Radios for the hobbyist

Shaastra 2007

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Radio building as a hobby

- Started with vacuum tubes in the early 1900s
- Transistors made more complex radios possible
- Build radios from ready made schematics or design your own

Amateur radio

- Certain bands allocated for amateur (i.e. non commercial) use
- Need a license to operate transmitters
- $\sim 10,000$ hams in India, ~ 3 million worldwide
- A good fraction of radio amateurs build their own transmitters and receivers
- Great way to learn about radios and meet a diverse set of people

Hobby electronics and the Internet age

- Wireless communication not a novelty by itself—cellphones
- Talking to people across long distances is also easy—email
- Can’t make cheaper than what is available on the market—Flooded by inexpensive consumer electronics

But, once people build something, they have a very good chance of getting hooked on to the hobby

Advent of the integrated circuit

- 1960s
  - Integrated circuits (ICs) came to the market
  - Enabled more complex hobby circuits—e.g. 555 timer
- 1980s-1990s
  - Microcontrollers, microprocessors
  - Made even more complex hobby circuits possible—e.g. 8051 μC
- Present day ICs
  - Very complex systems
  - Very small form factors
  - More difficult for the hobbyist to handle

Advantages of the IC era

- You can build very complex systems with modern ICs
- You can build circuits at higher frequencies than before
- Starters can buy older ICs that they can handle—inexpensive!
- Cannibalize consumer electronics—good electronics inside and very cheap
- Can get IC datasheets and loads of other information from the internet.
- Easy to get good printed circuit boards fabricated (for advanced designs)

Bottomline: A lot of homebrewing activity is still possible by using transistors, older chips, and innards of consumer electronics

Radio signals

- Modulate a high frequency “carrier” with desired “message”—speech
- Radios distinguished by carrier frequency and type of modulation
  - Amplitude modulation
  - Frequency modulation

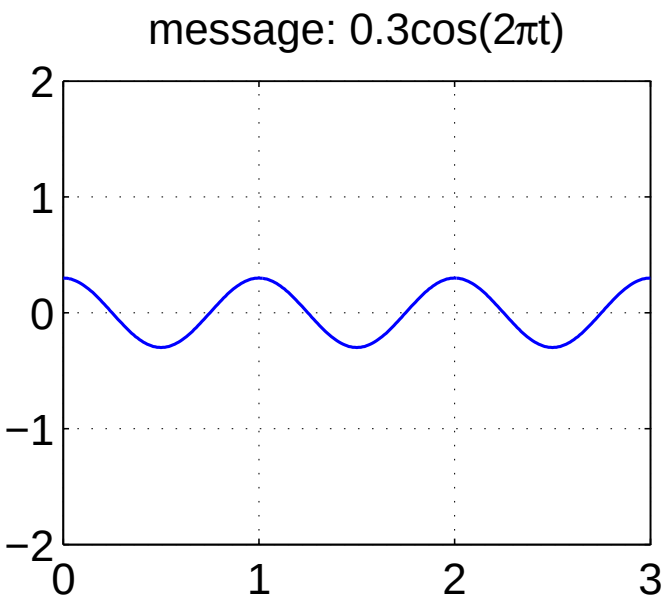
Radio transmitter and receiver functions

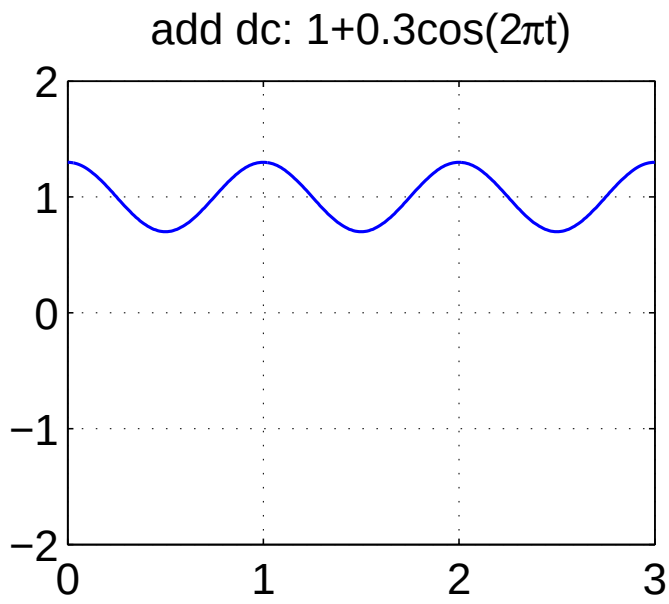
- Transmitter
  - Generate the carrier frequency—oscillator
  - Modulate the carrier
    - Amplitude modulator
    - Frequency modulator
- Receiver
  - Select the desired signal from among a number of signals
  - Amplify it
  - Change it to a different carrier frequency
  - Demodulate the signal—recover audio from high frequency carrier
    - Amplitude demodulator
    - Frequency demodulator

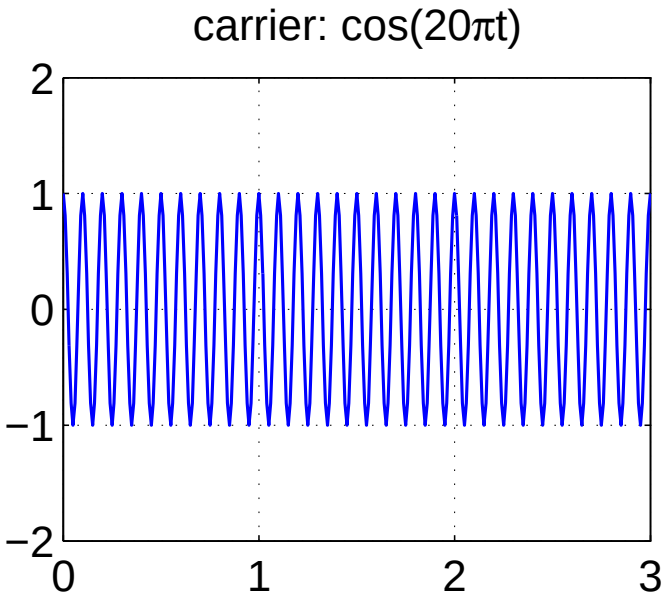
Radio bands

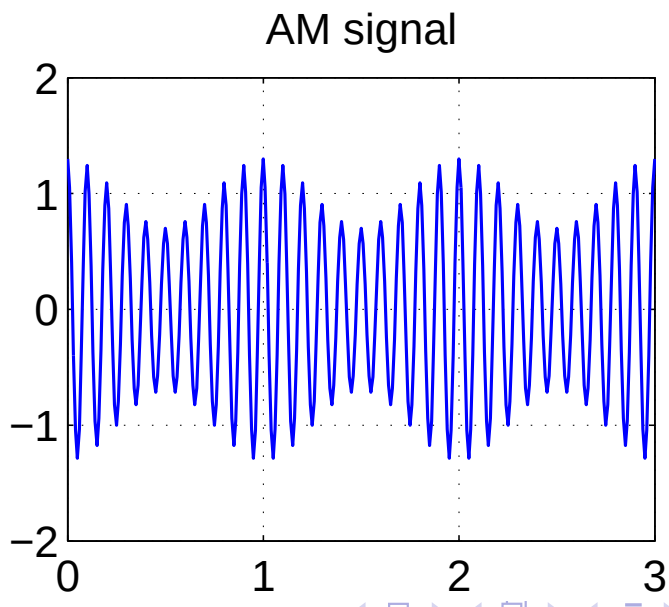
- Broadcast bands:
  - AM: Medium wave—510 kHz to 1610 kHz in 10 kHz steps
  - AM: Short wave—3.5 MHz to 30 MHz in various bands (see a 9 band radio)
  - FM: 88-108 MHz in 0.2 MHz steps
- Amateur bands:
  - HF: 7-7.1 MHz, 14-14.35 MHz, 21-21.45 MHz, 28-28.3 MHz
  - VHF: 144-146 MHz
  - UHF: 434-438 MHz

AM radio signals



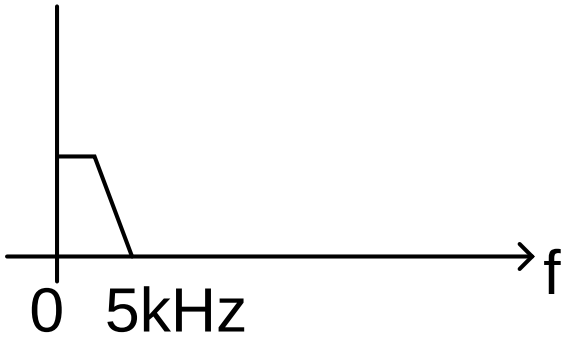




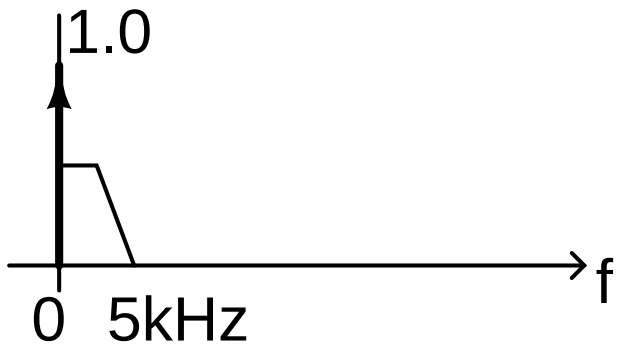


Broadcast AM radio signals

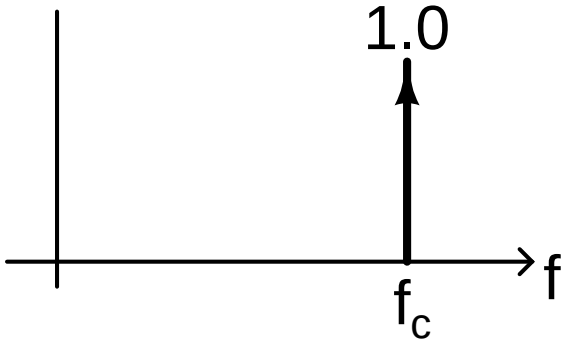
message: m(t)



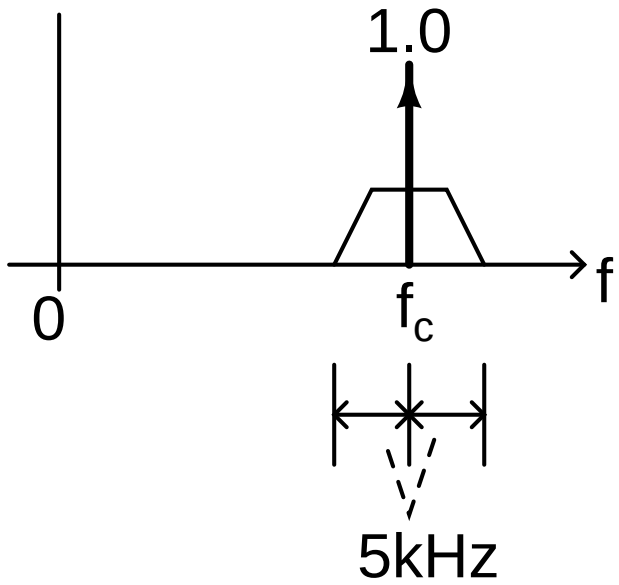
dc added: 1+m(t)



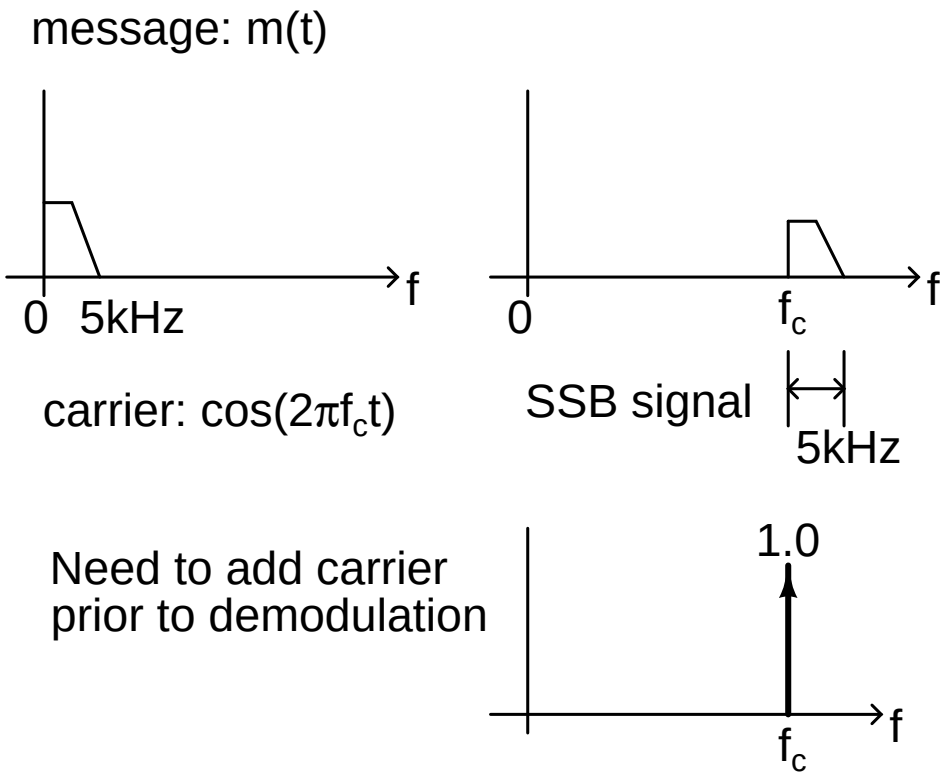
carrier: $\cos(2\pi f_c t)$



AM signal

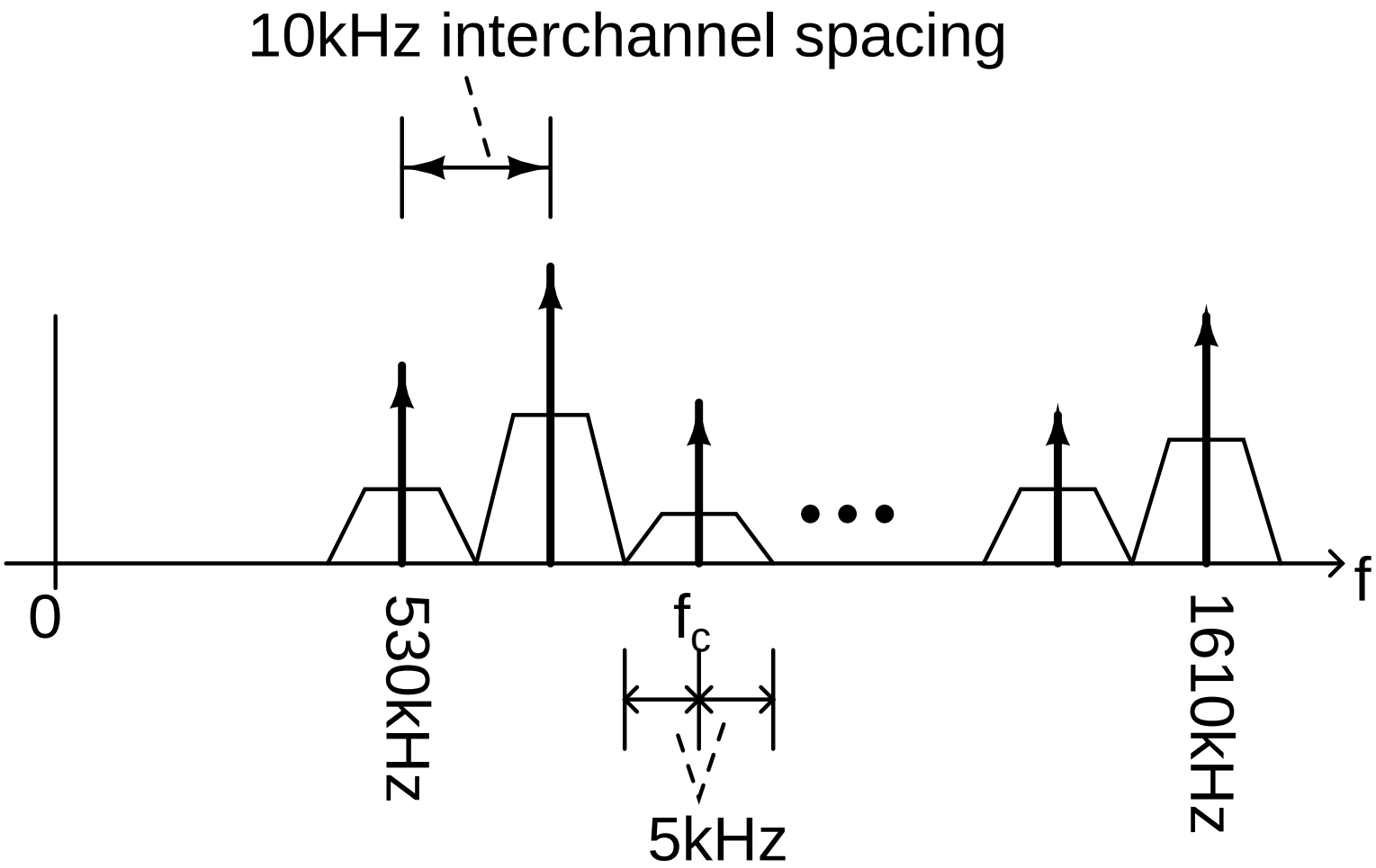


Amateur SSB radio signals

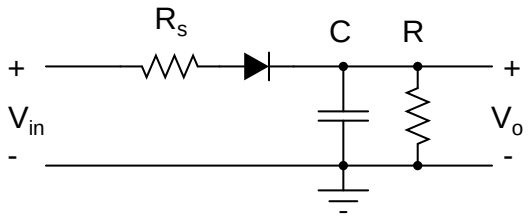


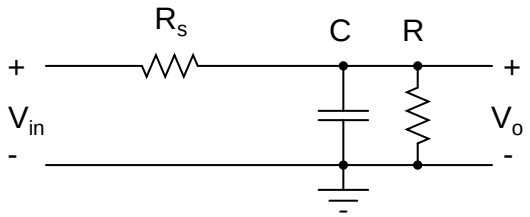
- Single sideband (SSB) suppressed carrier modulation
- Need to add carrier prior to demodulation with a “regular” AM receiver
- Place an oscillator at the carrier frequency close to the AM receiver-The receiver picks up the radiation and detects SSB signal

Medium wave band

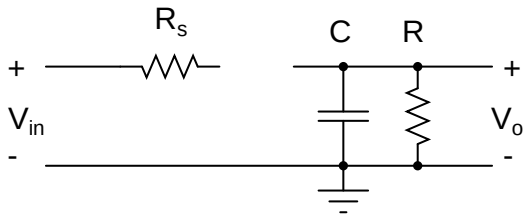


Amplitude demodulator—peak detector





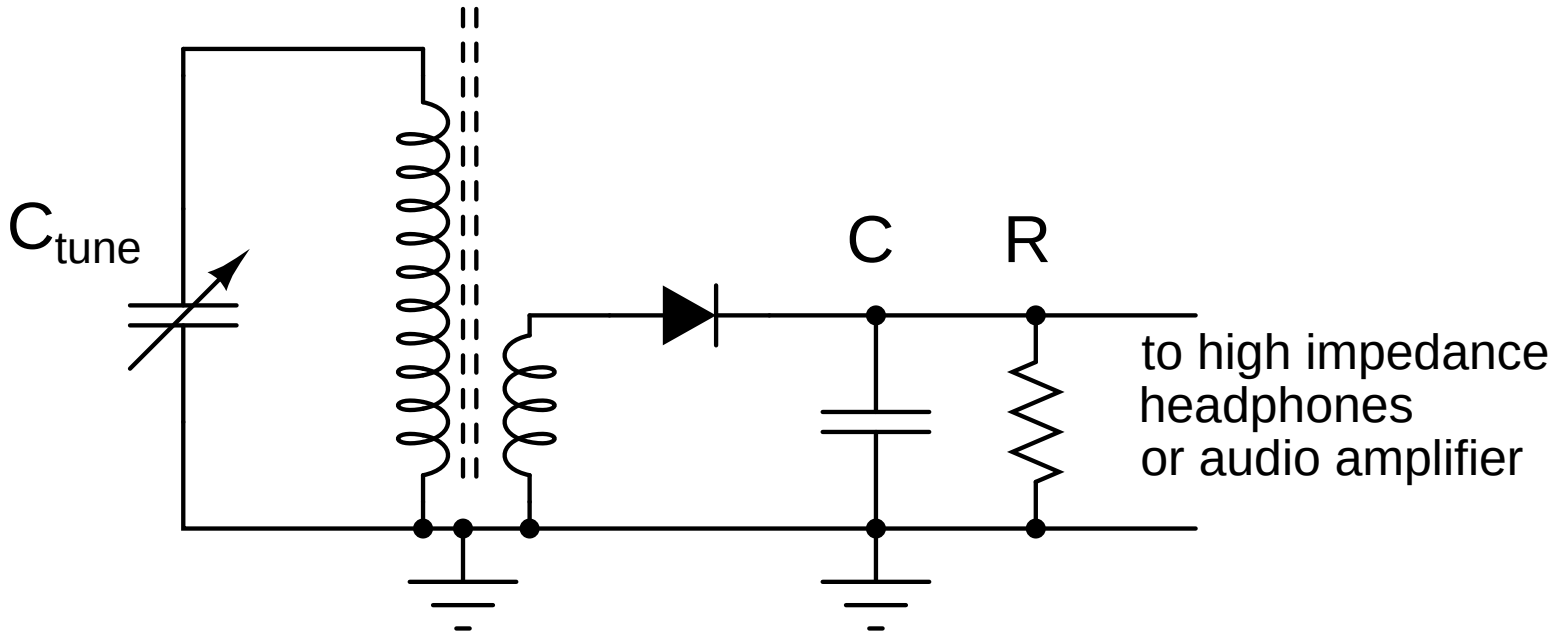
diode on
charge through R_s



diode off
discharge through R

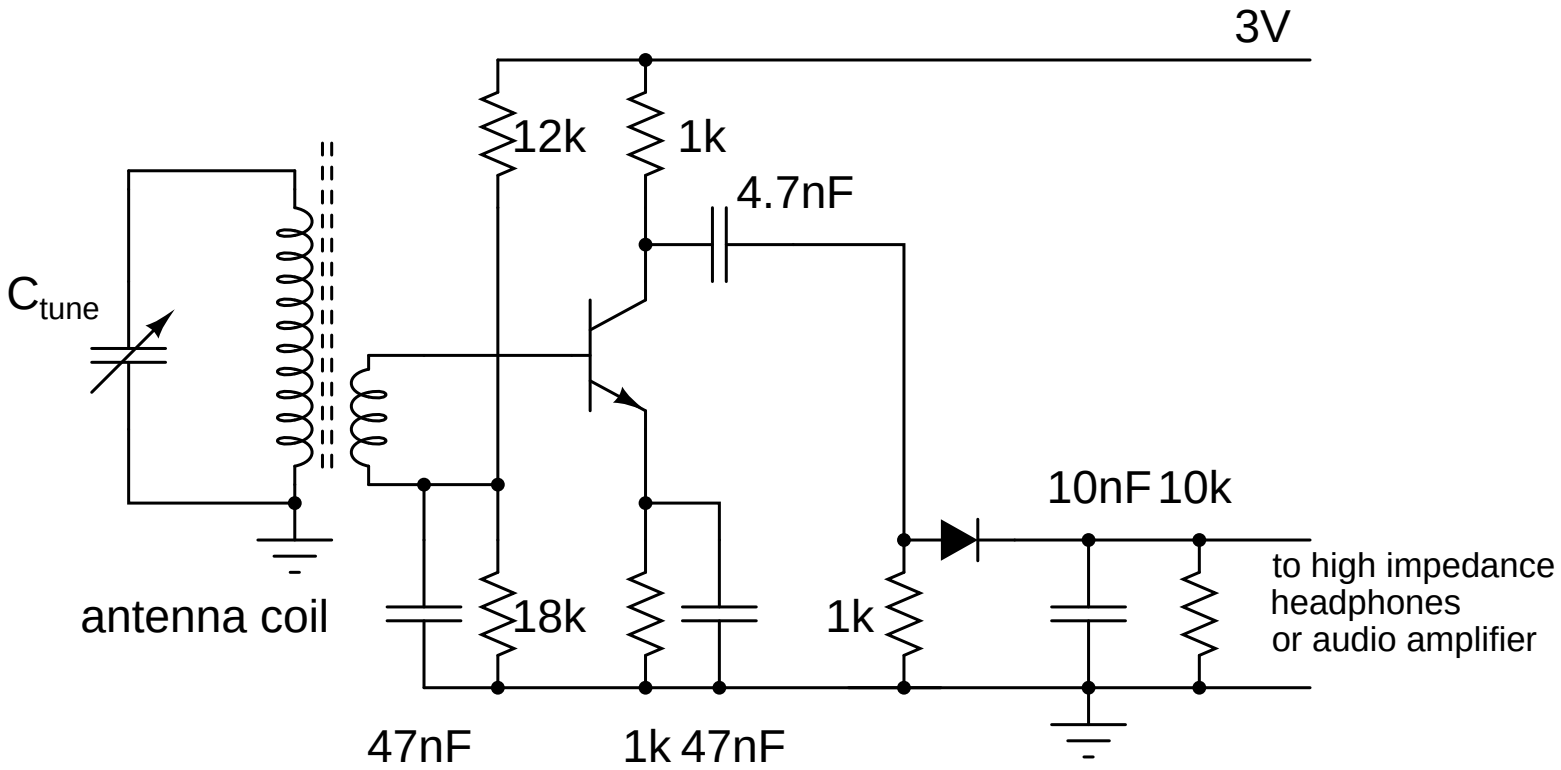
- Germanium diode for low cut in voltage (1N34 etc.)
- *RC* too small: follows the carrier frequency
- *RC* too large: fails to follow the speech signal
- Choose proper *RC* with the largest possible *R*

TRF radio-MW/AM



- Single tuned circuit for selection
- MW antenna coil with ferrite rod acts as antenna
- Works without amplification for powerful stations—connect detector directly to coil secondary
- Variable capacitor for tuning the radio. Move the ferrite rod to the appropriate place for proper tuning range

TRF radio



- Add an amplifier for weaker stations

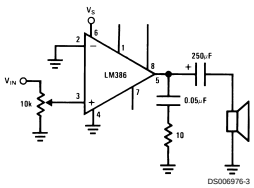
Audio amplifier

- LM386 audio amplifier IC—Rs. 12/-
- Works without fuss with a minimum number of external components
- Gain of 20 or 200
- Can be used for any of your projects
- Data sheet has several example circuits

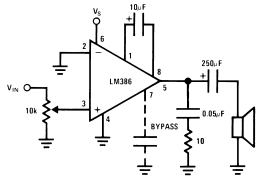
Audio amplifier

Typical Applications

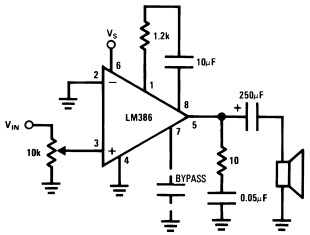
Amplifier with Gain = 20
Minimum Parts



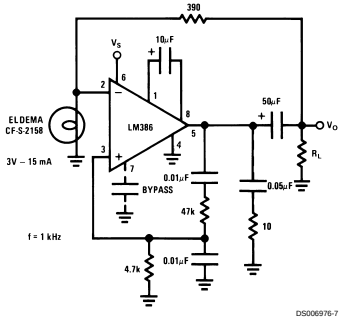
Amplifier with Gain = 200



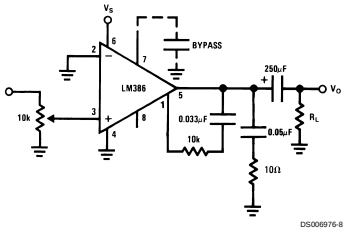
Amplifier with Gain = 50



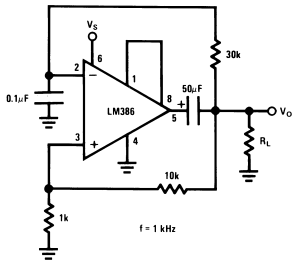
Low Distortion Power Wienbridge Oscillator



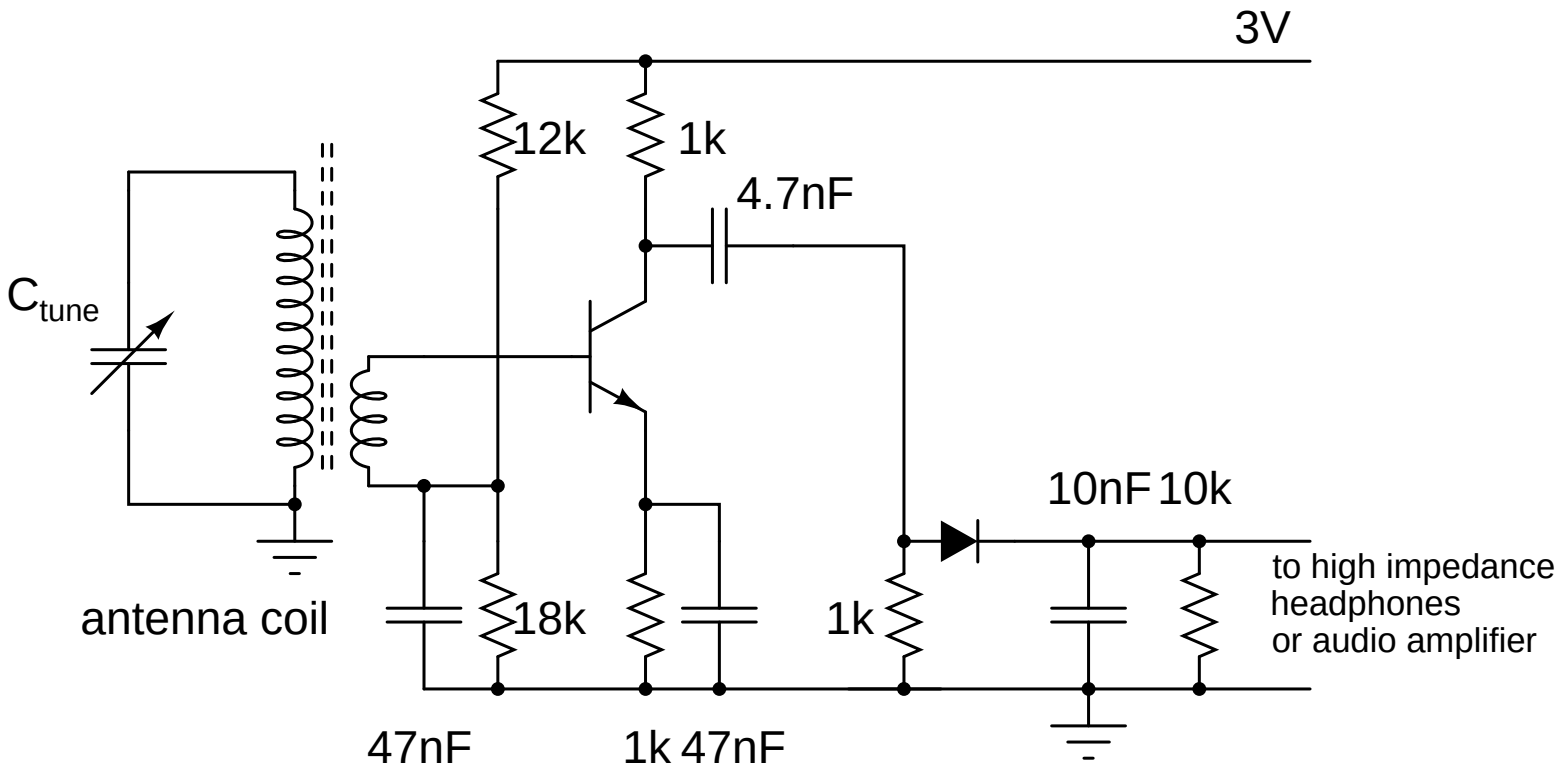
Amplifier with Bass Boost



Square Wave Oscillator



Project suggestion: TRF radio



- MW antenna coil with ferrite rod
- A single transistor amplifier with gain 20
- Peak detector
- LM386 Audio amplifier (gain 200)

TRF radio-disadvantages

- Bandwidth changes with tuning $\Rightarrow$ poor selectivity
- Not suitable for high frequencies or wide tuning ranges

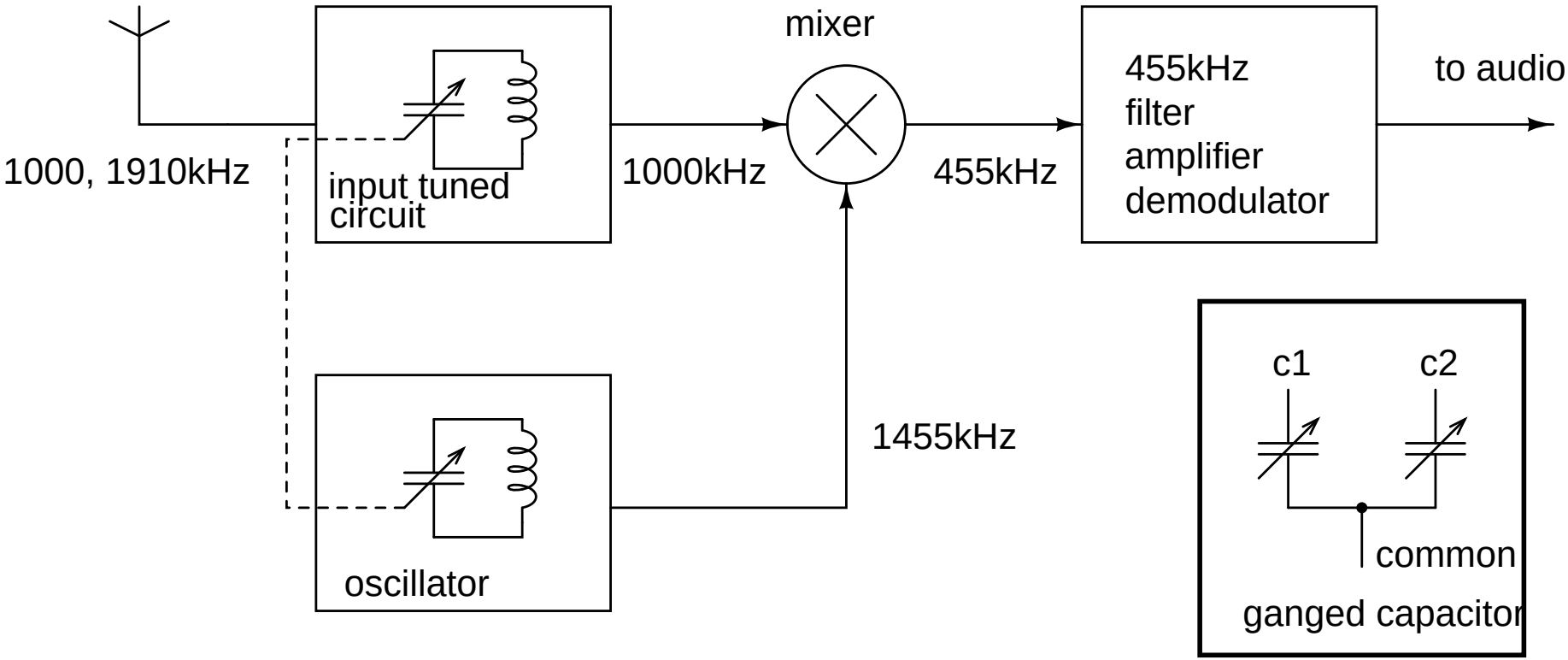
Superheterodyne radio

- Make a fixed frequency radio for high selectivity
- For AM radios, this is at 455 kHz and for FM radios, this is at 10.7MHz (intermediate frequency-IF)
- Translate desired carrier frequency to 455 kHz using a mixer
- Detector operates at 455 kHz
- Input circuit can have limited selectivity
- Invented in 1920s by Edwin Armstrong—still the best choice for receivers today!

Mixing

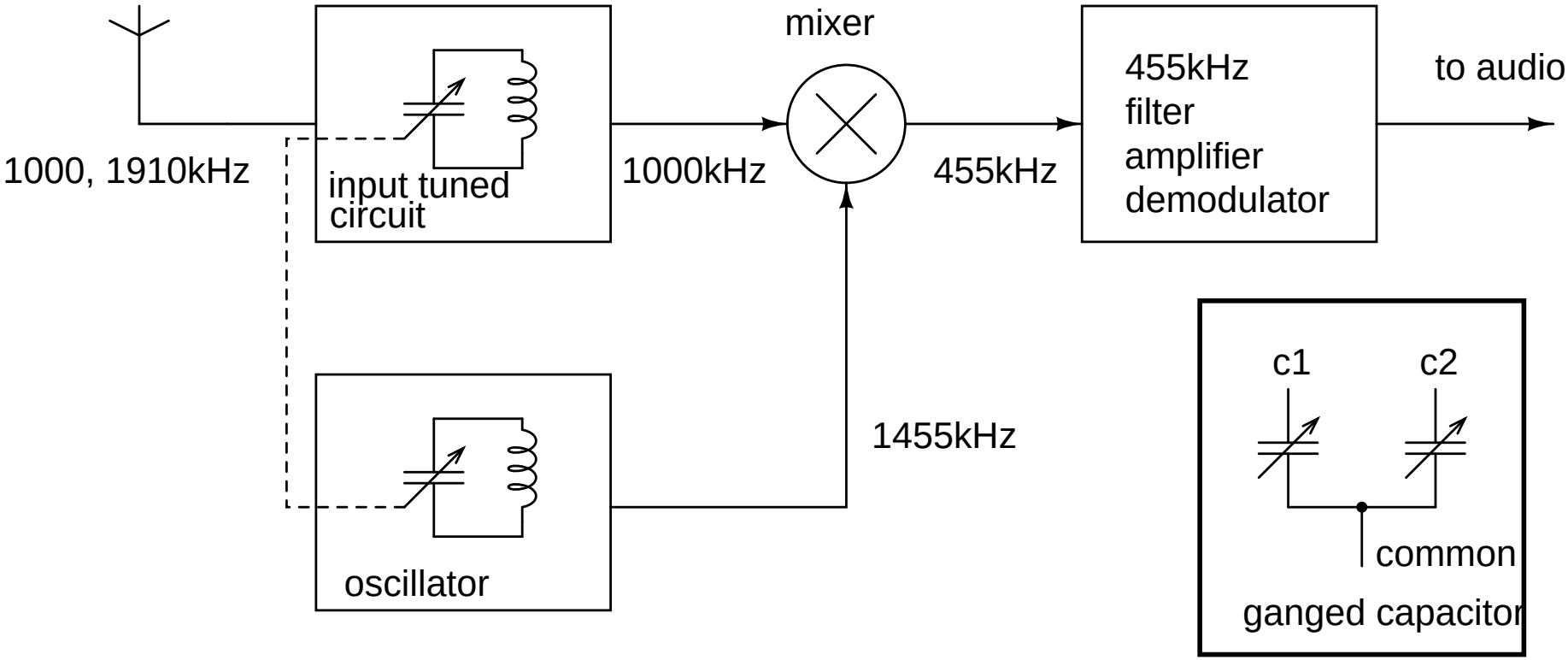
- $\cos(2\pi f_{in}t) \times \cos(2\pi f_{LO}t) =$
  $1/2\cos(2\pi(f_{LO} + f_{in})t) + 1/2\cos(2\pi(f_{LO} - f_{in})t)$
- Mixing (multiplication) produces sum and difference frequencies
- Difference frequency is the intermediate frequency
- $f_{IF} = f_{LO} - f_{in}$
- Sum frequency component is filtered out

Superheterodyne radio



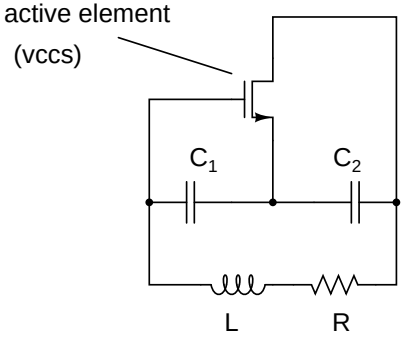
- Local oscillator to mix the input signal to 455 kHz
- To receive 1000 kHz, local oscillator at 1455 kHz
- 1455 kHz LO also translates 1910 kHz to 455 kHz!
- Input tuned circuit to remove 1910 kHz (image) signal
- Doesn't have to remove the next channel, as in a TRF radio

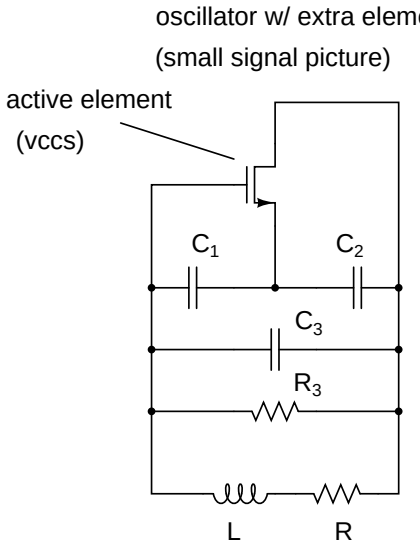
Superheterodyne radio

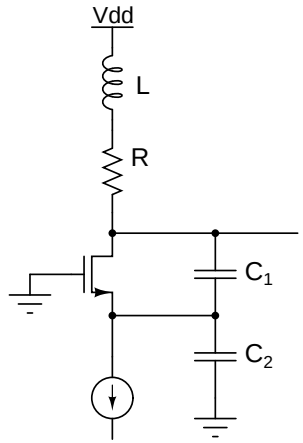


- Local oscillator and input circuit must be tuned together
- Ganged variable capacitor with a common shaft
- One common terminal

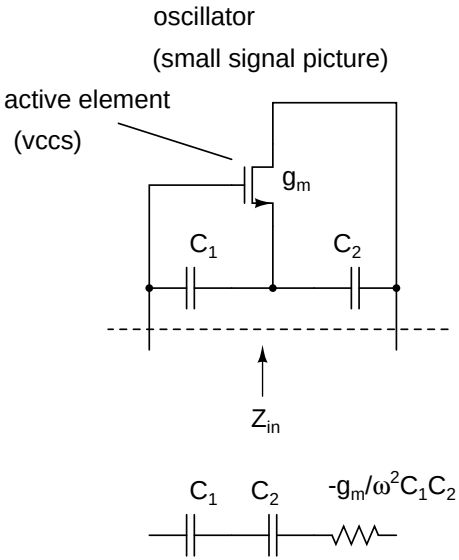
Oscillator

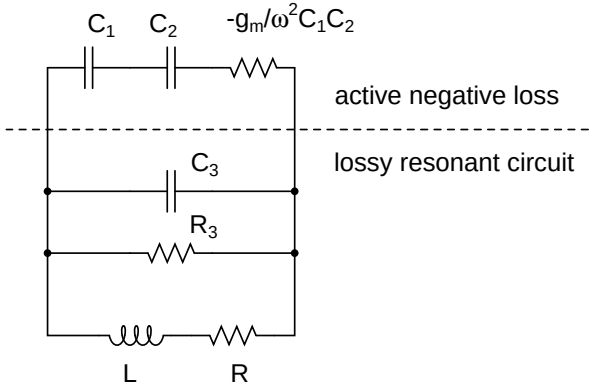


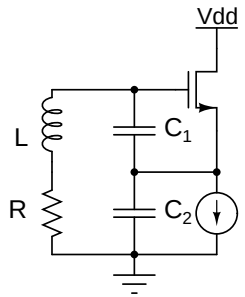




common gate version



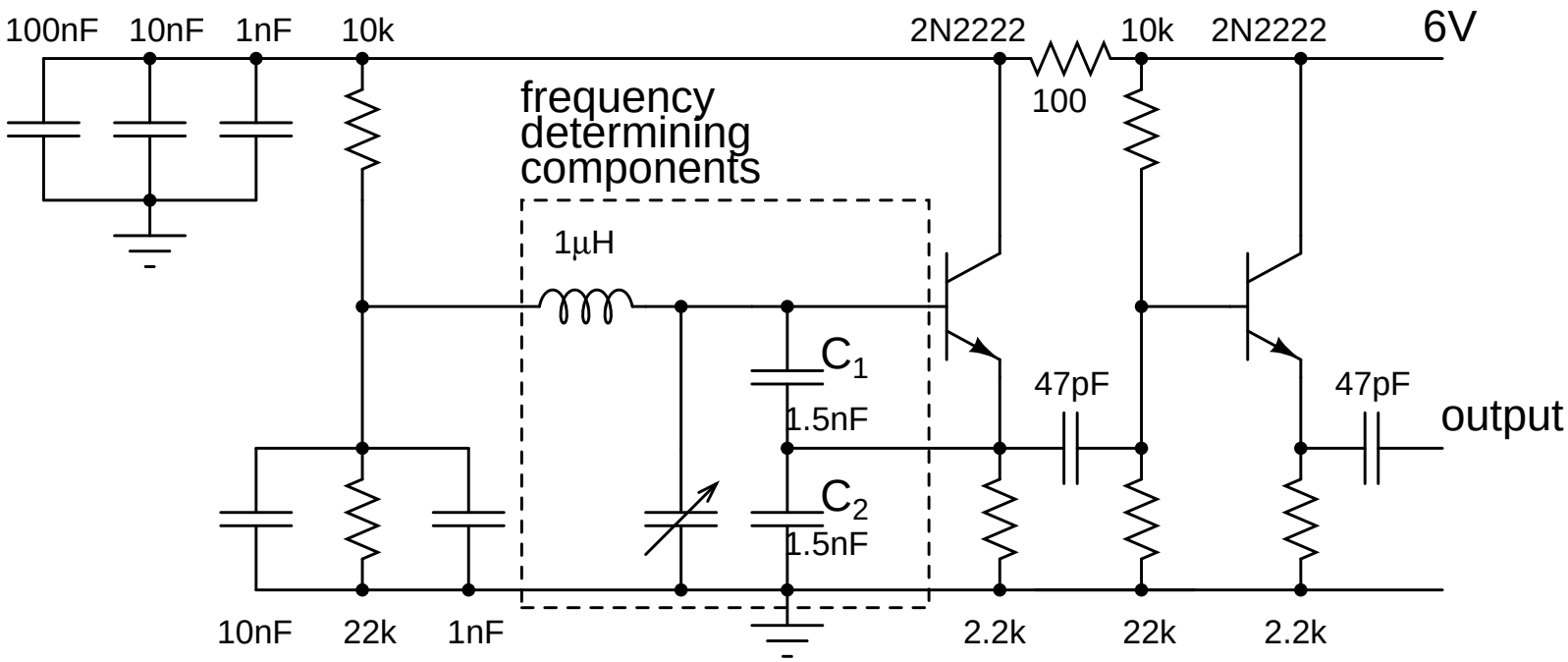




common drain version
(colpitts oscillator)

- Active circuit provides negative resistance
- Wide variety of oscillators—variants of the circuit above

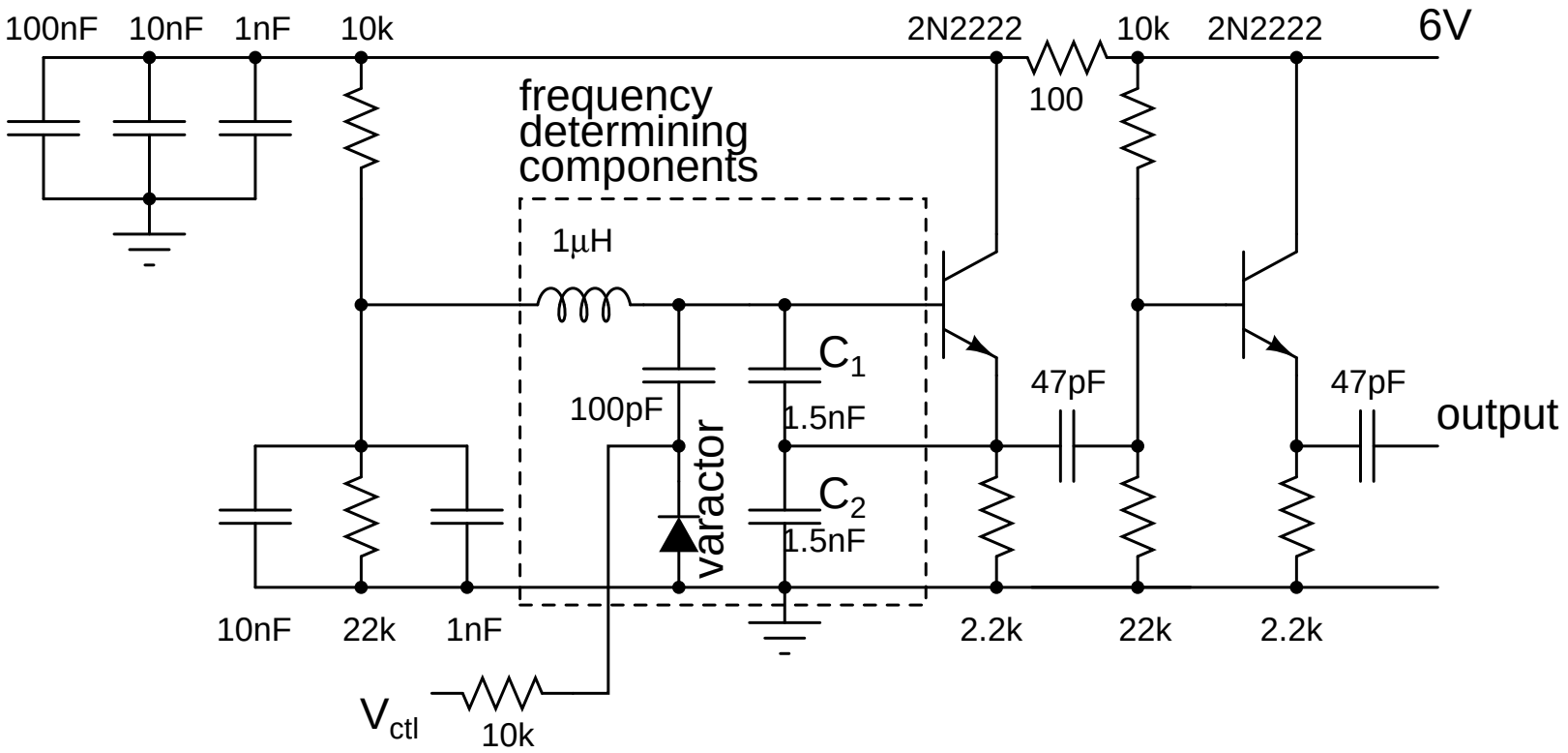
Colpitts oscillator



1μH and 1nF resonate at ~ 5MHz

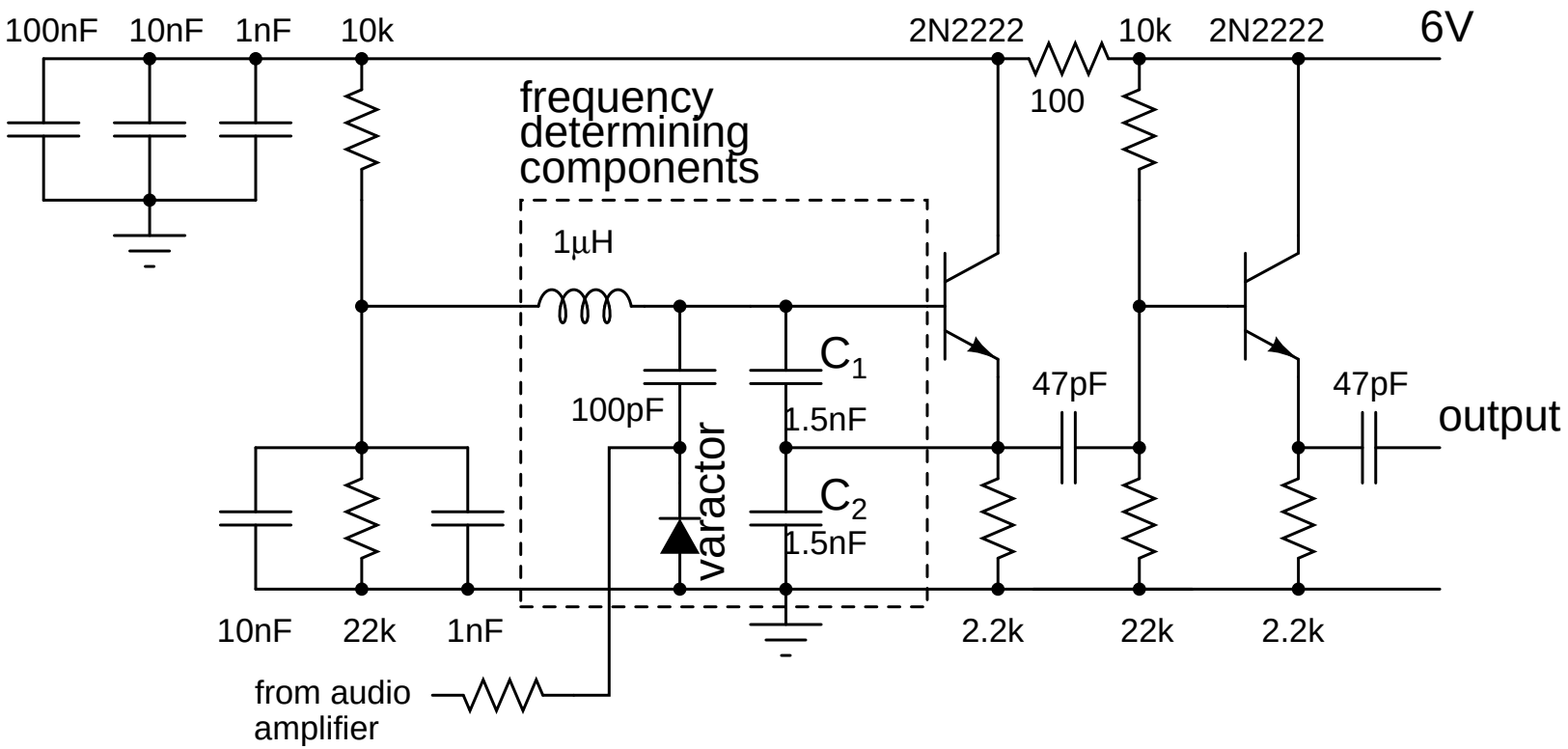
- You can also use an FET (biasing circuit will be different)
- C_1/C_2 influences output amplitude
- Take the output from the emitter to reduce loading on the oscillator
- Additional buffer stage to increase oscillator stability (Amateur radio use)

Colpitts voltge controlled oscillator



- Use a varactor for tuning
- MVA2102 varactor for wide range
- General purpose diodes like 1N4148 can be used—lower tuning range

FM transmitter

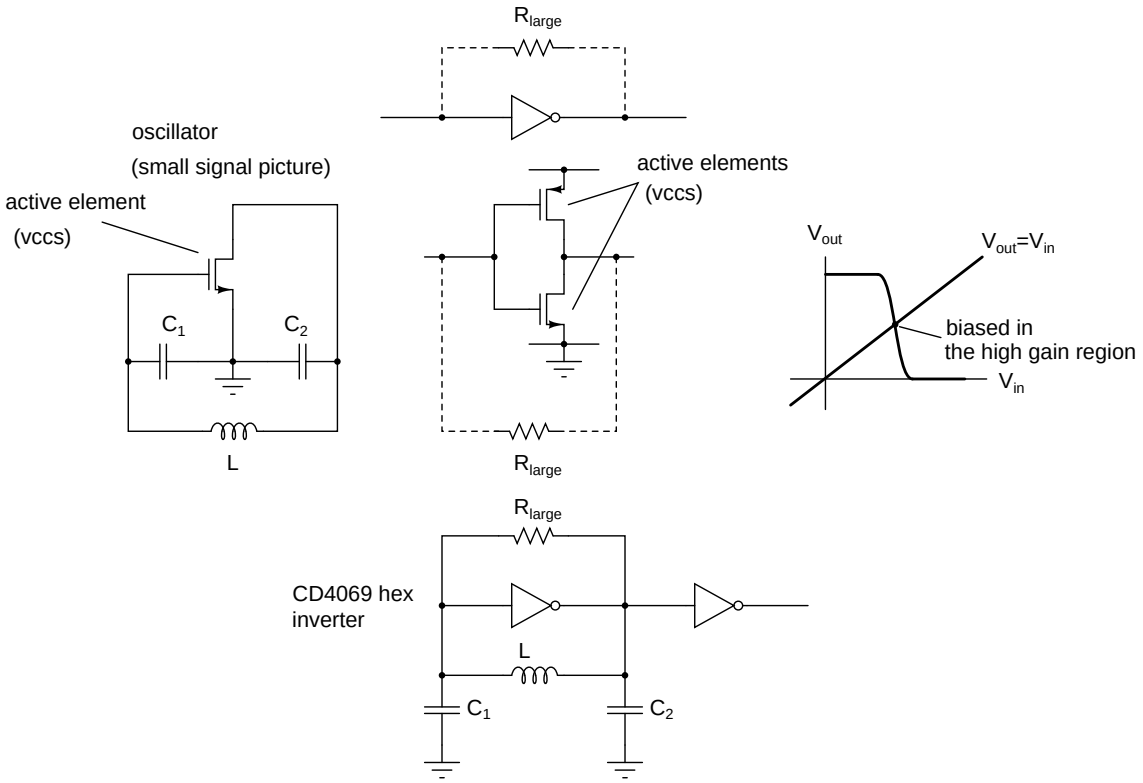


- Drive the varactor with audio
- Audio amplitude and varactor characteristics determine frequency deviation

Making good oscillators

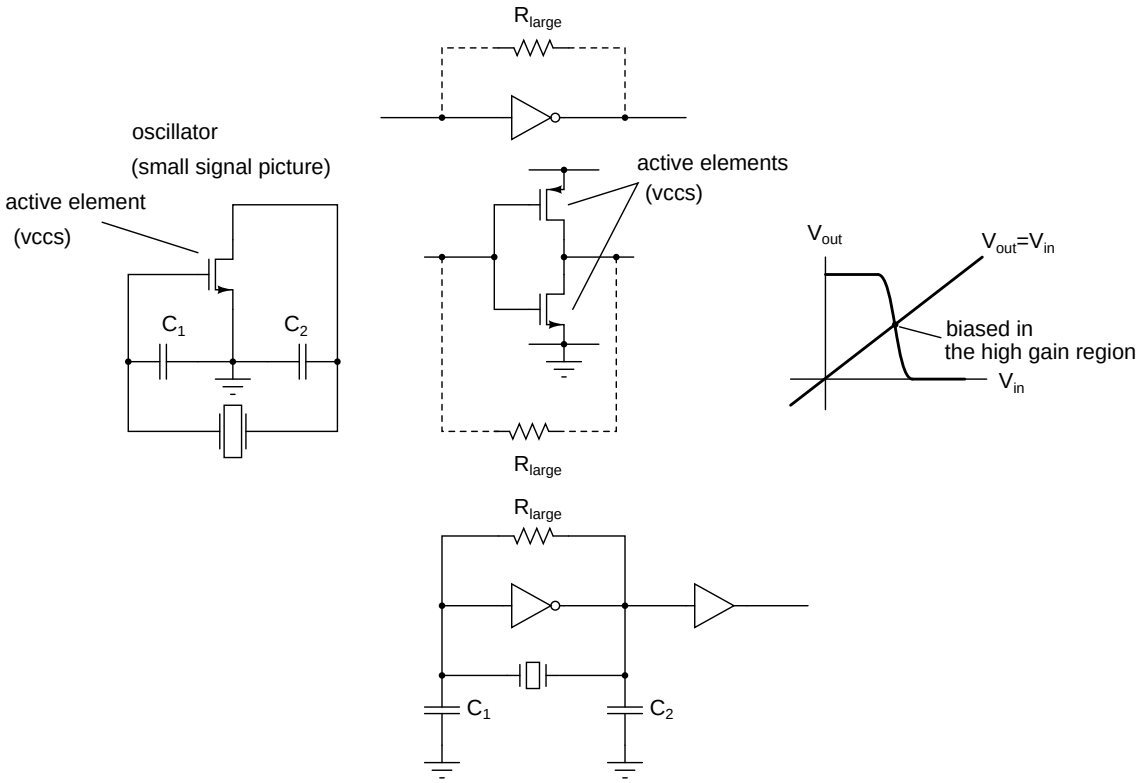
- Mechanical stability very important
  - Pour glue on the inductor to keep the turns from moving
- Light coupling to the load—load changes shouldn't influence the oscillator
- Shielded box—aluminum box or make your own box with copper clad boards and a heavy soldering iron
- Clean power supply—regulated; Battery supply to further reduce noise

Oscillator using inverters



- Inverter biased in the active region works as an amplifier
- Can be used in an oscillator
- CD4069 hex CMOS inverter can be used for this (Only chips that have single stage CMOS inverters can be used in this way)

Crystal oscillator



- Very high stability; Frequency determined by the crystal
- Use the crystal in place of the inductor
- Use small values of $C_1, C_2 \sim 10\,\text{pF}$ to avoid damaging the crystal
- A small variable (trimmer) capacitor in series/parallel with the crystal gives a small variable frequency range

Mixer—MC1496 double balanced modulator

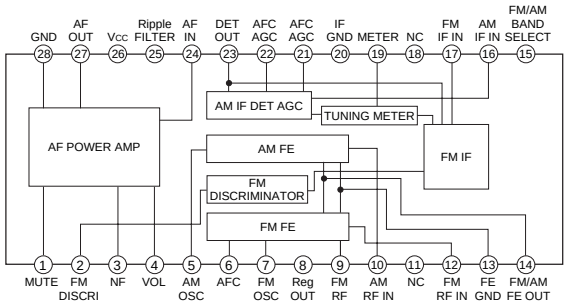
- Works well over the HF band
- Can be used for transmit modulators and receive mixers
- Data sheet has a variety of example circuits
- 40m (7 MHz) transceiver circuit using MC1496 available on the web

CXA1619BM/BS AM/FM radio chip

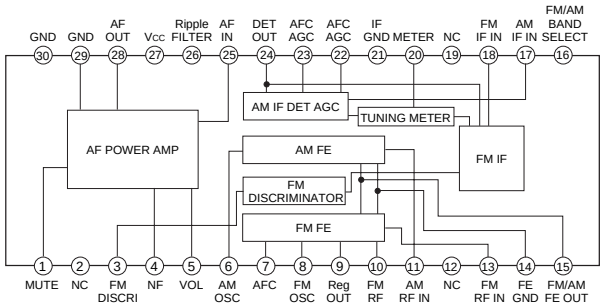
- Apparently common in inexpensive radio sets
- Available in the market
- Has all the blocks required for AM/FM radios including audio amplifiers
- External tuning components: Input tuning, oscillator tuning, IF filter
- BM: SOP package; BS: DIP package; Latter more suitable for homebrewing

Block Diagram

CXA1691BM

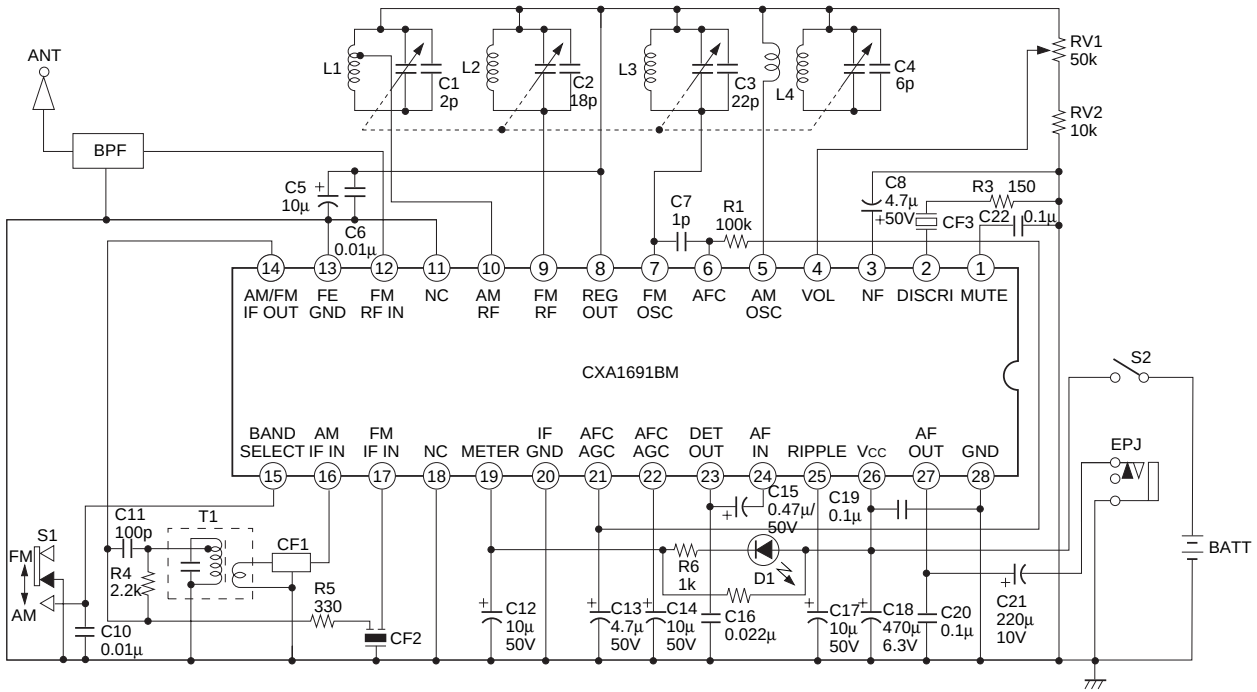


CXA1691BS



CXA1619BM/BS AM/FM radio chip

Application Circuit 1



Application circuits shown are typical examples illustrating the operation of the devices. Sony cannot assume responsibility for any problems arising out of the use of these circuits or for any infringement of third party patent and other right due to same.

FM receiver using CXA1619BM

- Connect FM oscillator, Antenna tuning circuits
- Connect FM IF ceramic filter
- Connect FM ceramic discriminator
- Complete Automatic frequency control (AFC) loop
- Connect detector output to audio amplifier

Assembly tips

- Start assembling backwards from the audio amp
- Verify each stage as much as possible before going on to the next one
- Audio oscillator to test audio amplifiers—NE555 timer oscillator
- Signal generator and oscilloscope aid debugging; but can be assembled even without them

Uses for the CXA1619BM

- Oscillator (AM band, FM band)
- Audio amplifier
- IF amplifier and detector
- RF amplifier (AM band, FM band)

Hacking a cheap broadcast radio—Kchibo KK-939B

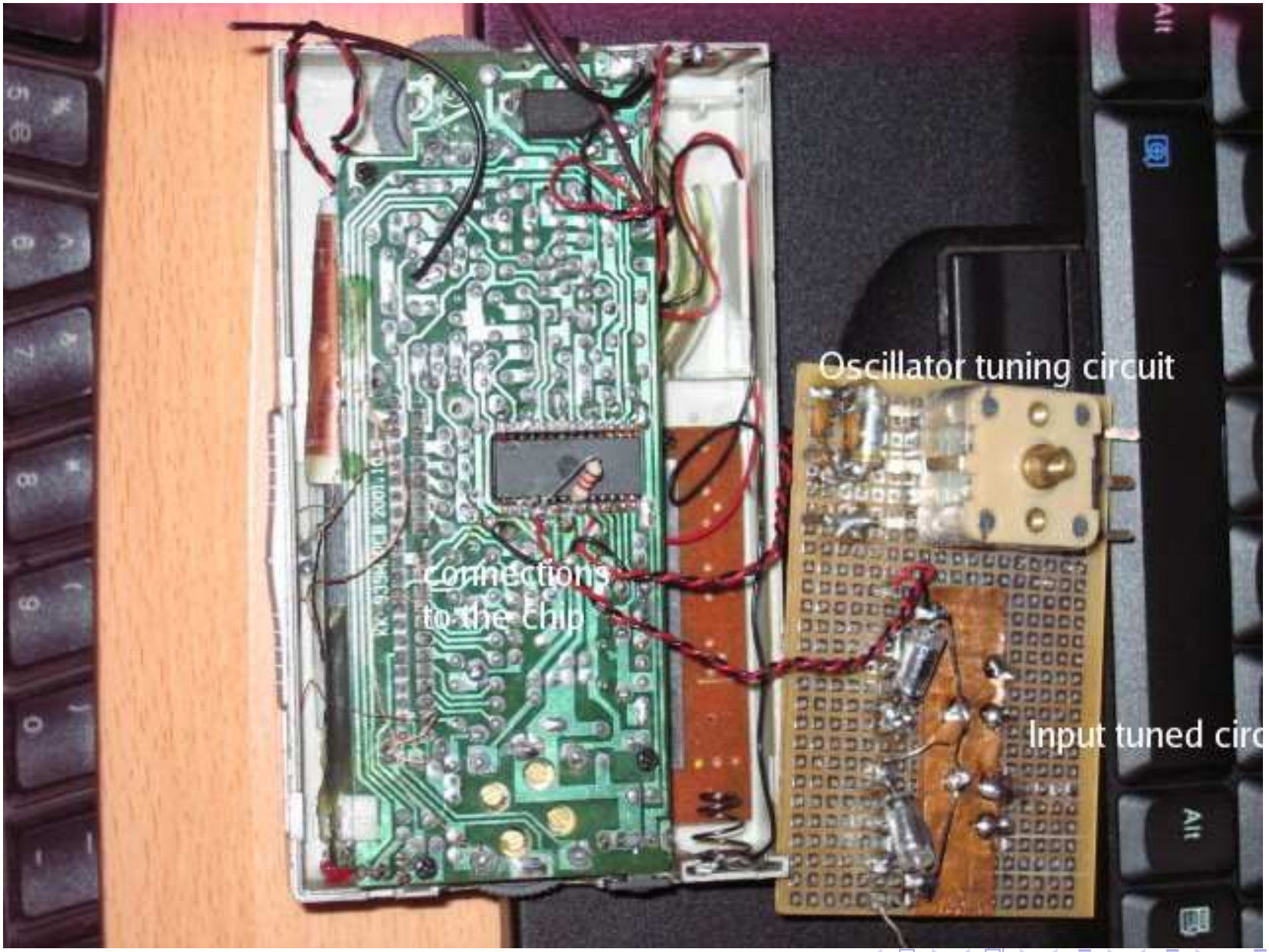
- 10 band radio—FM, MW, eight SW bands
- Radio based on CXA 1691BM
- Digital frequency meter
- Reads oscillator frequency (pin 5 for AM, pin 7 for FM) and gives a readout of $f_{LO} - 455\,\text{kHz}$ for AM and $f_{LO} - 10.7\,\text{MHz}$ for FM

Kchibo KK-939B-Modifying it for 40m (7MHz) amateur band

- Oscillator
  - Open circuit the jumper from AM oscillator pin (pin 5)
  - Connect a parallel LC tank between pin 5 and pin 8
- Input filter
  - Open circuit the jumper from AM RF pin (pin 10)
  - Provide a 10k bias resistor between pin 10 and pin 8
  - Connect the input RF filter to pin 10
- Frequency meter
  - Connect the am frequency meter to pin 5 through a 10 pF capacitor
- Need to add a beat frequency oscillator for SSB reception

Bradcast radio modified for 40m amateur band

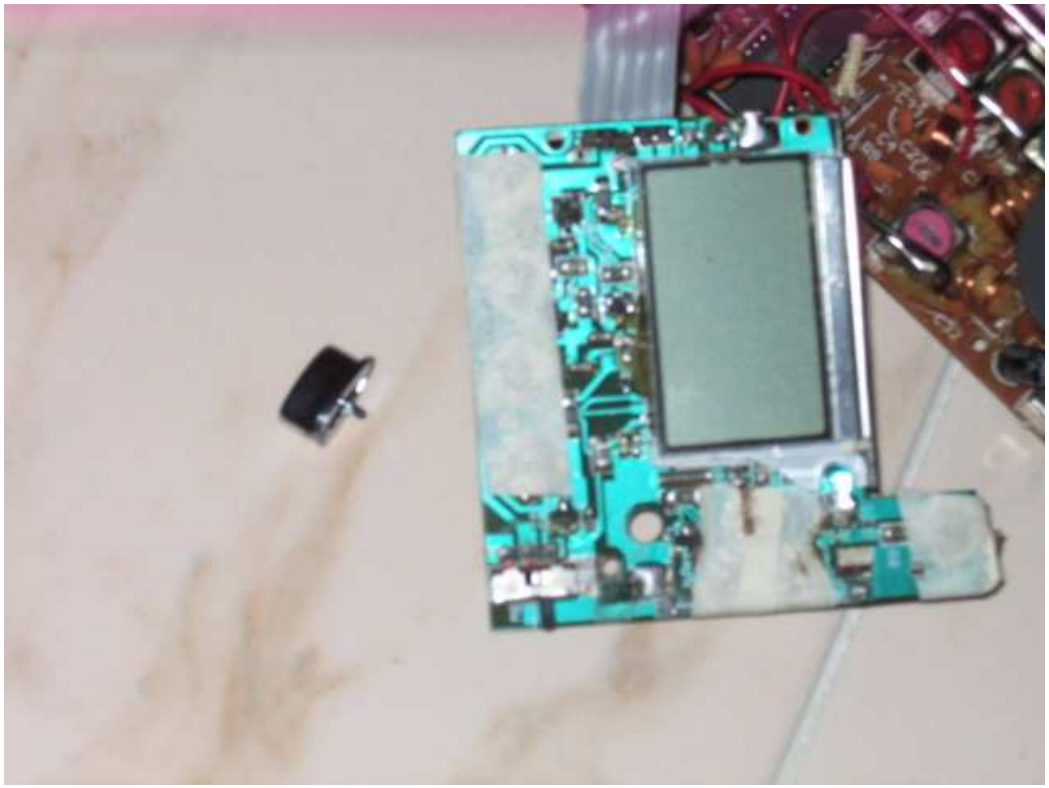
Connections to AM RF and Oscillator pins



Hacking a cheap broadcast radio—Kchibo KK-939B

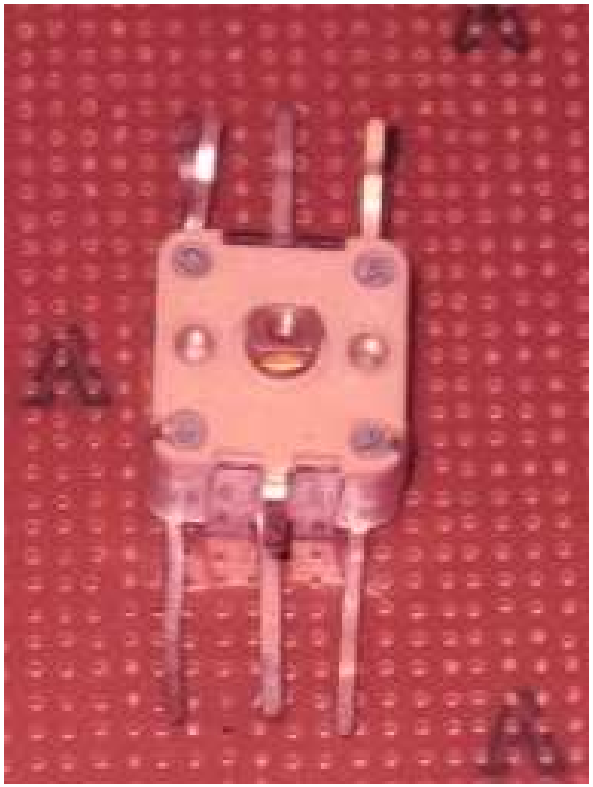
- Top board: Oscillator LC; Input tuning circuit

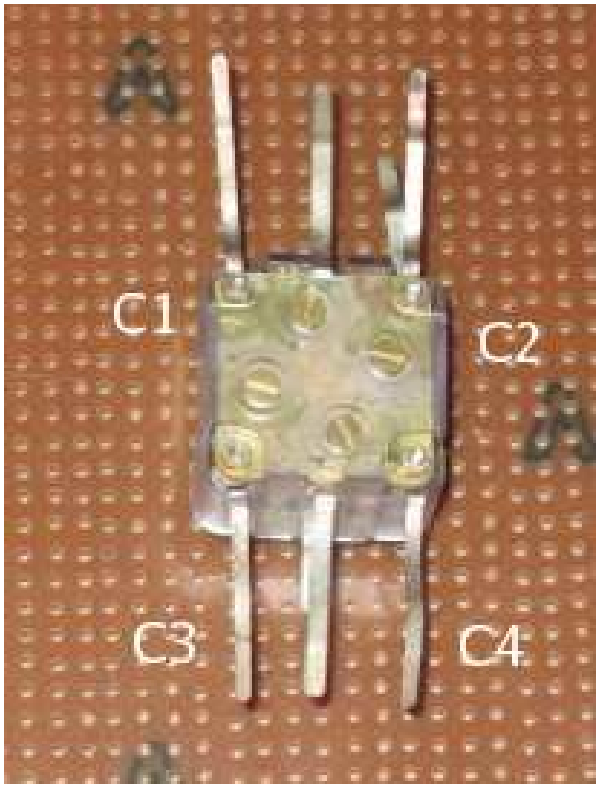
Kchibo KK-939B—Frequency meter

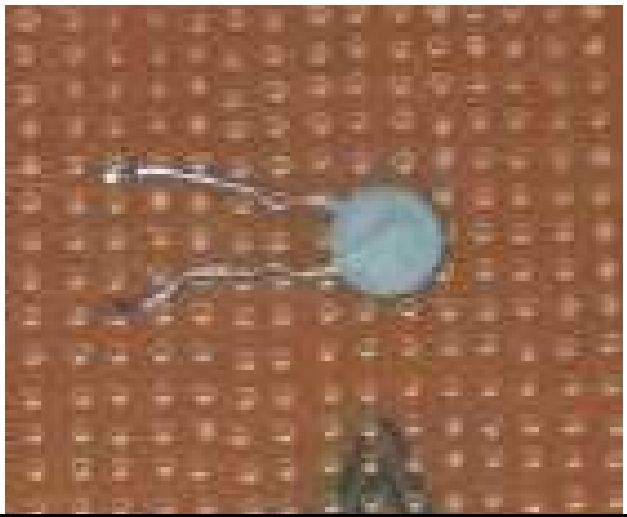


- Red and black wires connecting to the oscillator
- Red: AM, Black: FM
- Couple signals through a small (10pF) capacitor to measure their frequency

Variable capacitors; Capacitors for oscillators







Hacking a cheap broadcast radio—Results

- A receiver that covers 40m (7MHz) amateur radio band
- A frequency meter with 0.5 to 100+ MHz range; 4 significant digits

Suggestions for projects-beginner

- Passive AM radio
- TRF AM radio
- Superheterodyne AM radio using an AM receiver chip
- Broadcast FM radio using an FM receiver chip
- Low power AM transmitter (oscillator, MC1496 modulator)
- Low power FM transmitter (oscillator, varactor to get FM)
- Short range wireless digital data link (AM transmitter with digital data; peak detector receiver)

Suggestions for projects-advanced

- TRF AM radio using only CMOS inverters
- Superheterodyne AM radio using transistors
- Broadcast FM radio using transistors
- Software defined radio (Front end filter, amplifier, mixer to IF, A/D converter)
- Antenna for your mobile—get coverage where you don't have it (2 GHz wavelength $=$ 15 cm; Antenna $\sim$ few cm long)

Ham radio projects-beginner

- Beat Frequency oscillator
- Variable frequency oscillator
- Convert broadcast radio to ham bands
- 40m (7MHz) direct conversion receiver (Oscillator, MC1496 mixer)

Ham radio projects-advanced

- 40m (7MHz) superhet receiver (oscillator, MC1496 mixer, crystal filter)
- 40m (7MHz) transmitter/transceiver
- Receivers/transceivers for other HF bands
- VHF receiver using CXA1619BM
- Frequency synthesizer
- Packet radio receiver

Measurement/support equipment

- Power supplies
- Frequency meters
- RF power meters
- PC based Oscilloscope
- Audio amplifier
- Signal generators

Once you are into the hobby, you can build up a collection of general purpose projects which also help in testing other projects

References: The internet

- Circuit schematics
- Data sheets
- Troubleshooting information
- `http://www.flashwebhost.com/circuit/index.php`
- `http://www.juliantrubin.com/fairprojects/electronics/radio.html`
- `http://my.integritynet.com.au/purdic/`

References: American Radio Relay League (ARRL)

- 0.6 million radio amateurs in the US—a lot of homebrewing activity
- `http://www.arrl.org/`
- ARRL Handbook: Great source of information on communications and building radios
  - Latest editions: Circuits using latest ICs, digital radio etc.
  - 1980s editions: Lots of transistor level circuits
- Wes Hayward and Doug Demaw, *Solid State Design for the Radio Amateur*—A great source on high quality radio building
- *Experimental methods in RF design*

References: *The Electronics of Radio*

- David Rutledge, *The Electronics of Radio*, Cambridge University Press, 1999
- Good combination of theory and practice
- Complete schematic and construction methods for a 40m (7MHz) transceiver

References—Radio, crystal oscillator, inverter amplifiers

- http://www.ee.iitm.ac.in/ nagendra/E4332/2005/courseinfo.html
  - E4332: VLSI design laboratory
  - Design of an AM radio and a digital clock on an integrated circuit
- http://www.ee.iitm.ac.in/ nagendra/E4332/2005/handouts/amradio-trf.pdf
  - AM radio on a chip
  - Theory of Tuned frequency radios
  - Receiver block and schematic diagrams (more suitable for IC designs)
- http://www.ee.iitm.ac.in/ nagendra/E4332/2005/handouts/digital-clock.pdf
  - Has information on crystal oscillators
- http://www.ee.iitm.ac.in/vlsi/courses/ec330/start
  - Many experiments using CMOS inverters as amplifiers

Conclusions

- Tinkering with radios is a lot of fun
- You can build radios from scratch or modify existing ones for your use
- Amateur radio is a great way to get into building quality radio transmitters and receivers

Happy tinkering!