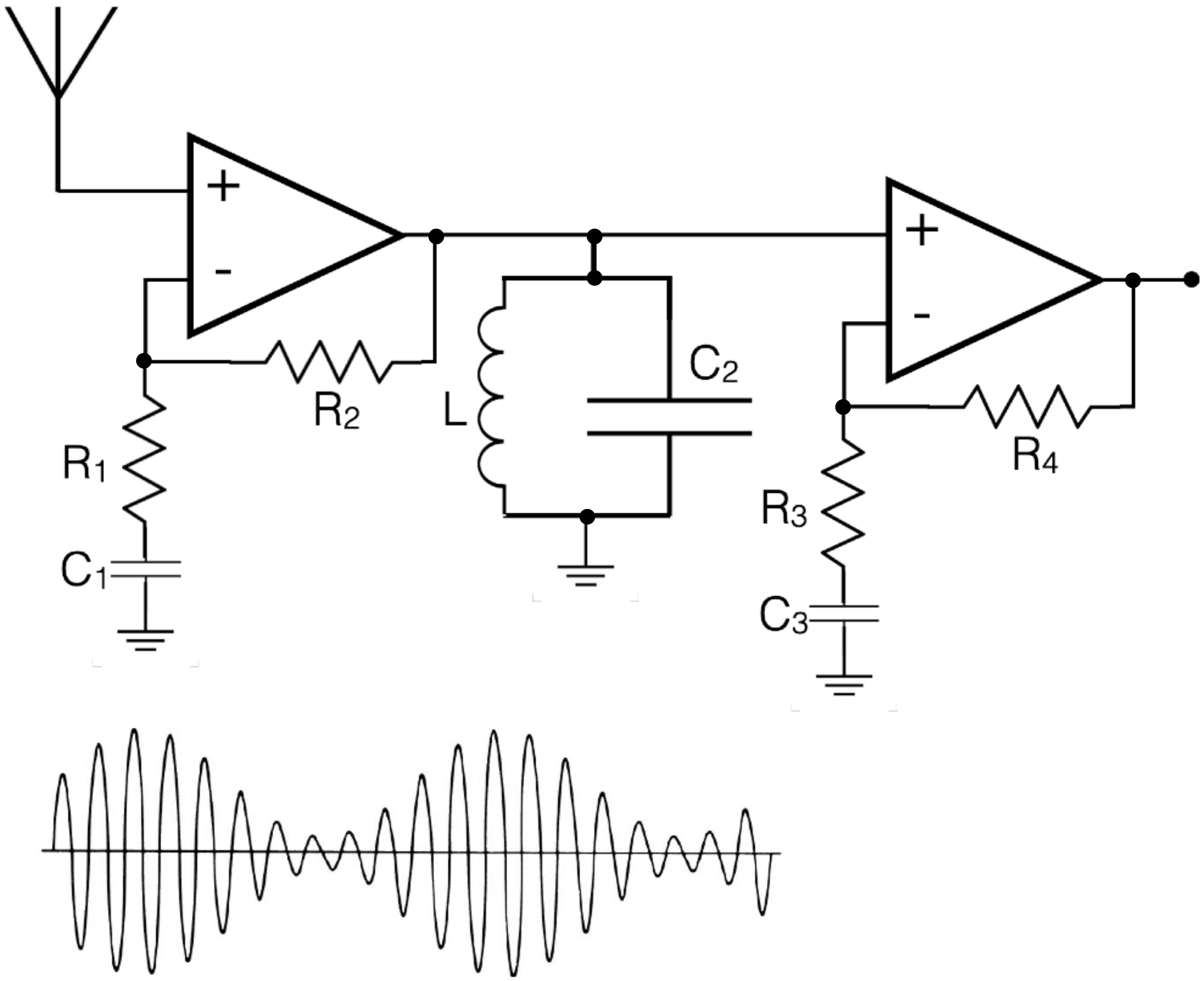


AM radio circuit

Amplify; not for volume but for impedance.



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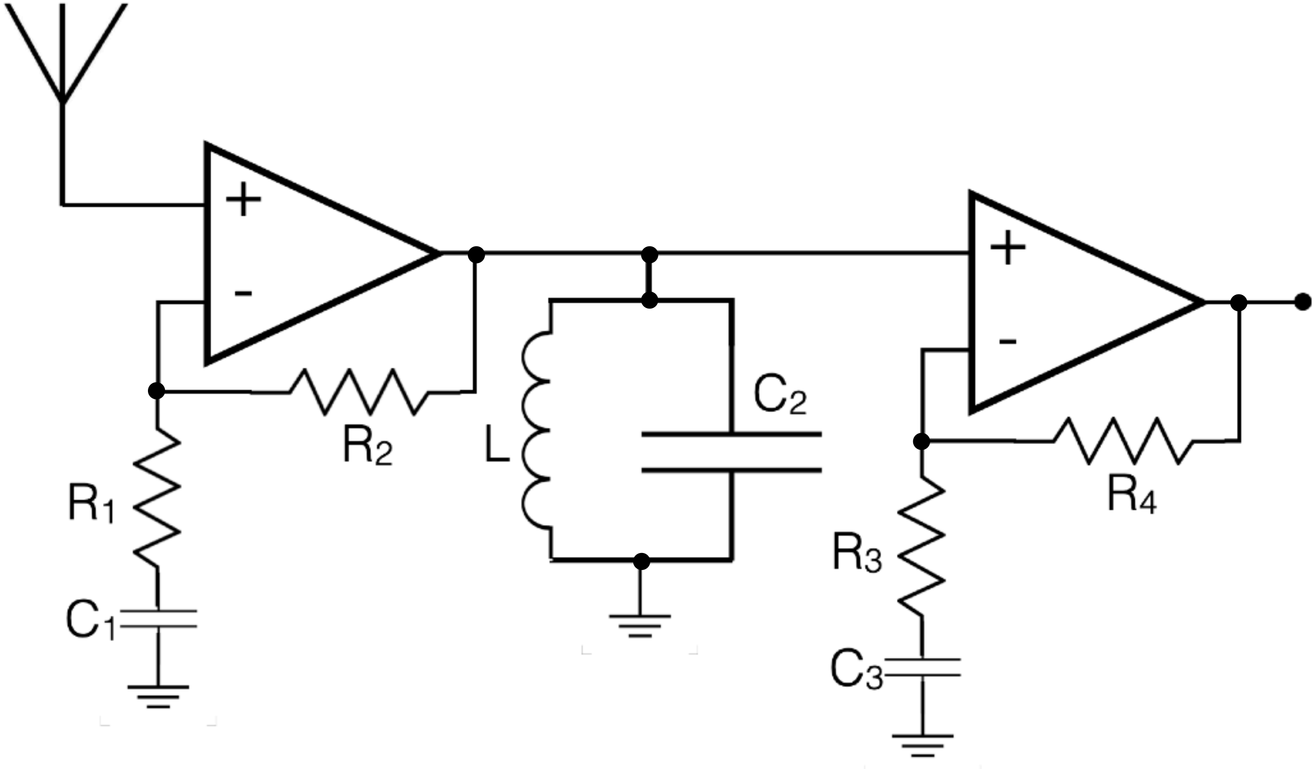

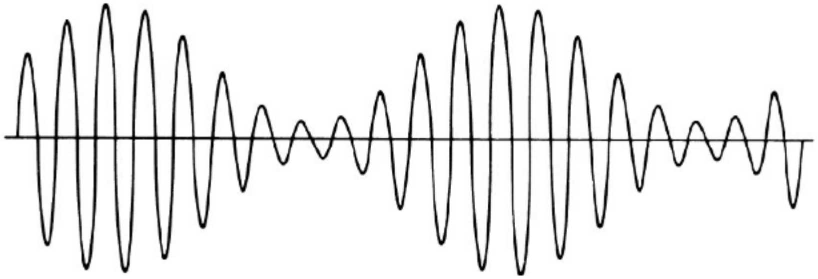

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low frequency signal from the
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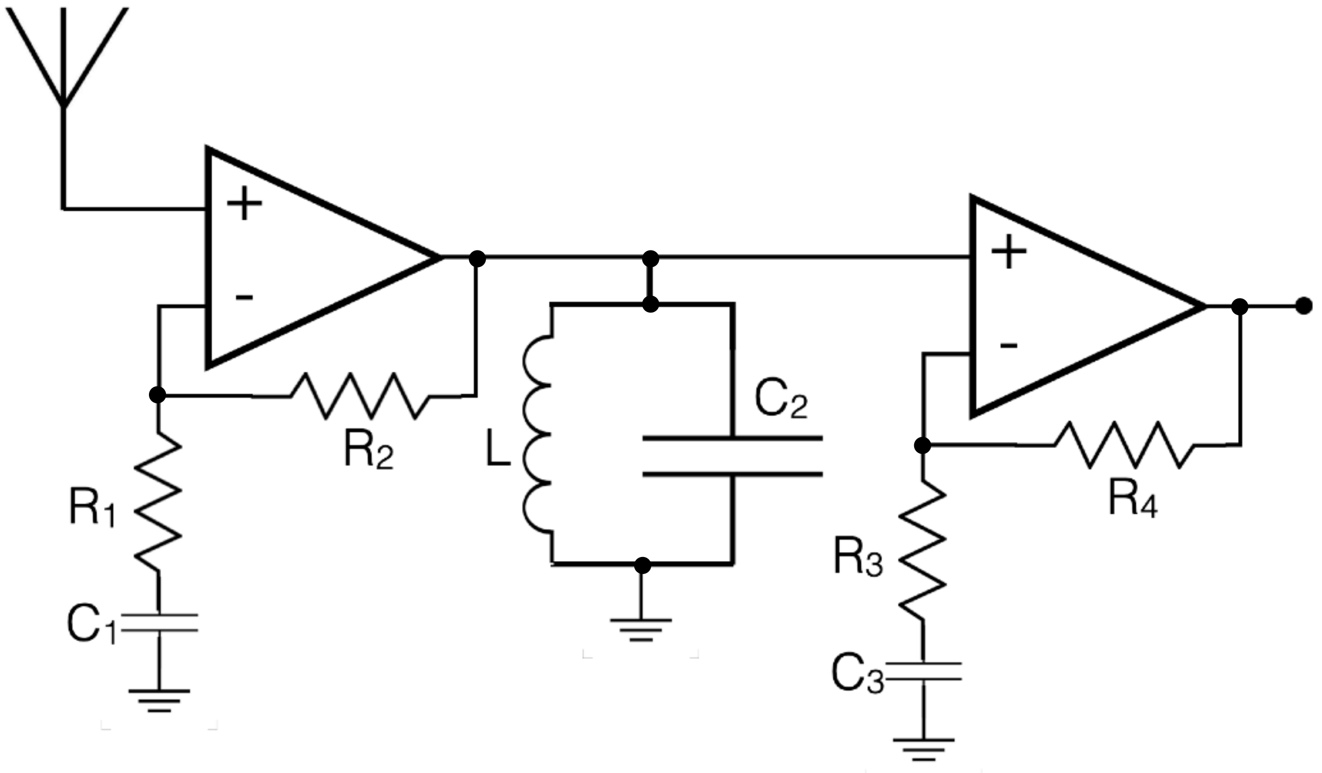
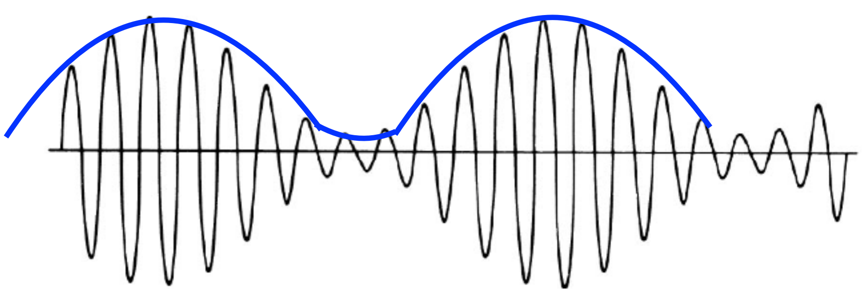
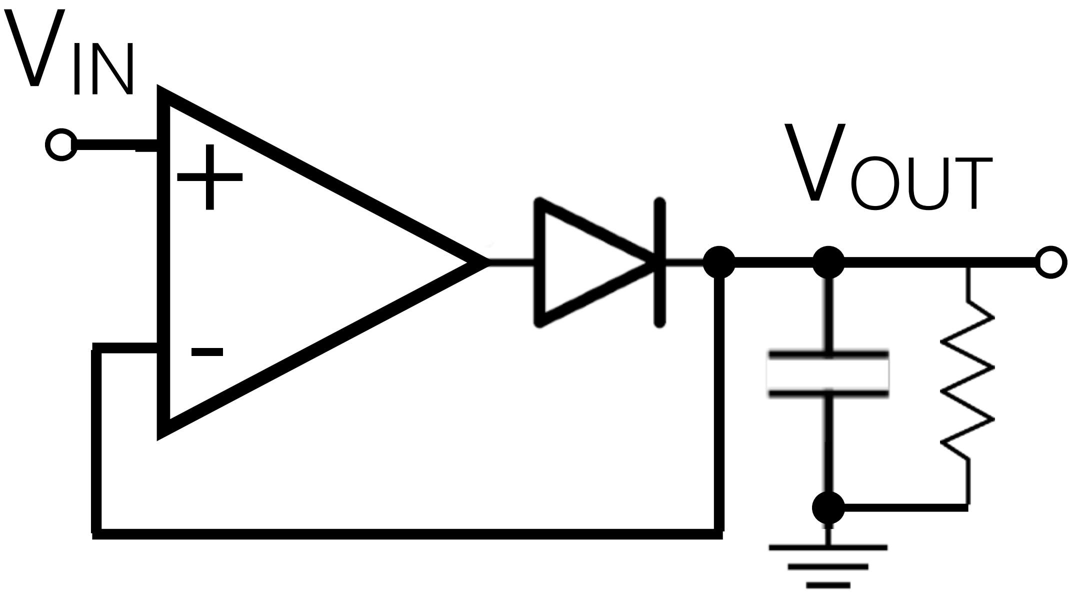




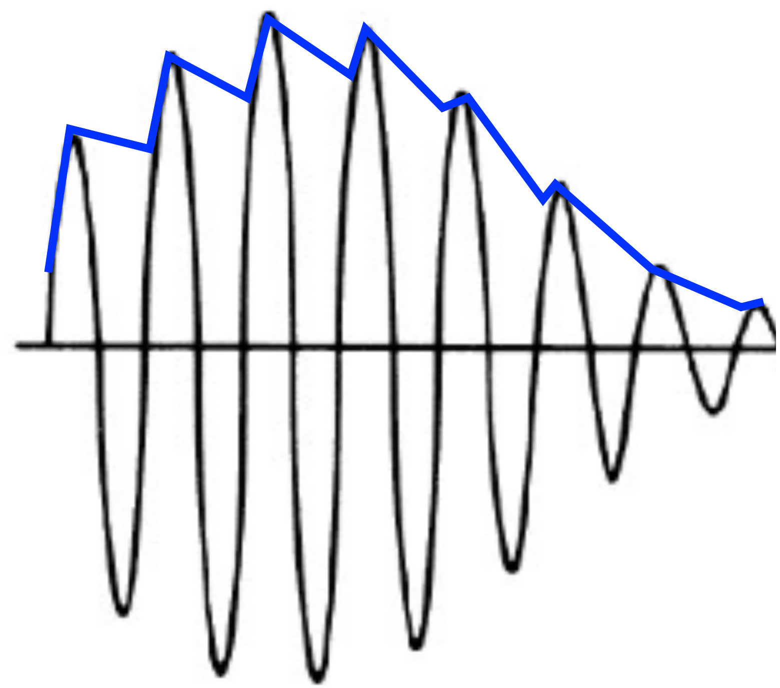
Then we need to extract the
low frequency signal from the
high frequency carrier and side bands.
That is in the envelope.

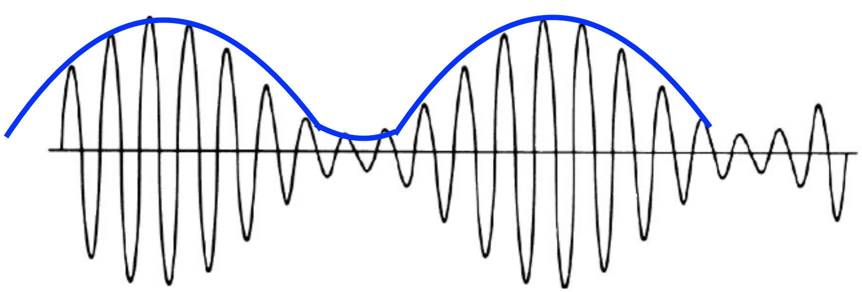
AM radio circuit: extracting the envelope

Extract the envelope with a "leaky peak detector"



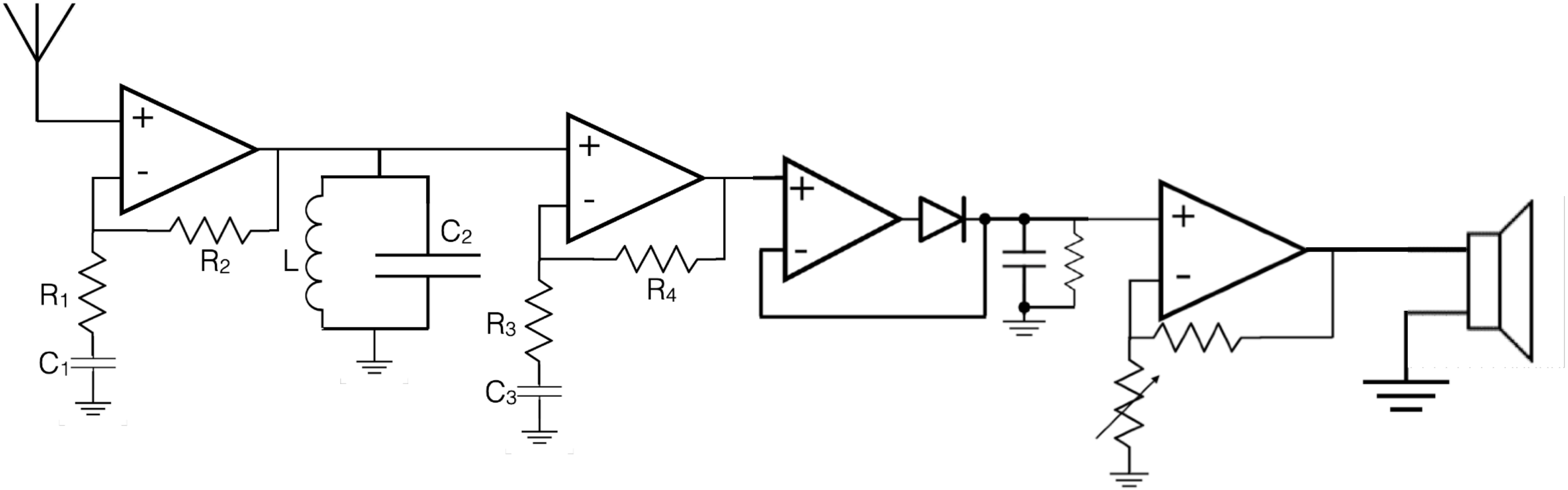
Choose RC to match the frequency of the signal, not the carrier.
$f_s = 10$ kHz
RC = (1kΩ)(100nF) = 100μs.





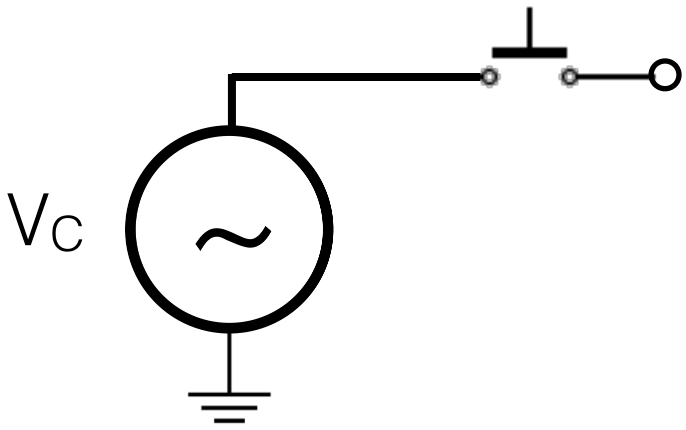
AM radio circuit: extracting the envelope

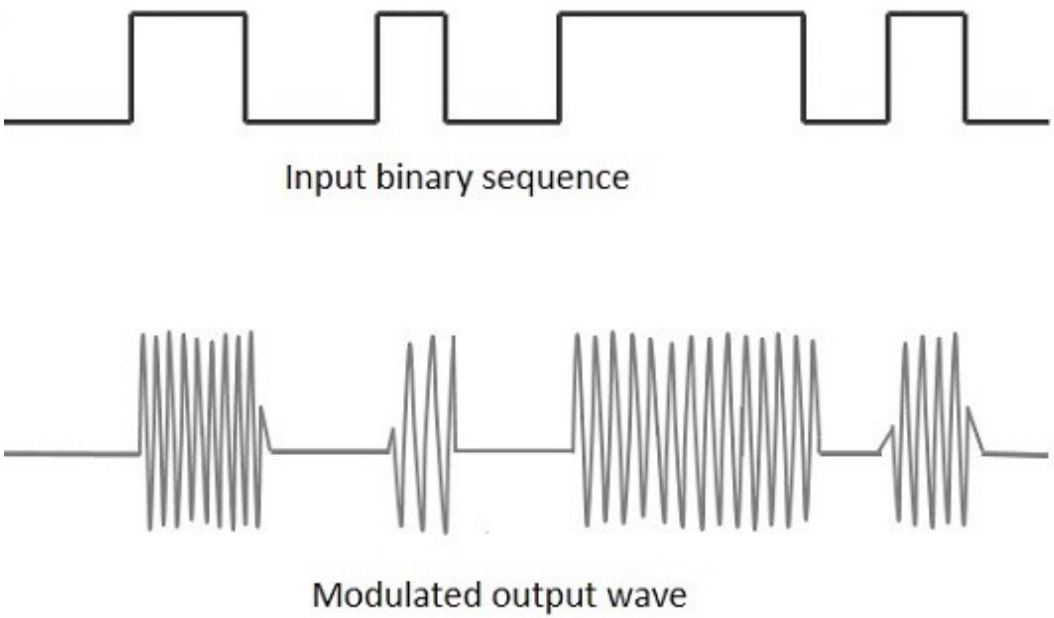
Now we have a signal, e.g., music, that we can amplify and drive a speaker.



AM radio modulating circuit

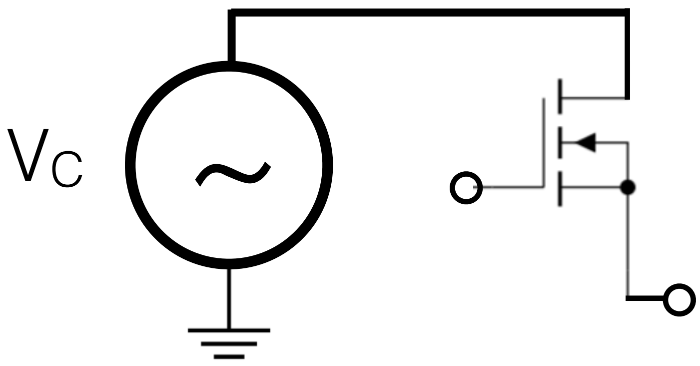
To modulate the signal onto the carrier, you could use a simple switch, like morse code.

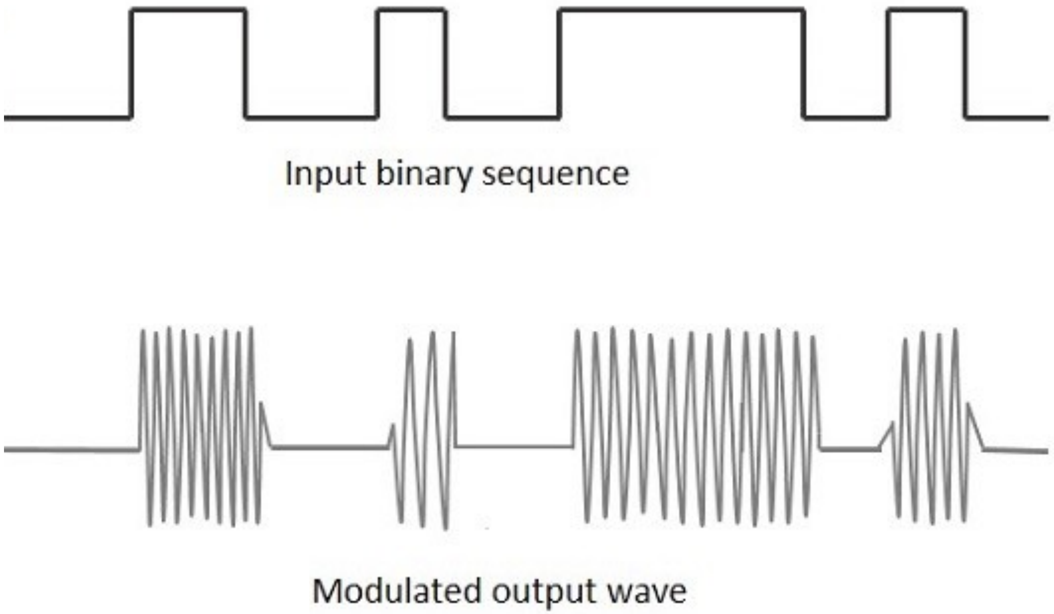




AM radio modulating circuit

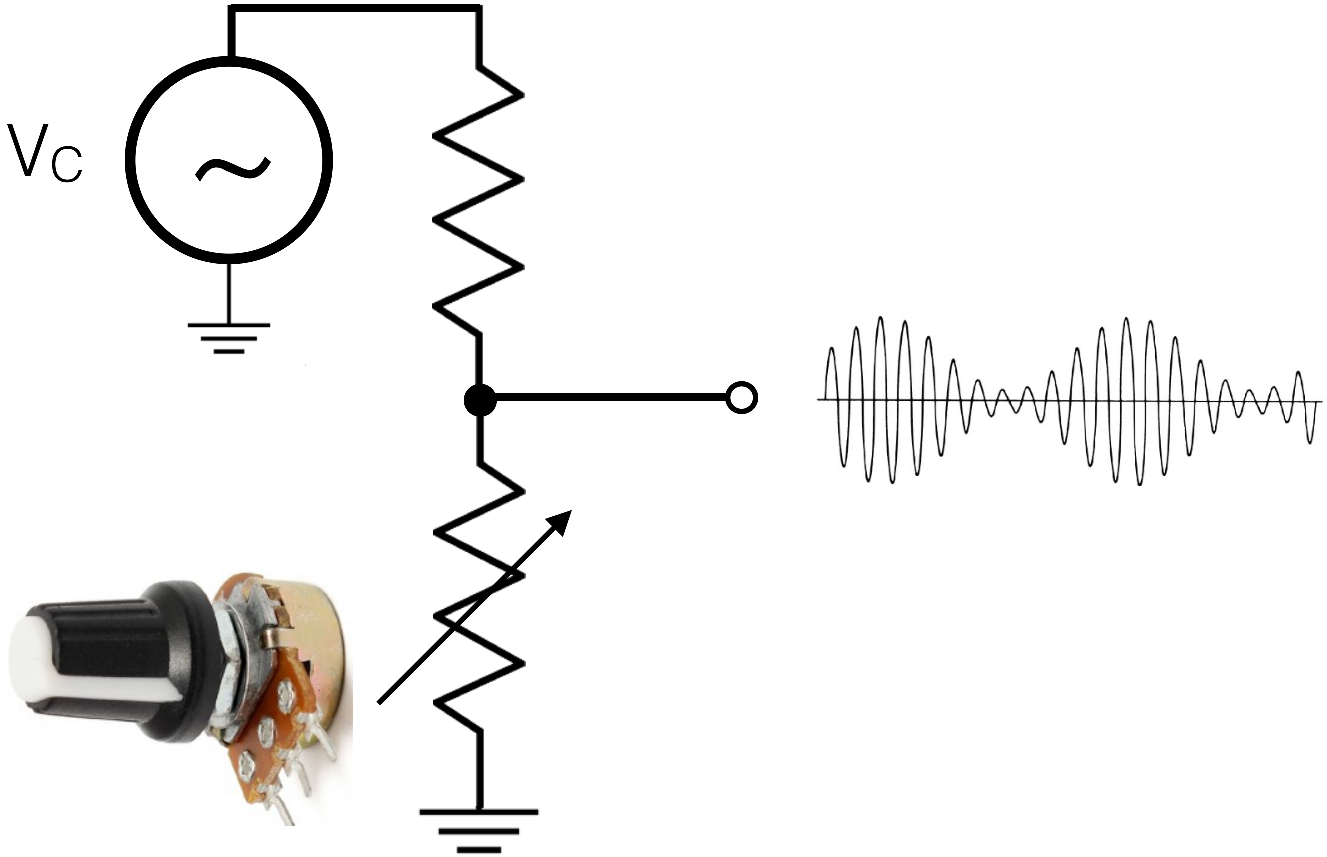
To modulate the signal onto the carrier, you could use a MOSFET switch.





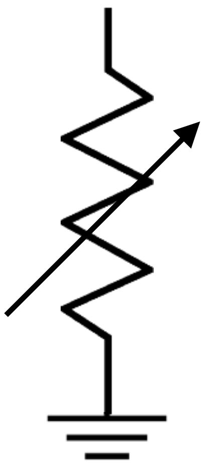
AM radio modulating circuit

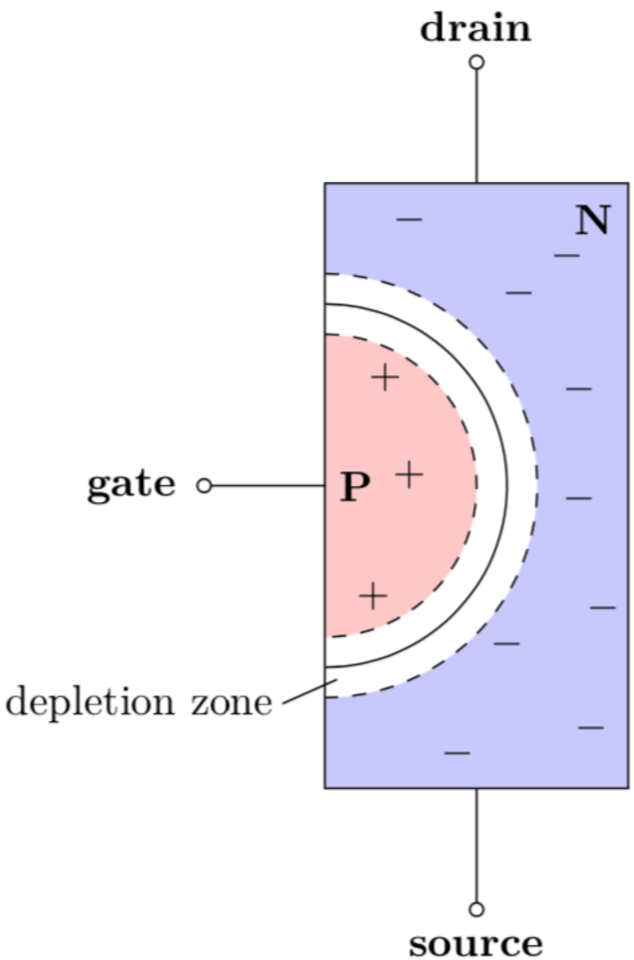
To modulate the signal onto the carrier, you could use a variable resistance voltage divider.



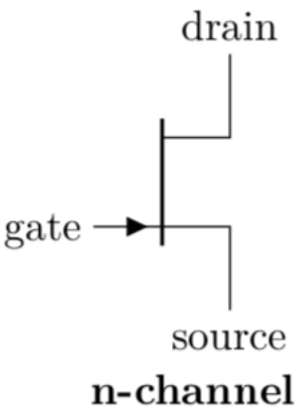
AM radio modulating circuit

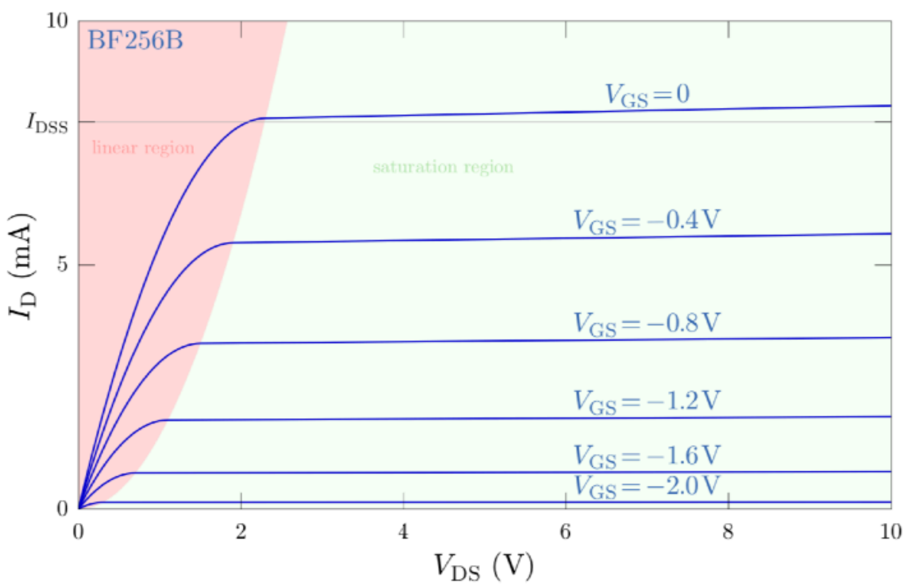
To modulate the signal onto the carrier, you could use a variable resistance voltage divider.
We want a voltage-controlled variable resistance.





$$R = \frac{1}{2k(V_{GS} - V_{\Theta})}$$





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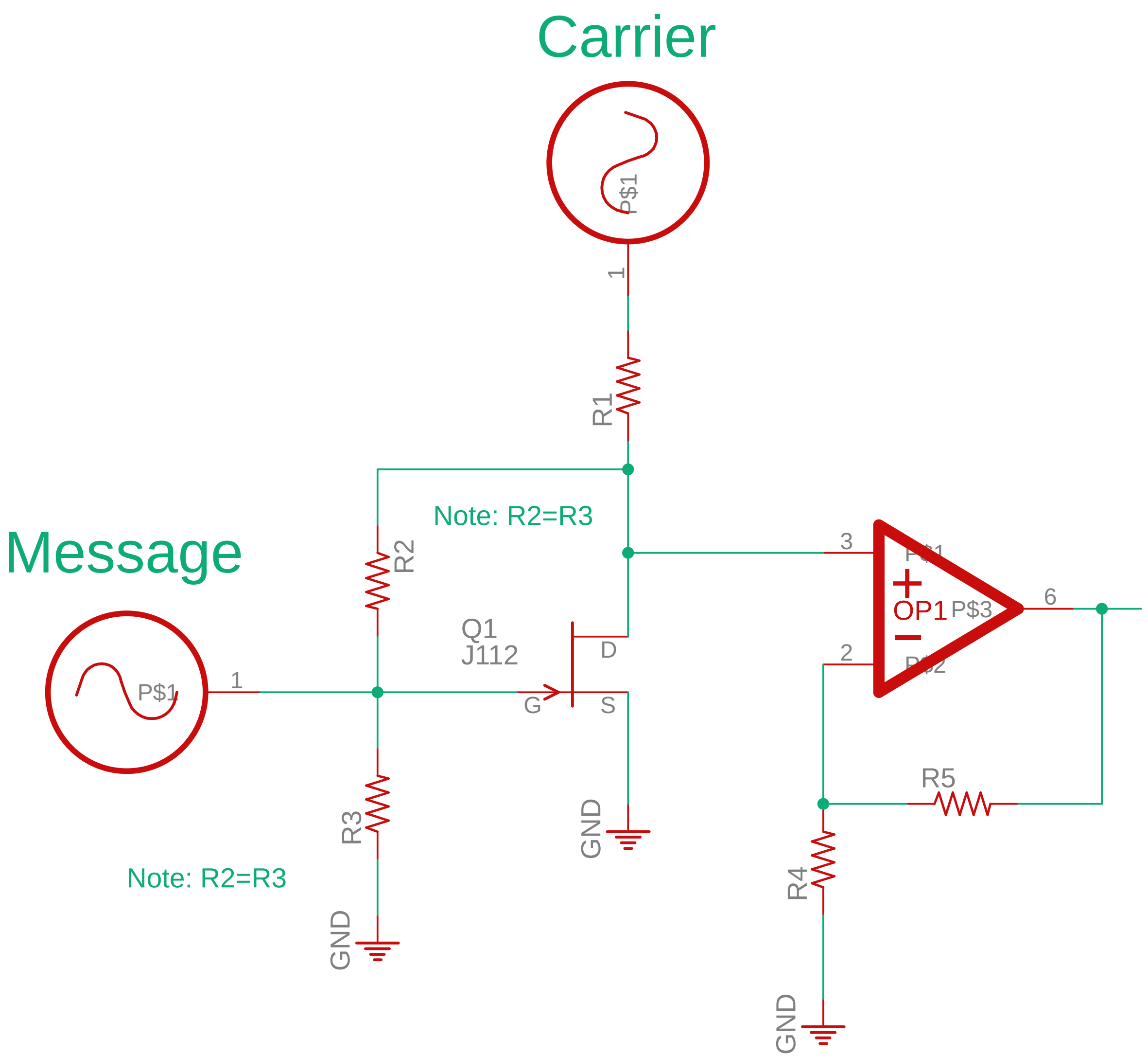

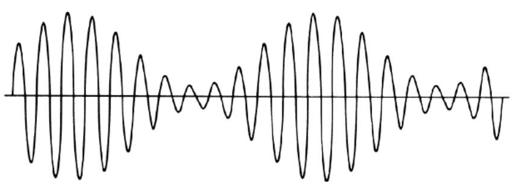

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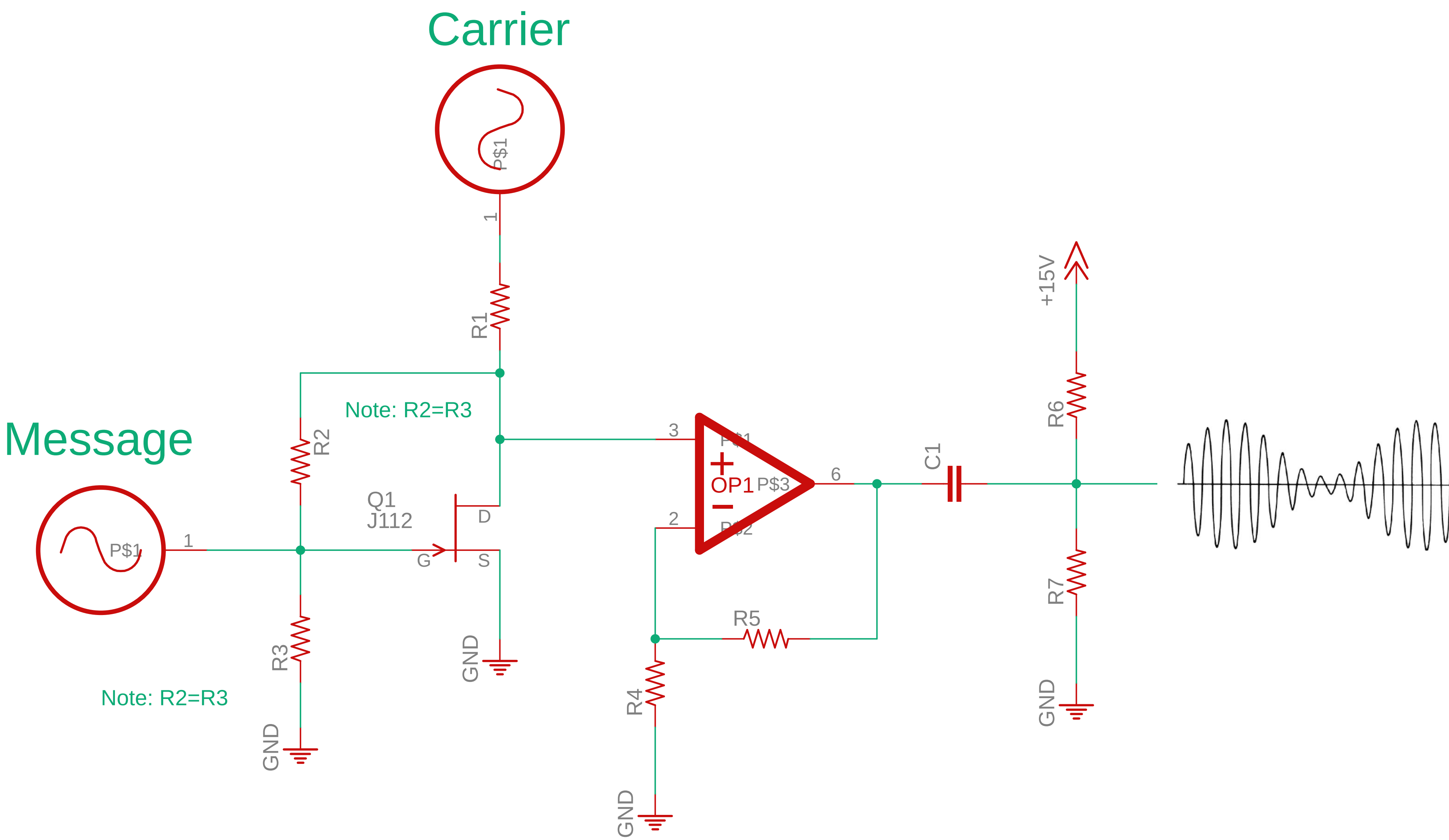
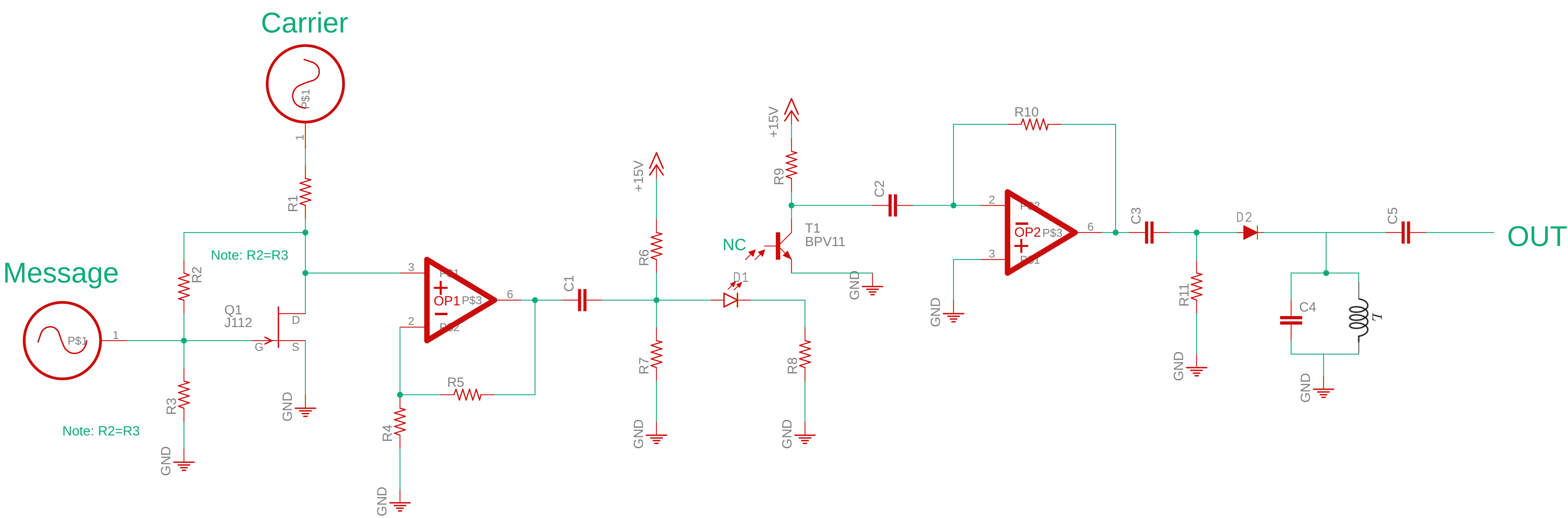


AM radio with LED TX/RX

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.

AM radio with LED TX/RX

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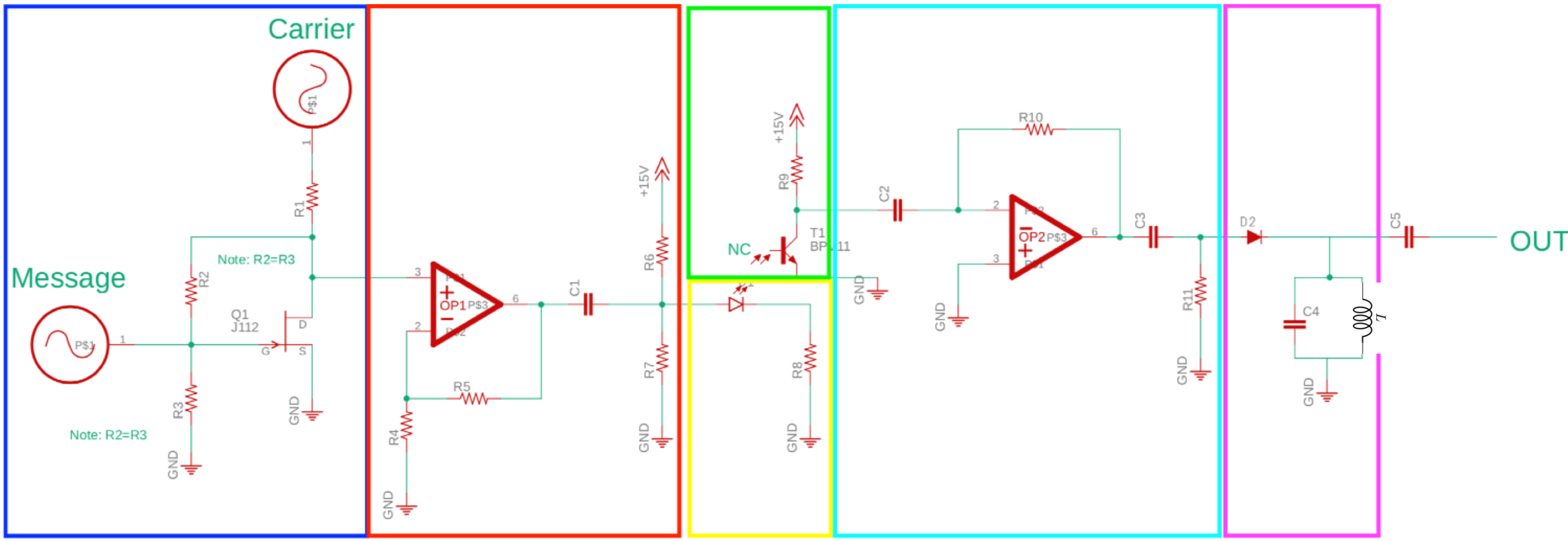


It is important to factorize the stages to ease debugging.

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.

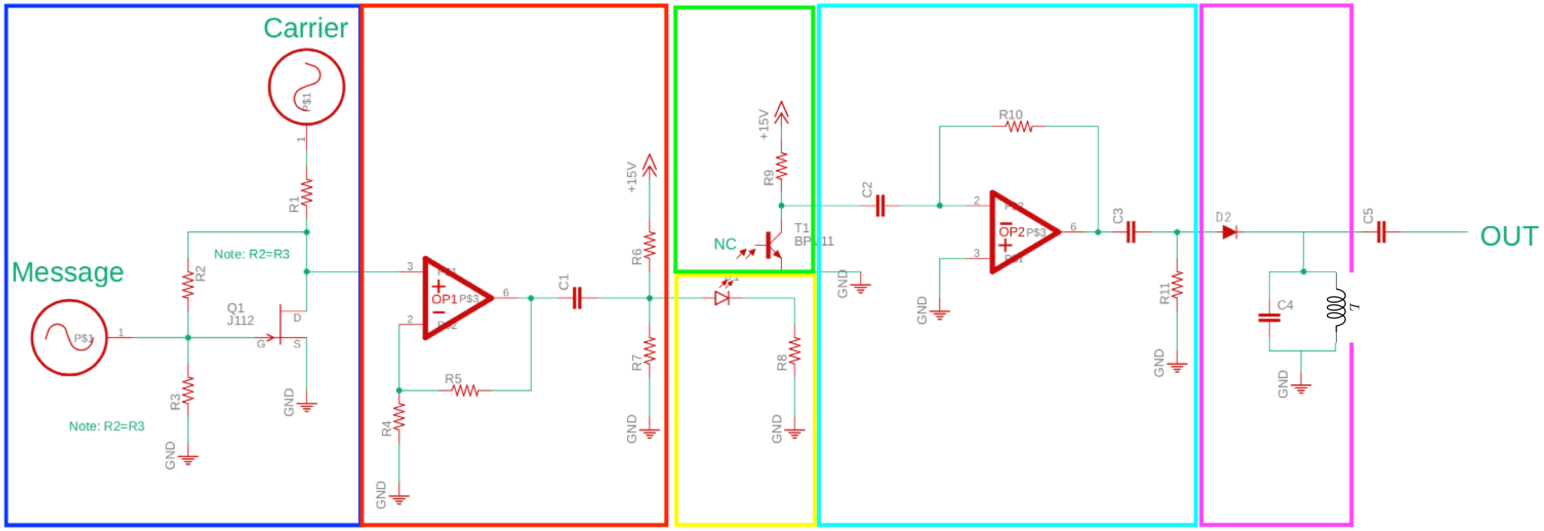
Separate stages with easy probe points to recheck their behavior.

Documentation is important to recheck previous behavior.

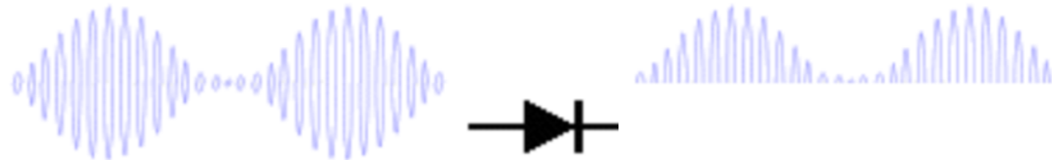
Allow each stage to be self tested.

- 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

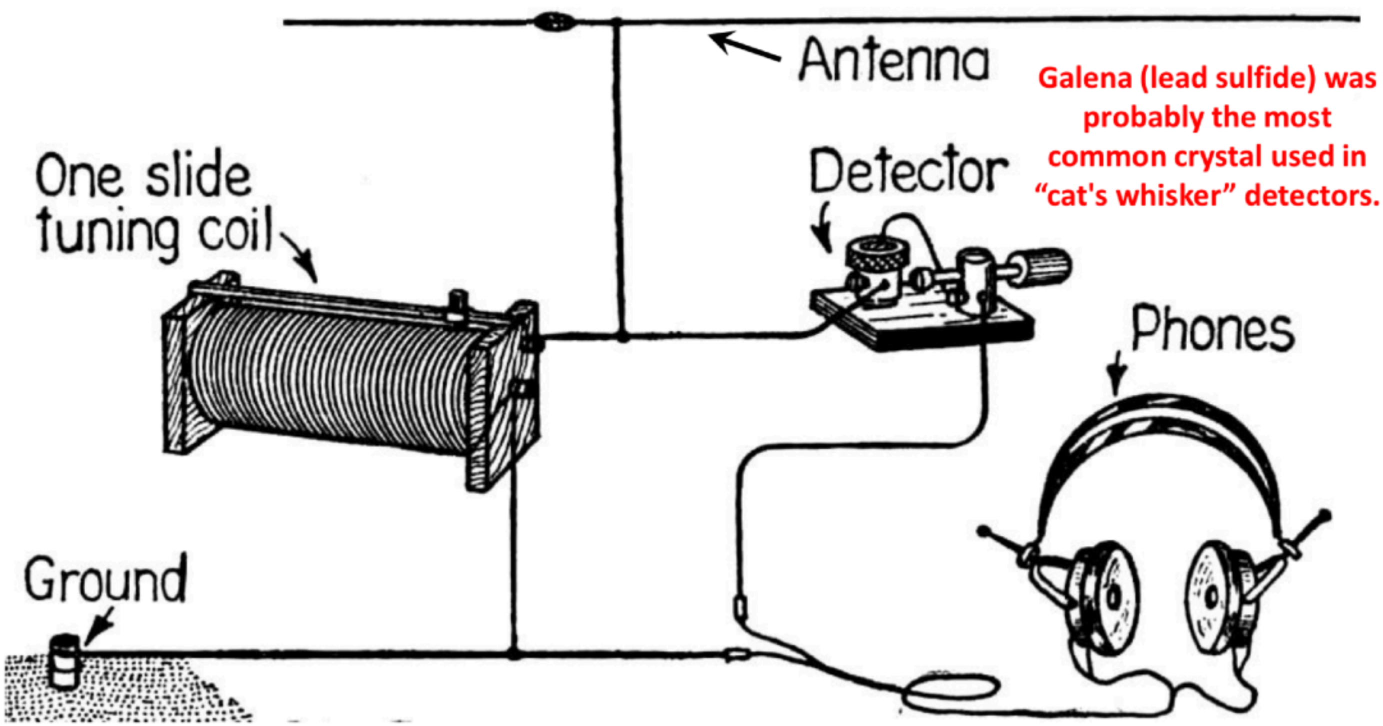
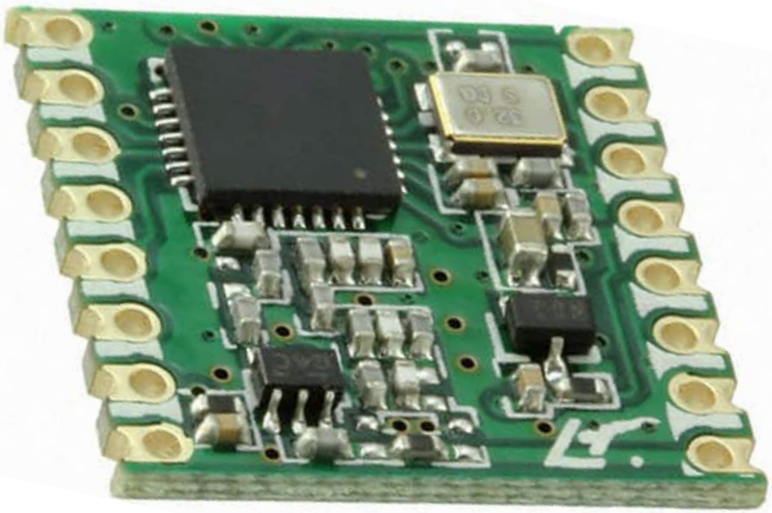


Diagram from 1922 showing the circuit of a crystal radio. This common circuit did not use a tuning capacitor, but used the capacitance of the antenna to form the tuned circuit with the coil.

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.