Advanced Course Ch.8 Receivers

de VE1FA

"If you can't hear the station, you can't work it…"

Marconi 16 crystal receiver 1914

Kenwood TS-890 transceiver 2019

What a receiver must do:

1. Signal capture →

2. Selection →

3. Amplification →

4. Detection (signal processing to recover information) →

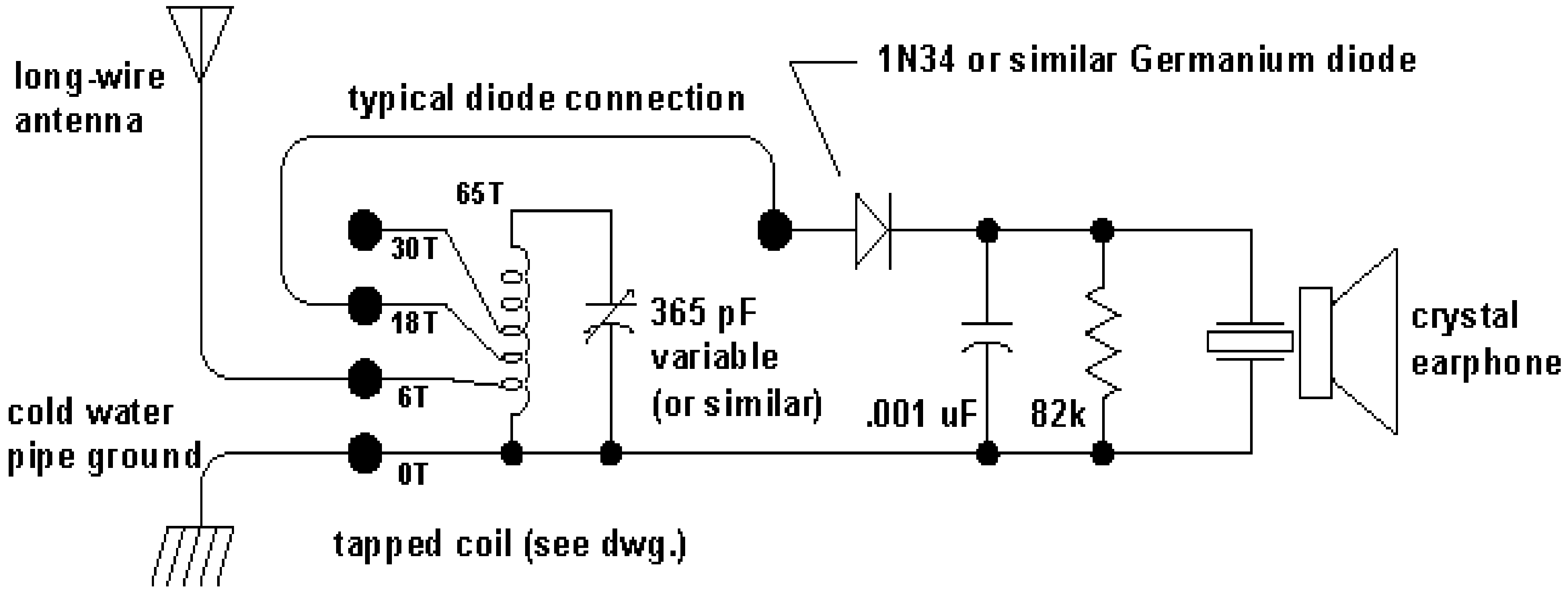
5. Amplification →

6. Present information in human-understandable form →

Key Properties of Receivers

- **Sensitivity**: minimum detectable signal (uV or dbm) (S/S+N ratio)
- **Selectivity**: ability to separate two close signals + reject out-of bandpass signals
- **Stability**: ability to stay on frequency (absence of drift)
- **Frequency precision**: to how many places can the received frequency be measured?
- **Frequency accuracy**: how close to the true frequency is your receiver's display?
- **Resettability**: ability to return to a frequency
- **Interference reducing features**: filters, DSP, noise blanker, noise limiter, notch filter, RF preselector
- **Dynamic range**: range of signal strength through which Rx operates properly and with little distortion of signal

1900-1920s Crystal Radio



Powered by the transmitter! (no ampifiers)!

Crystal radio with typical connections for a long wire antenna and good ground connections. The diode is connected for weak signals and moderate selectivity.

Despite what your T-book says, this is <u>NOT</u> what is called a TRF radio!

Regenerative receivers (1920s)

--simple circuits using active device(s)

--high sensitivity

--high selectivity (for weaker signals)

--cheap + easy to build!

--poor stability

--poor immunity to overload

--mediocre resettability + logging

--best performance requires careful design

Basic 1-tube regenerative receiver

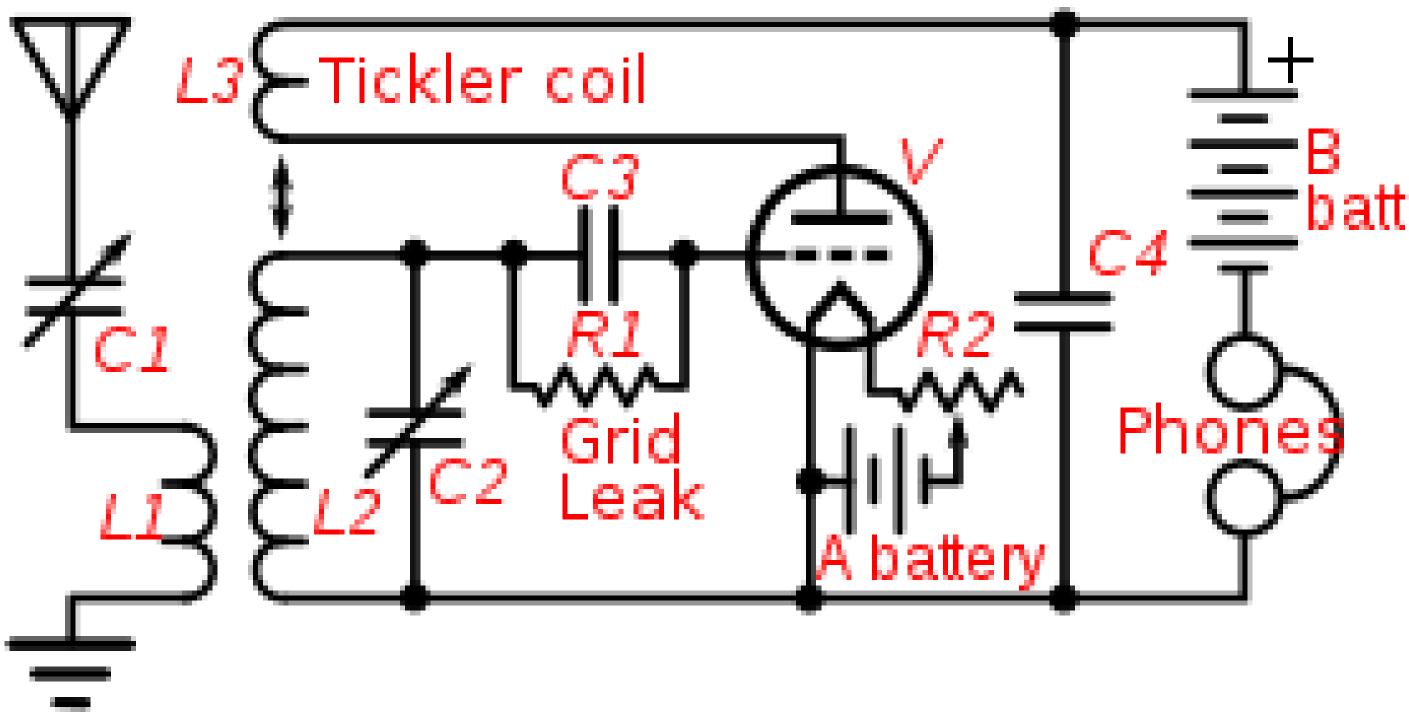
Regeneration allows:

-very high gain (close to oscillation point)

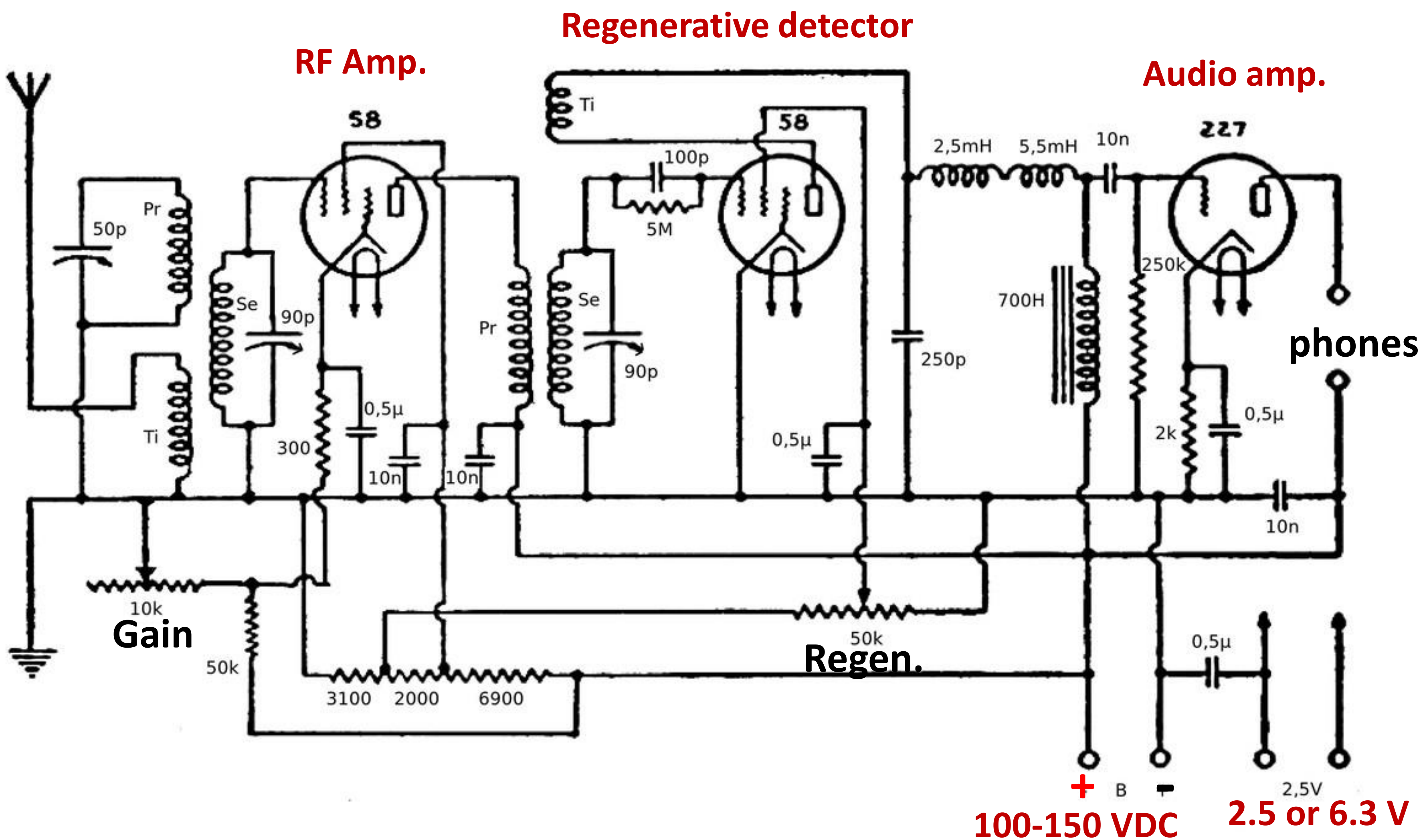
-very high coil Q → good selectivity

-poor stability

-transmitting with your receiver...not good!

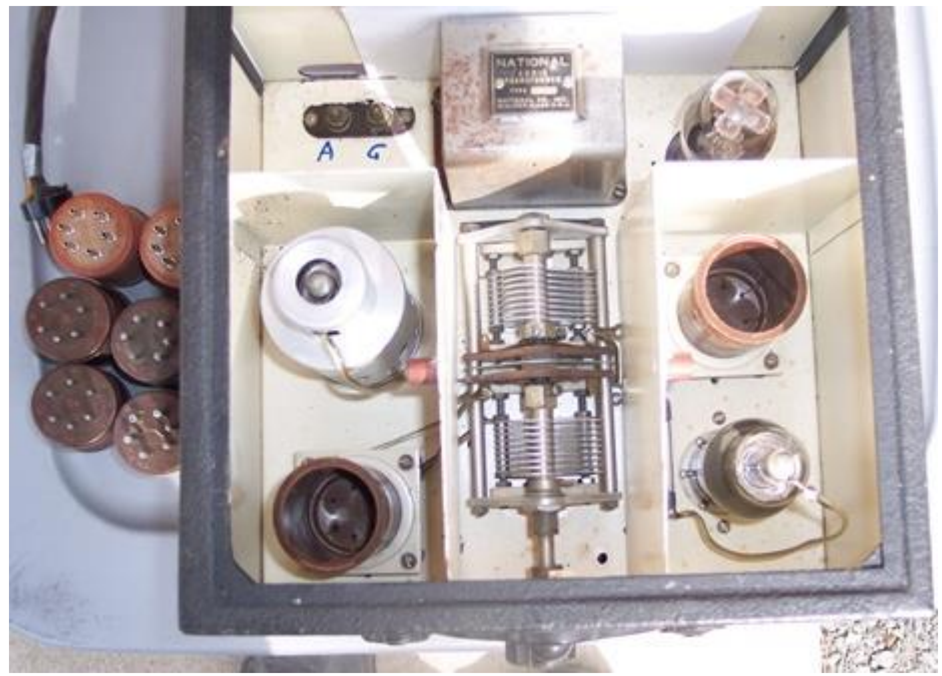


National SW-3 Regenerative Amateur Receiver
(100 kHz to 30 MHz (with all 10 coil sets!)

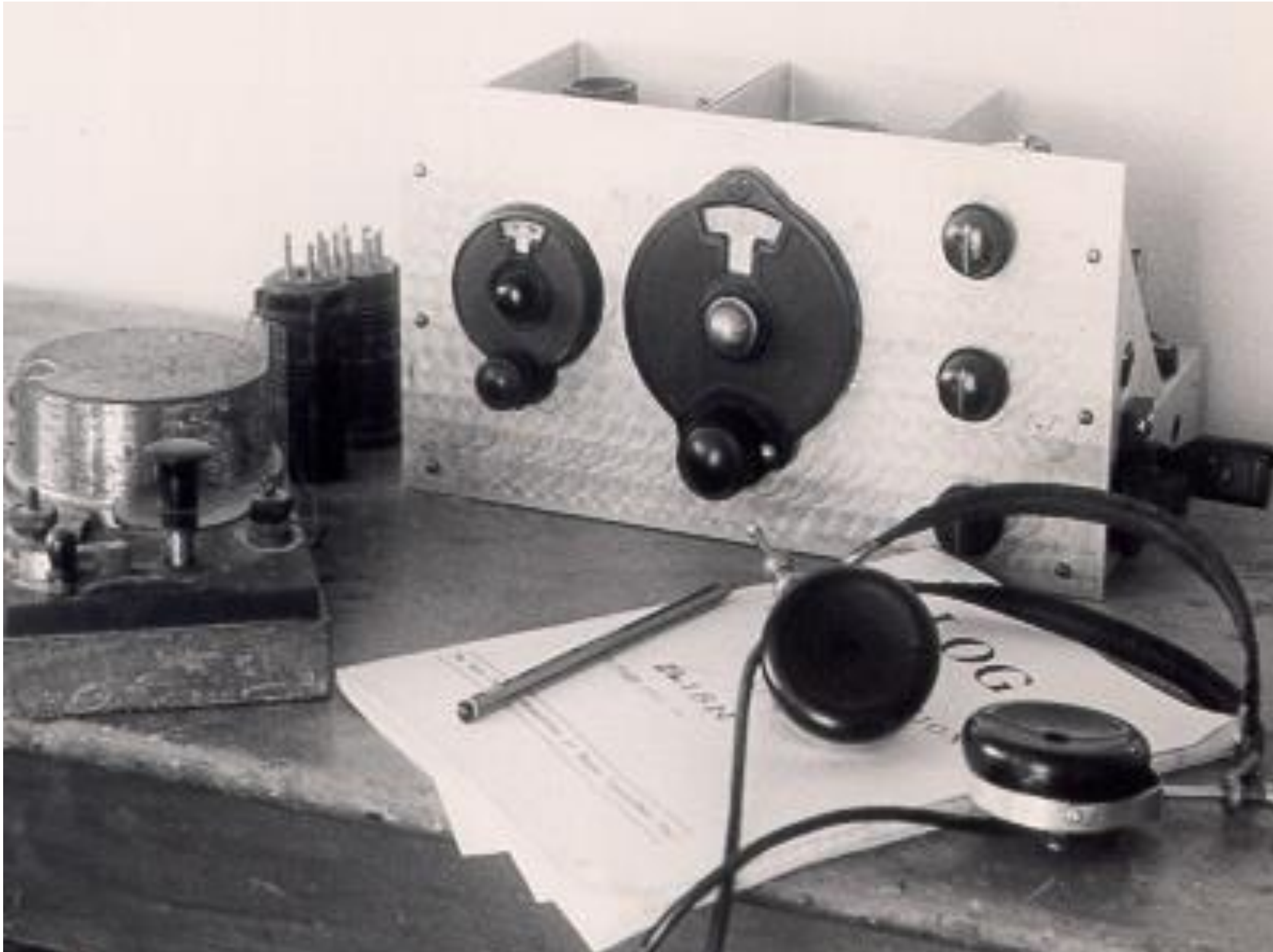


National SW-3 Regenerative receiver

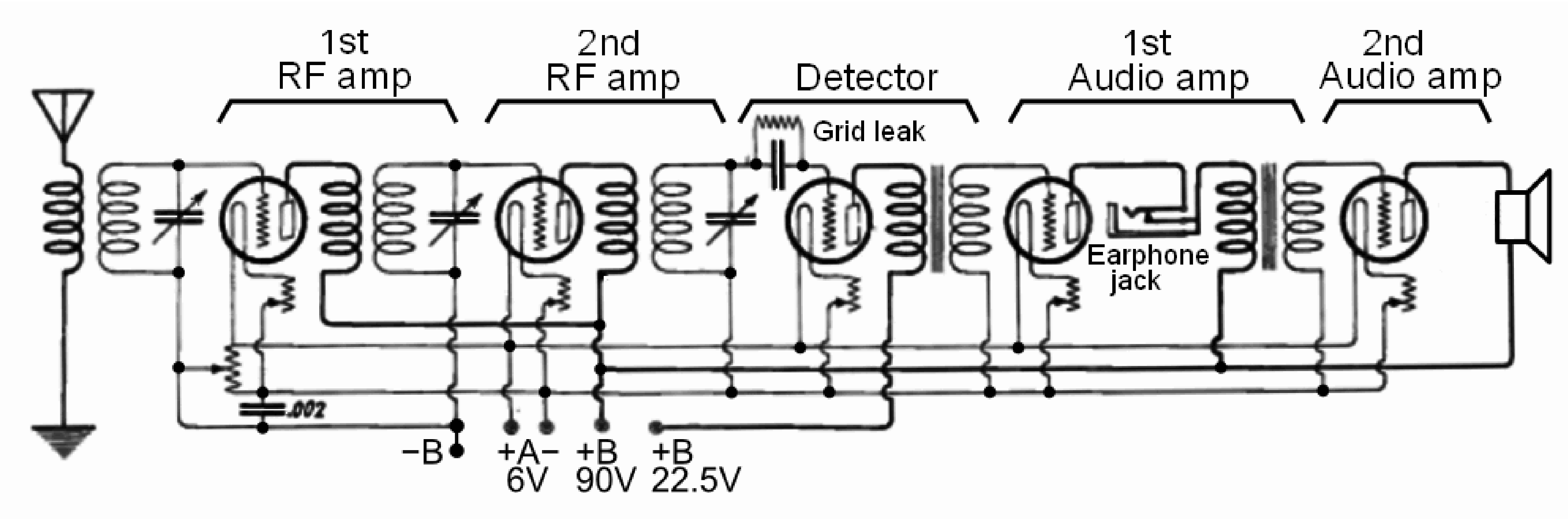
-cheap, high sensitivity, thousands sold in 1930s (Depression)
-widely copied in home-brew ham receivers in 1930s



1932 Home-brew 3-tube regenerative receiver by ZL1BN (capable of trans-Pacific CW DX!)



Tuned Radio Frequency (TRF) Receiver (1920s)



-commonest type of AM broadcast receiver in the 1920s

-poor selectivity and sensitivity on HF frequencies

-pre-1930s low-gain triodes almost useless above 2 MHz (2 Mc)

1920s: the Tuned Radio Frequency (TRF) Receiver or "three-dialer"

-RFamp=>RFamp=>Det => AFamp=>AFamp => output

-better AM, easier to use than regenerative

- amplifier gain very low at higher frequencies

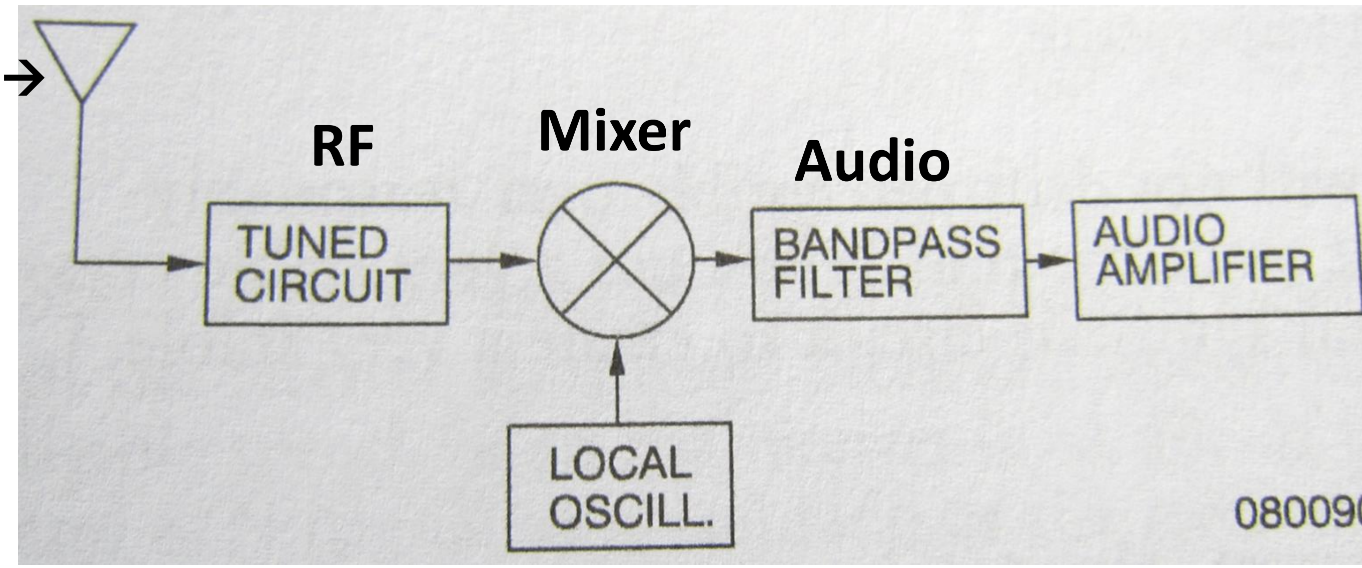
-on HF, bandpass much too wide

-stability problems on HF

Synchrodyne = Direct conversion = Homodyne = Zero IF receiver

- -mixes and downconverts to audio, <u>but no IF stages</u>
- -widely used in lightweight portable low-power “QRP” radios
- -can be very simple, sensitive, stable

SIGNAL →



→ OUTPUT

Signal =7030 <u>OR</u> 7029 →
LO= 7029.5 → MIXER → audio filter → audio amp. → 500 Hz

Signal=7030 →
LO=7029.5 <u>OR</u> 7030.5 → MIXER → audio filter → audio amp. → 500 Hz

Every signal received at 2 points on the dial!

"QRP-type" synchrodyne/direct conversion RX

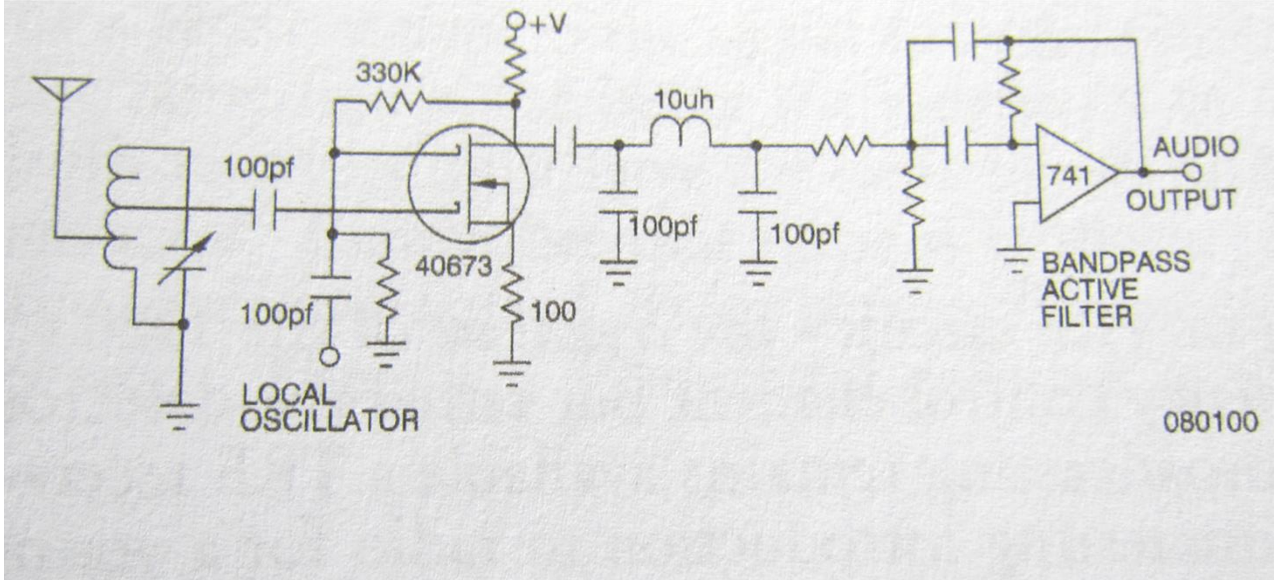


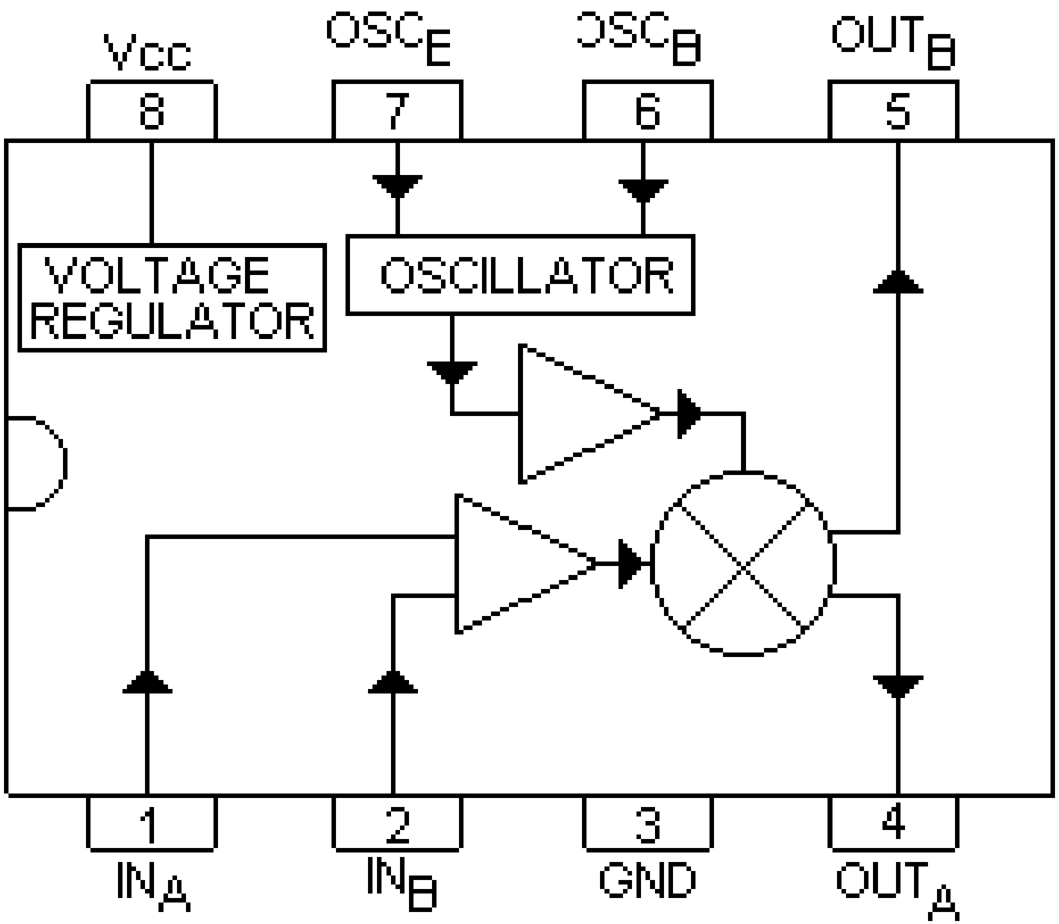
Fig 8-6

- -local oscillator tuned to carrier frequency of incoming signal
- -dual-gate MOSFET mixer
- -mixer produces oscillator output +/- the <u>audio</u> frequency of the signal
- -pi filter rejects RF, passes AF
- -LM-741 circuit selectively amplifies desired audio frequency range

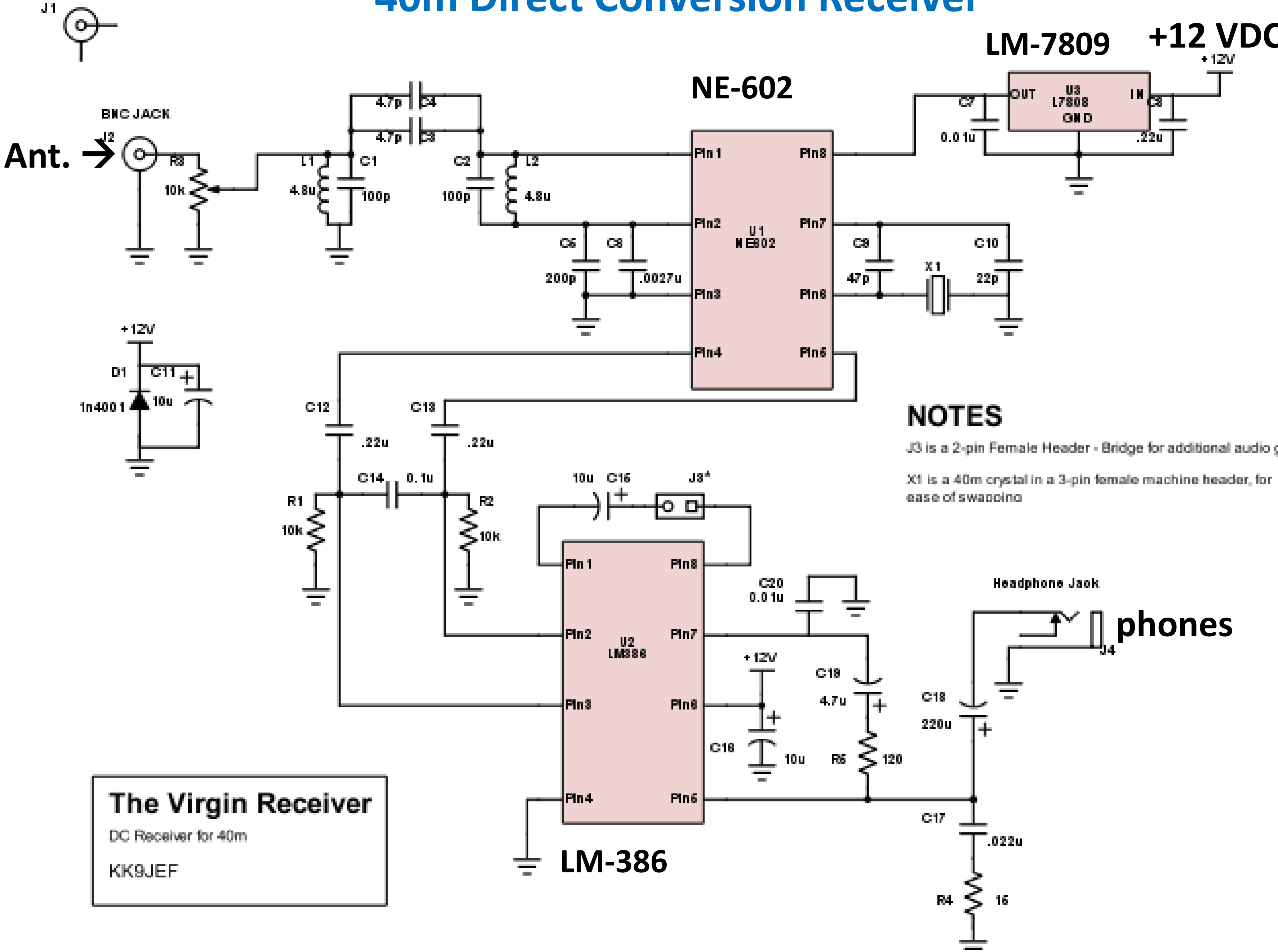
<u>Problems</u>: (1) <u>images</u>! (2) unprotected signal gate; (3)no GND ref.!
(4) low audio out!

NE602 : double-balanced mixer, oscillator and voltage regulator

Cheap, fully balanced, works up into VHF range



40m Direct Conversion Receiver



NOTES

J3 is a 2-pin Female Header - Bridge for additional audio gain

X1 is a 40m crystal in a 3-pin female machine header, for ease of swapping

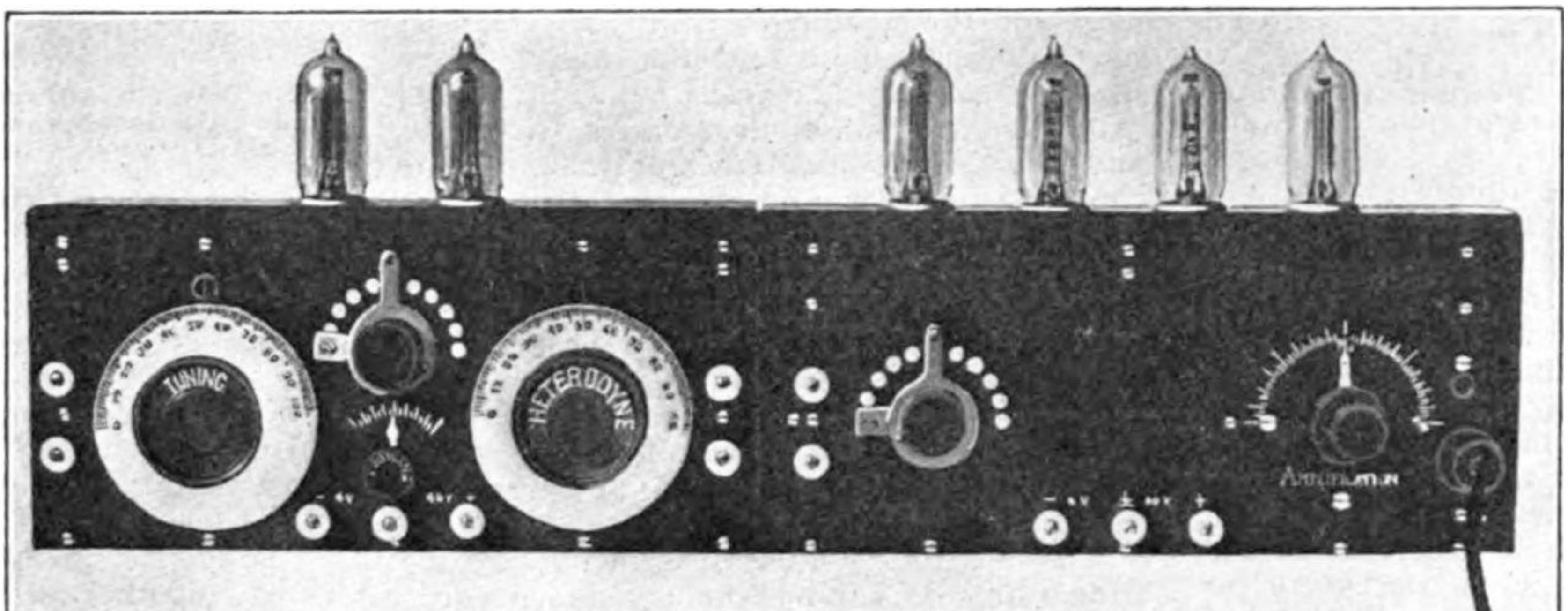
Direct conversion single band QRP CW transceiver

The Superheterodyne Receiver

Mixing ("heterodyning") two frequencies together to get a useful difference frequency suggested by R. Fessenden in 1905

Superheterodyne RX invented by E.H. Armstrong in US Army lab in Paris in 1917. Came into use in consumer AM 540-1500 kHz reception about 1930.

Came into use in HF communications after 5 "What's Wrong With Our Receivers" articles in QST by C. Lamb in 1931-32.



E.H. Armstrong prototype receiver (1917) IF = 75 kHz

RCA AR-88 (1940) -probably the best HF receiver in WW2

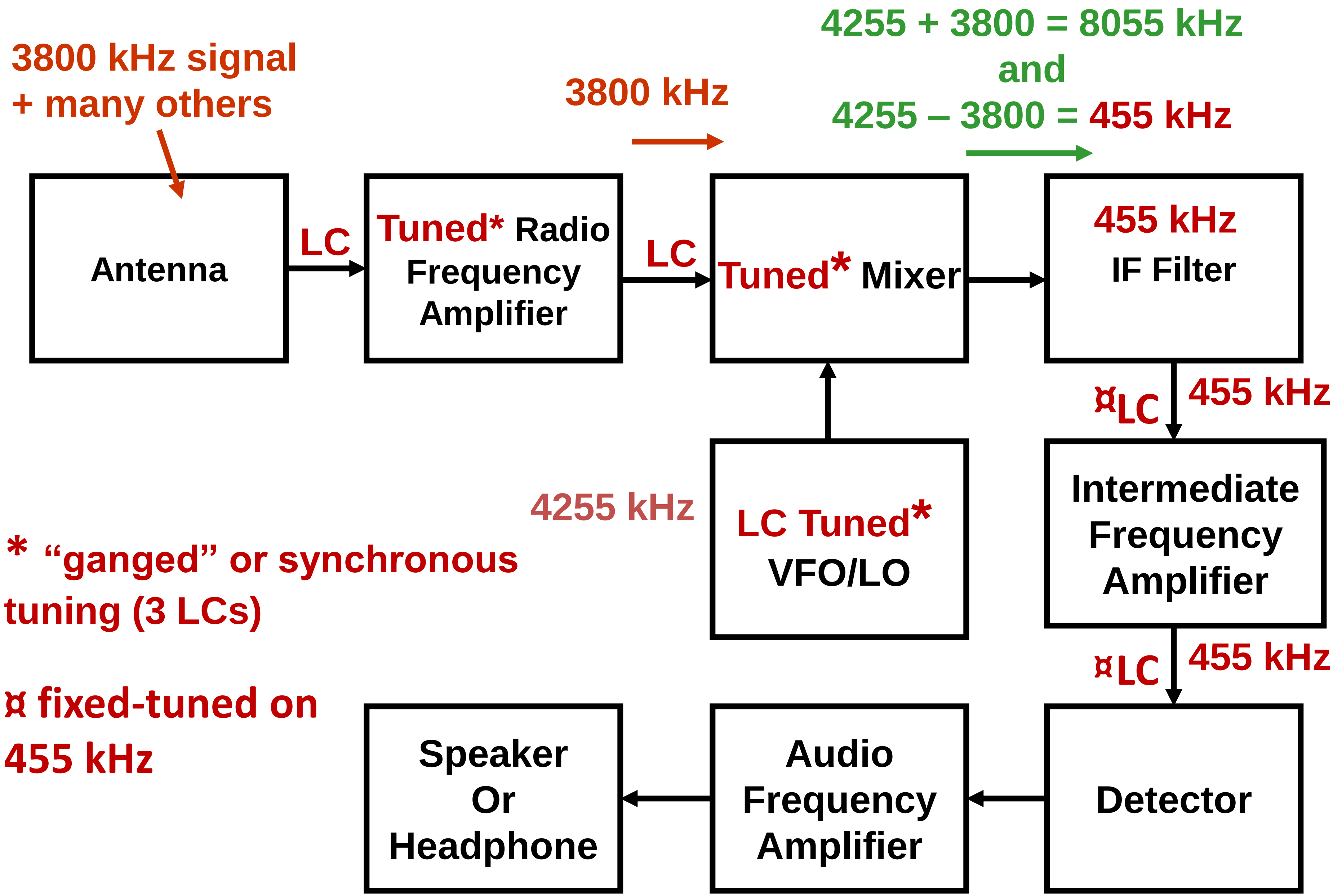
-single conversion, Xtal filter, high selectivity, noise limiter

-100+ lbs!, 100/240 V, 50-60 Hz, 0.54-32 MHz range

-lend-lease to Russia

-huge advance over any non-superheterodyne receiver

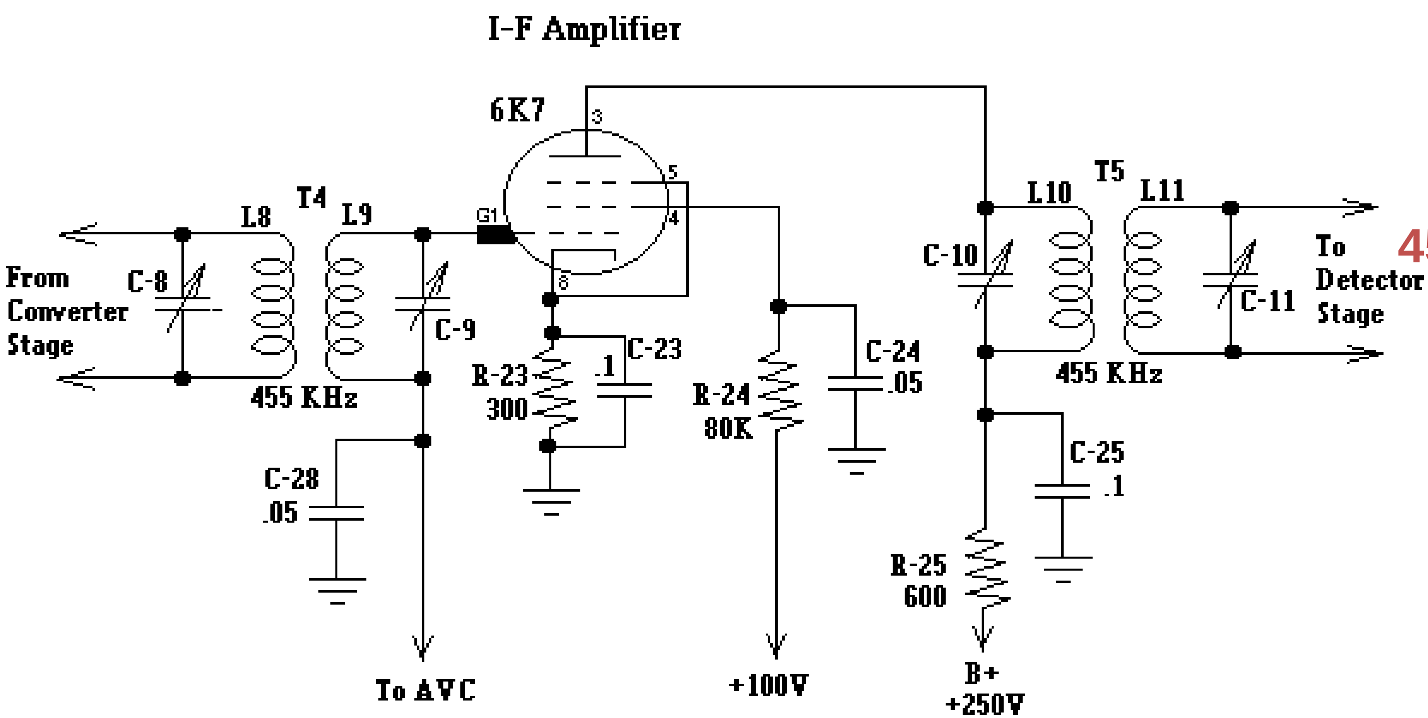
Single conversion 80m AM superhet



Advantages of a constant, low intermediate frequency (IF)

- 1. Optimized amplifier design.
- 2. Narrow bandpass (good selectivity with fixed LC, crystal and mechanical filters).
- 3. Stable, high gain amplifiers easy.

455 kHz=>



455kHz=>

Superhet Characteristics

-Stability of RX depends on the local oscillator(s).

-Gain mostly produced in the IF amplifiers (optimized for 1 frequency)

-Selectivity: fixed IF allows selective crystal, mechanical, and DSP filters.

-Internal noise depends on “front end” (RF and first mixer stages).

-Image problems: minimized by good IF design + multiple IF frequencies (dual or triple conversion).

-Tracking problems: removed by broadband front end tuning + digital display.

-Newer superhets: (1) diode switching of circuits; (2) optical encoding tuning; and (3) broadband front end filters.

Superheterodyne + SDR (software defined radio) are THE types of RX commonly used today.

Modern superhets have a lot of digital circuits controlled via software and firmware.

Modern SDRs depend on superhet-like local oscillators and frequency mixing.

Main advantage of superhet over older RX designs: amplification and bandpass shaping (selectivity) done a low constant frequency where they can be optimized.

Local oscillator (LO)

-may be any design, e.g. Hartley, Colpitts, Clapp, Armstrong, etc
-LO stability determines stability of whole radio
-clean output reduces spurious outputs of mixer
-LO usually stronger than signal entering mixer (by design)
-may be set either <u>above</u> or <u>below</u> signal frequency

Image frequencies

Signal		LO		IF		
1545 kHz	–	2000 kHz	=	455 kHz		
2455 kHz	--	2000 kHz	=	455 kHz	(Image)	1545 is <u>63%</u> of 2455

28.000 kHz	–	27.545 kHz	=	455 kHz	(Image)	27.090 is <u>97%</u> of 28.000
27.090 kHz	–	27.545 kHz	=	455 kHz		

<u>Distant image</u>: <u>well rejected</u>
<u>Close image</u>: <u>poorly rejected</u>

<u>Q</u> and <u>number</u> of tuned circuits in front of mixer also key to making image much weaker than selected frequency

By increasing the IF frequency: difference between correct signal and image increases

Increased signal:image difference → better image rejection

BUT lower IF = better LC, crystal, + mechanical filter selectivity!

Solution: use both high + low IFs! (dual conversion)

Requires 2 mixers
Example: (9.0 MHz and 455 kHz)

Triple conversion: typically
70 MHz→ 8 -12 MHz → 455 kHz

Reduces images even more

9 MHz First IF

Band	Centre Freq	LO	Image
160	1.900	10.900	19.900
80	3.750	5.250*	14.250
		12.750	21.750
40	7.150	16.150	25.150
30	10.130	19.130	28.130
20	14.175	5.175*	3.825
		23.175	32.175
17	18.118	27.118	36.118
15	21.225	12.225	3.225
12	24.940	15.940	6.940
10	28.850	19.850	10.850

Fig 8-8

Birdies- unintended internally-generated signals in a superhet. RX

-all superhets have them

-usually oscillator harmonics, or mixer, PLL, or DDS by-products

-remove the antenna...and the birdies remain unchanged

-reflection of circuit design quality

-the more different IFs, the more different LOs to produce birdies

-designers often add “suck-out” resonant traps to remove birdies

Other superhet problems

<u>Spurious responses</u>: out-of-band signals that end up in the IF bandpass due to mixing with stray internally generated frequencies.

<u>Cross-modulation/Intermodulation:</u> two strong input signals mix in the front end of the radio, resulting in poor or unintelligible signal.

-more common at VHF, where front ends allow a broad band of signals into the mixer.

-putting a big VHF or UHF antenna on a handie-talkie in a city often renders the radio useless, due to the number of nearby strong signals.

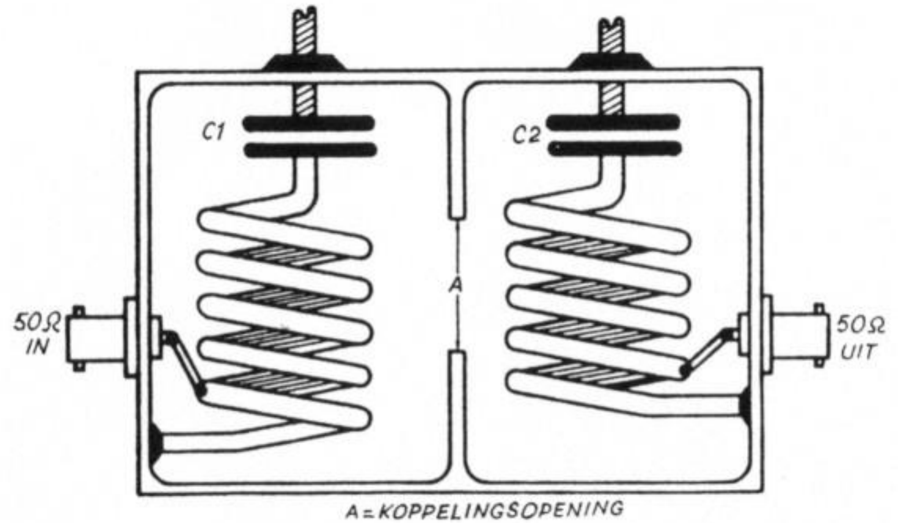
-one reason for “cavities” or ”duplexers” in VHF and UHF repeater systems. These are very high Q resonators.

VHF helical filter

-sharpens (narrows) front-end bandpass

-can have many sections for high selectivity

-coil tap sets Z



VHF+UHF repeater "cavities"

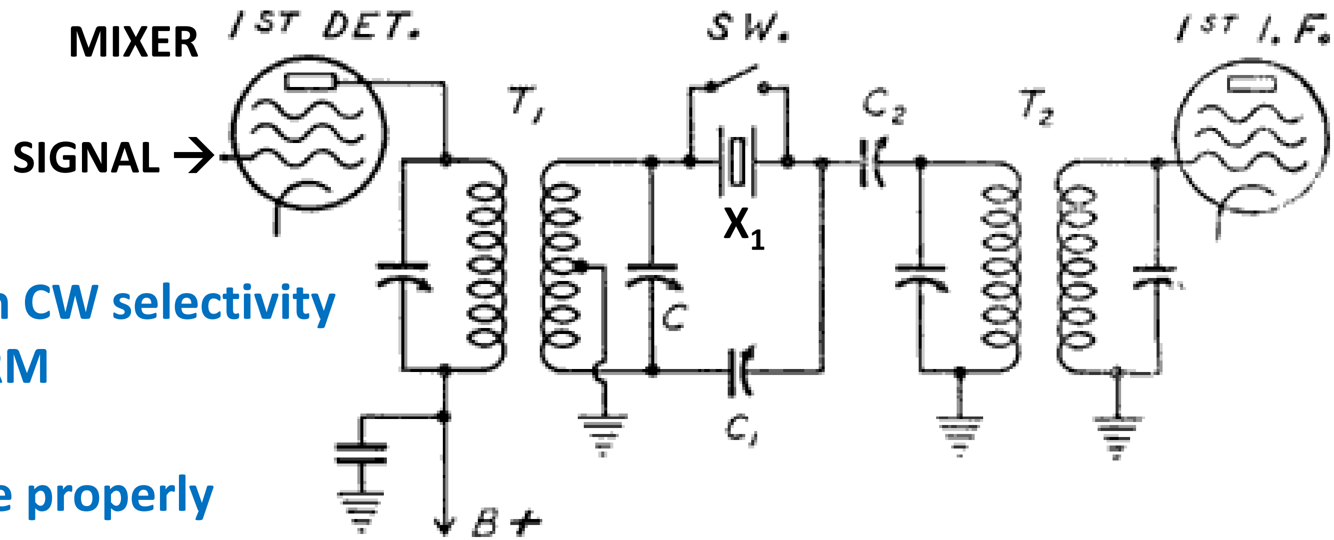
-very high Q resonators

-used on both TX output and RX input

-greatly reduces "intermod"

-prevents TX output from "drowning" RX input, which is just 600 kHz away

Classic Lamb single-crystal IF filter: widely used 1934-1960s



Great improvement in CW selectivity

- -also notches out QRM
- -improves S/N ratio
- -takes practice to use properly

Figure 4—Quartz Crystal Filter Circuit

C_1—Phasing control; 20 mmf.— 30 mmf.
C_2—Coupling control for impedance matching; 50 mmf.

X_1 ---at IF frequency (between 400 and 1000 kHz)

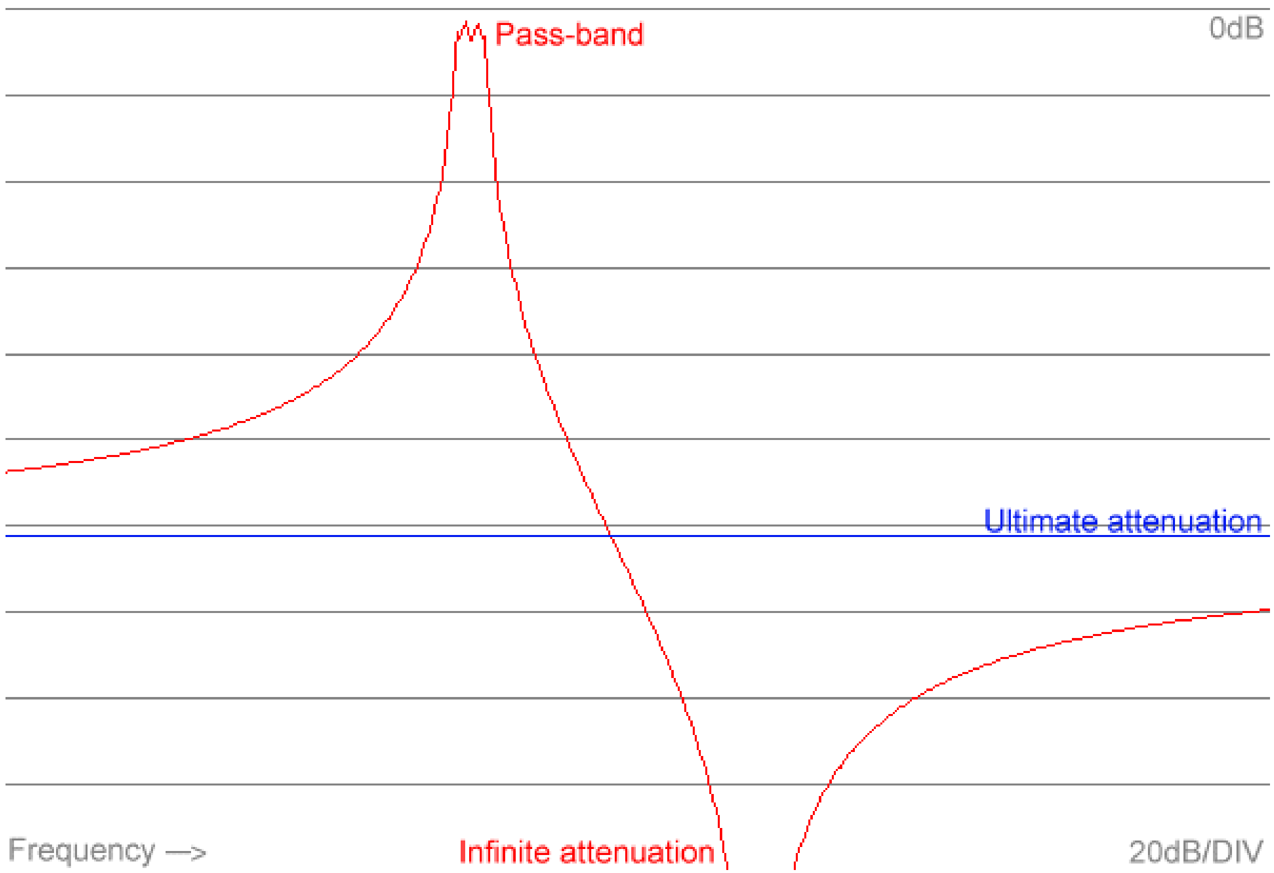
Proper filter tuning: requires: RF gain, tuning, crystal phasing (C_1), and crystal coupling (C_2)

Peak and notch: single-crystal filter in bridge

-peak and notch adjustable with phasing and coupling controls

-peak + notch can be made very sharp

-receiver drift is a problem



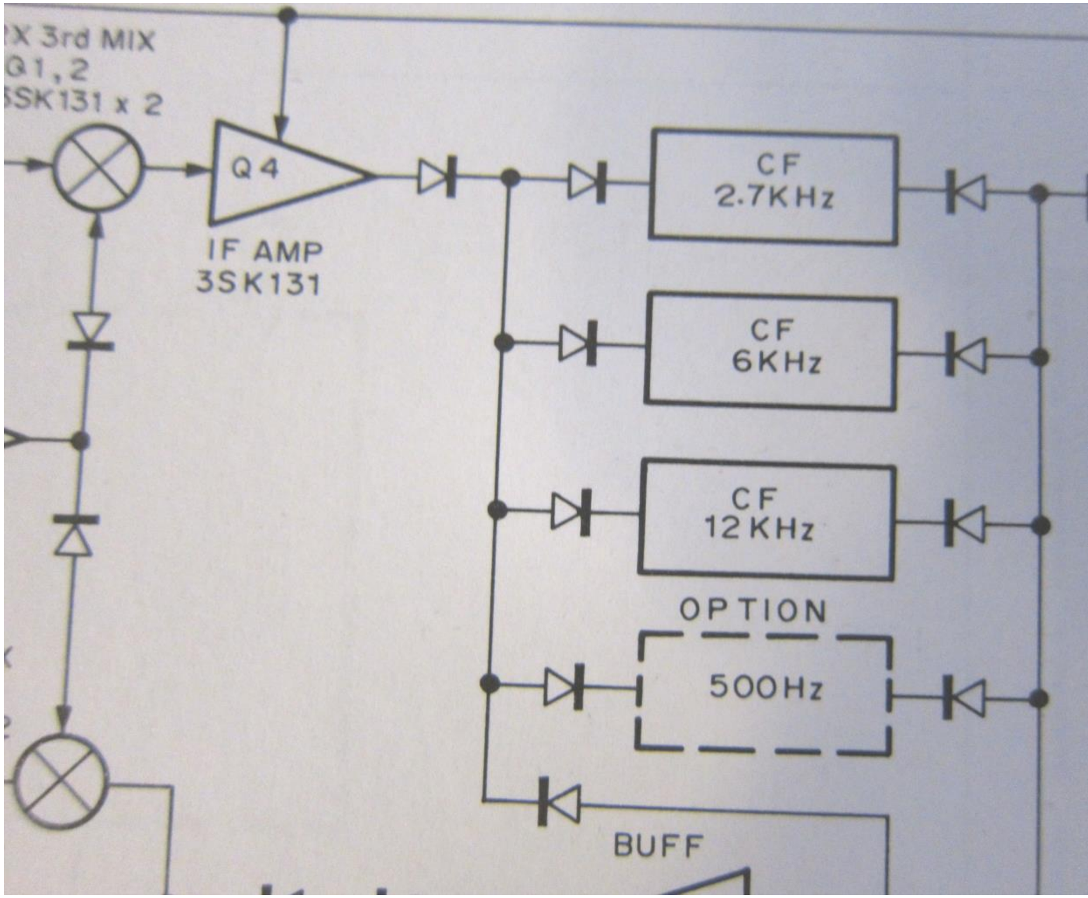
Modern variable selectivity: series of fixed bandpass filters selected/de-selected using "signal steering diodes"

-all on the same IF center frequency

-numbers indicate bandwidth at -6dB points

-ceramic filters, much cheaper than crystal, with slightly reduced performance

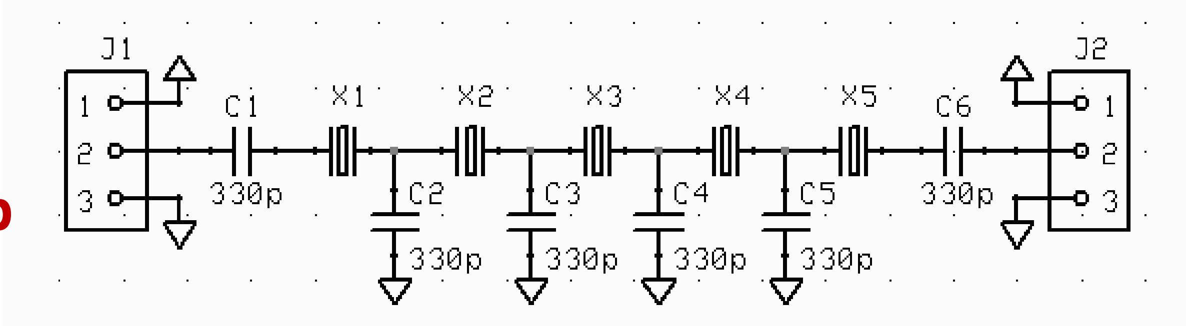
-filters are passive (attenuate the signal about 2-8 dB)

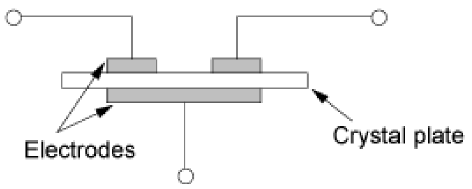


-in dual/triple conversion, filters used at at least 2 IFs, e.g. 9.0 and 0.455 MHz

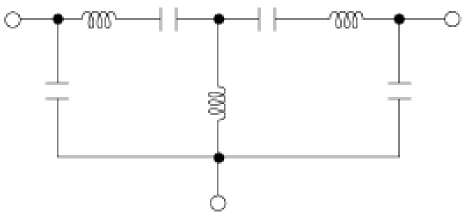
Discrete crystal filter

-build yourself with cheap computer crystals



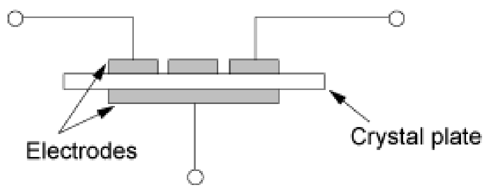


2-pole MCF basic structure

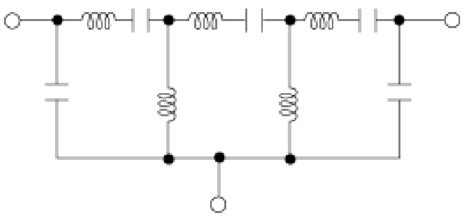


Equivalent circuit

MCF = monolithic crystal filter

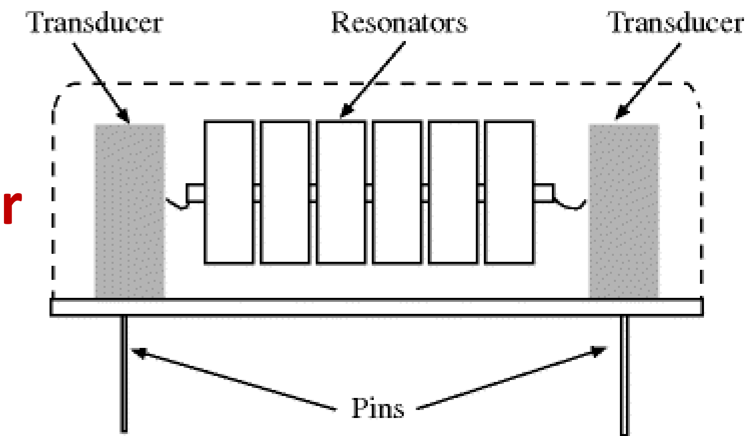


3-pole MCF basic structure



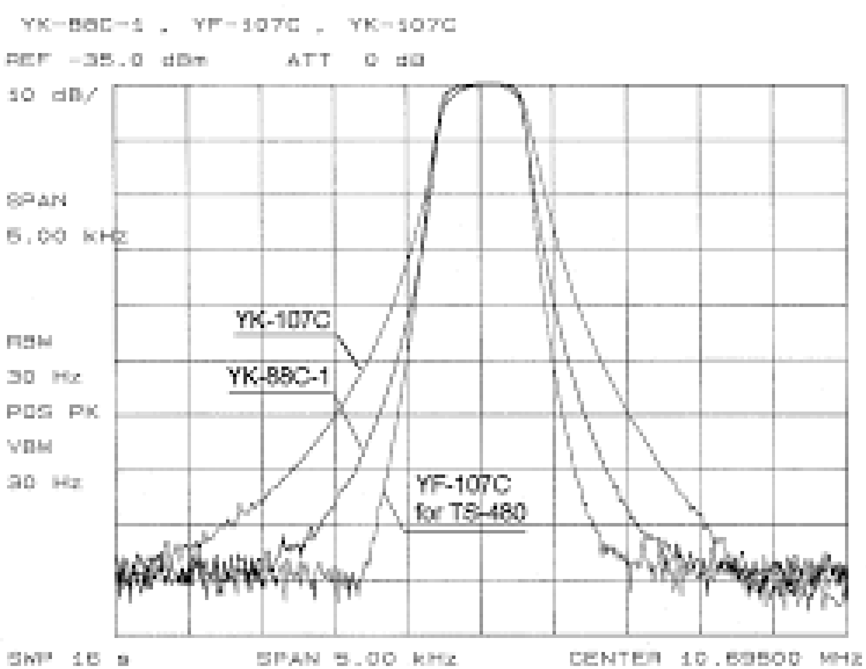
Equivalent circuit

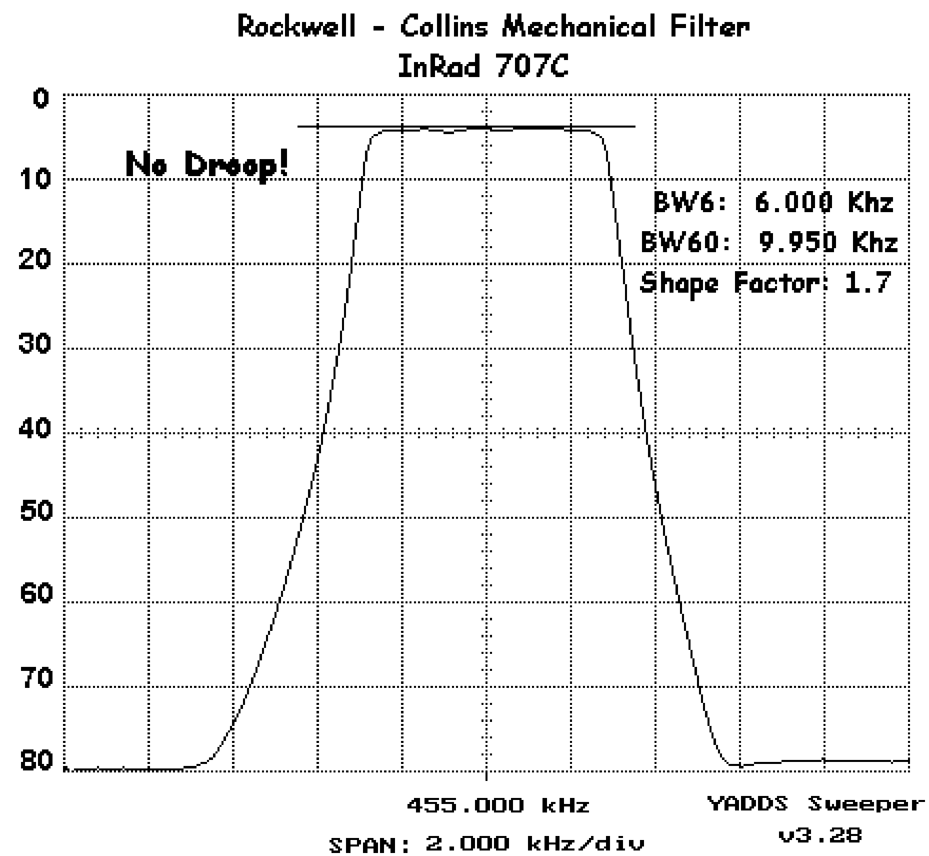
Mechanical filter



Rockwell-Collins mechanical filter at 455 kHz for AM

3 different Kenwood xtal filters at 8.83 and 10.7 MHz

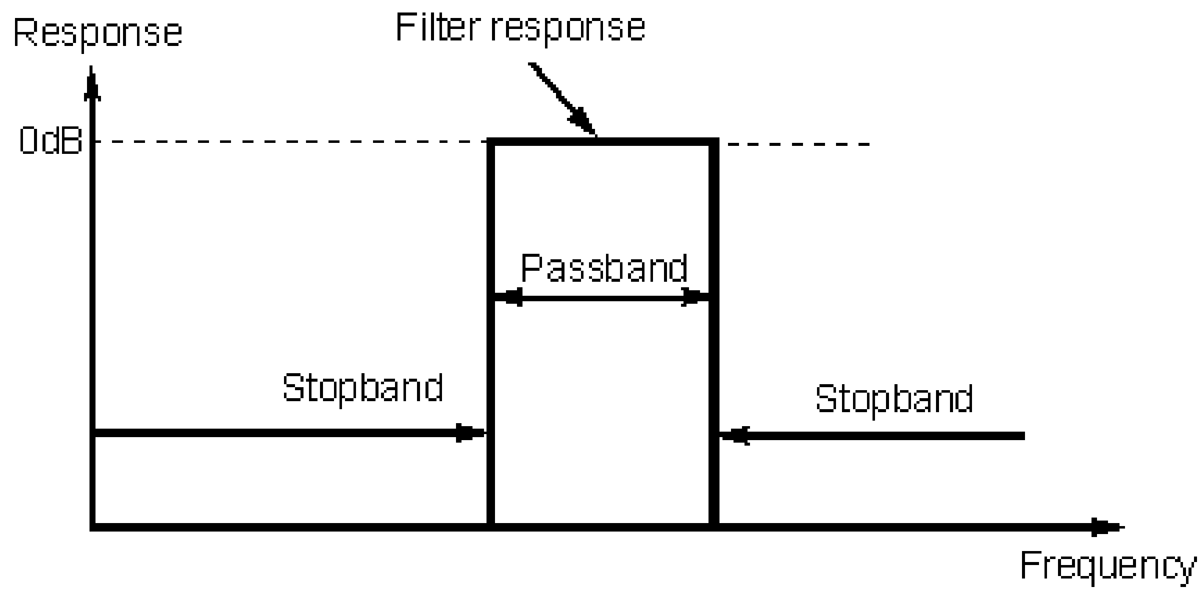




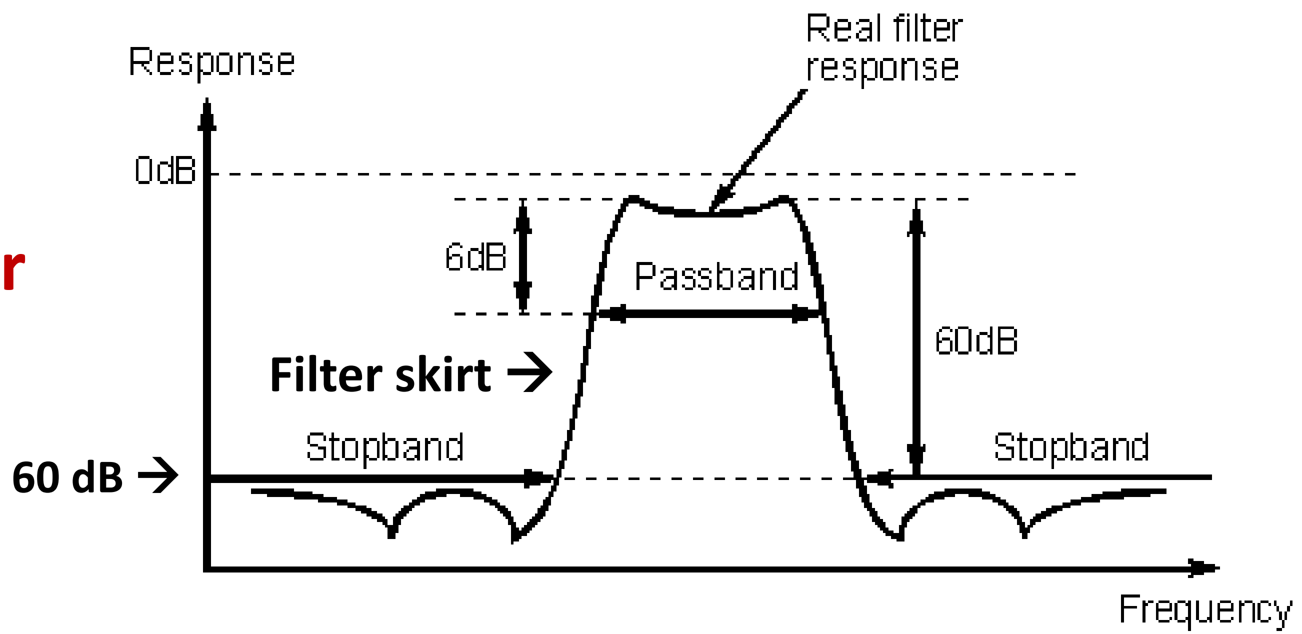
3 different shape factors

Filter performance can be ruined by "blowby"

Ideal Receiver Selectivity (perfect skirts)

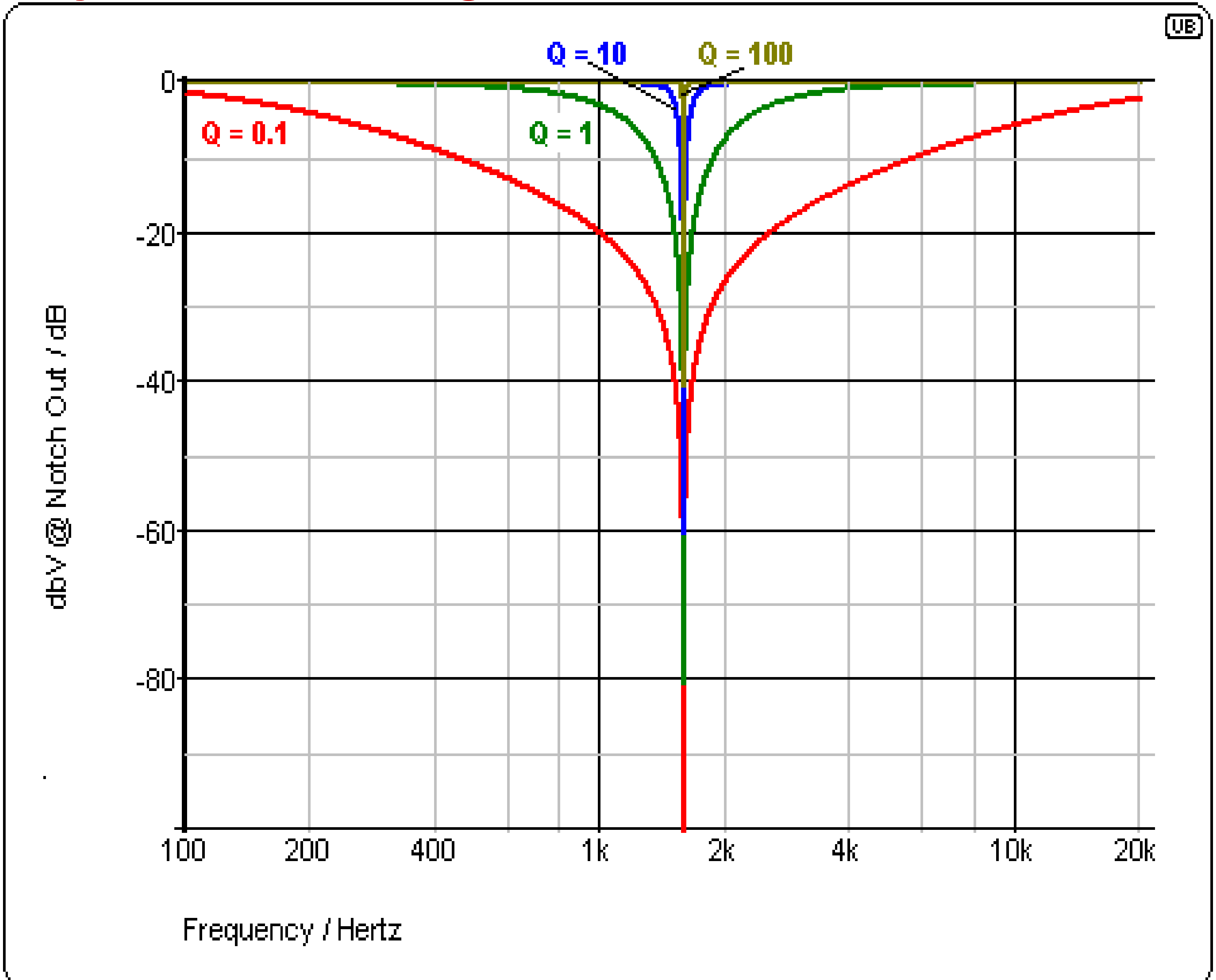


Real receiver selectivity

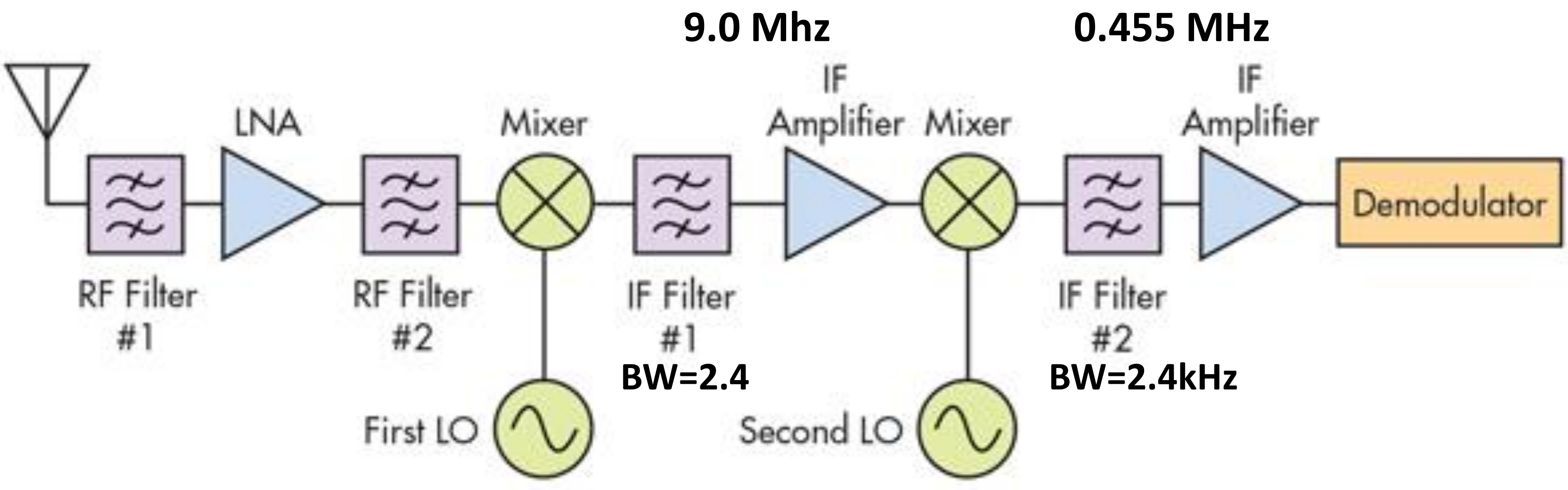


Shape factor: 6 dB to 60dB bandwidth ratio

Adjustable analog notch filter to take out tones



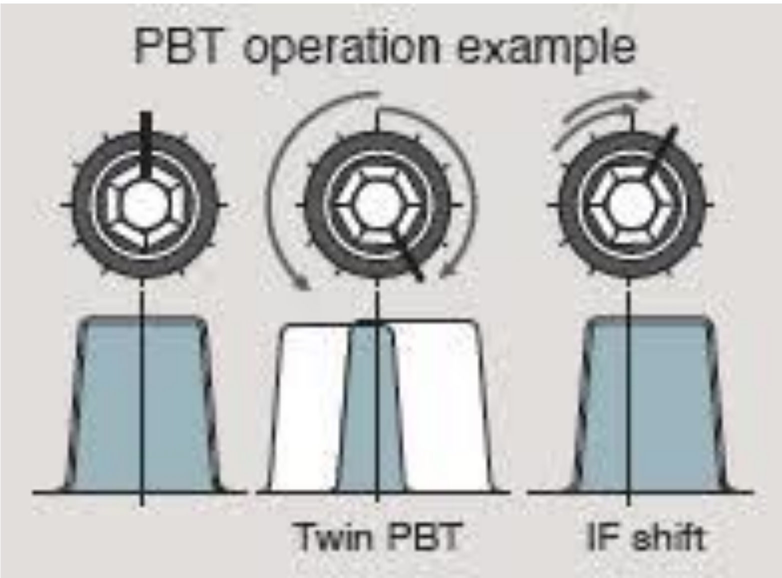
Dual-conversion superhet



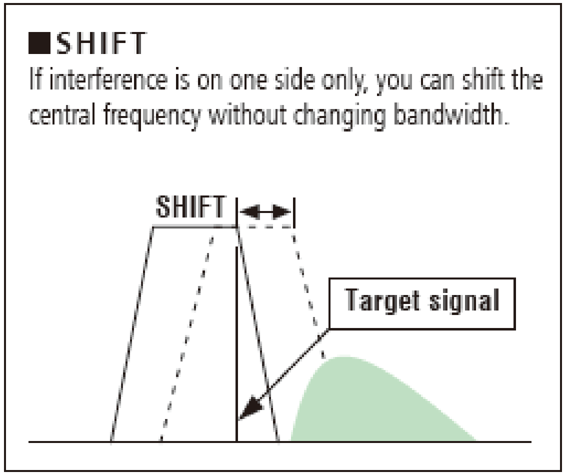
Q. What if you could slightly vary the frequencies of the 2 LOs??

Variable IF selectivity: 2 IF frequencies, with both LOs adjustable

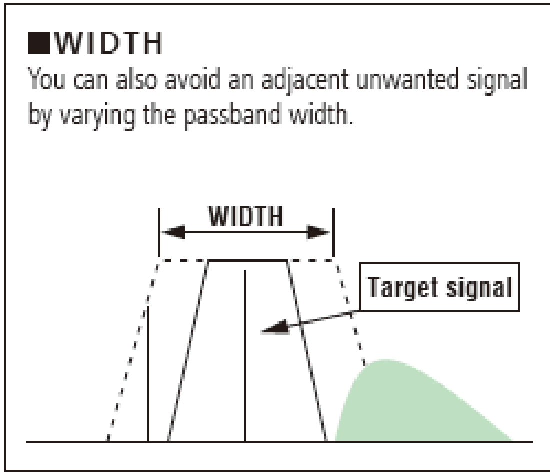
"Passband tuning"



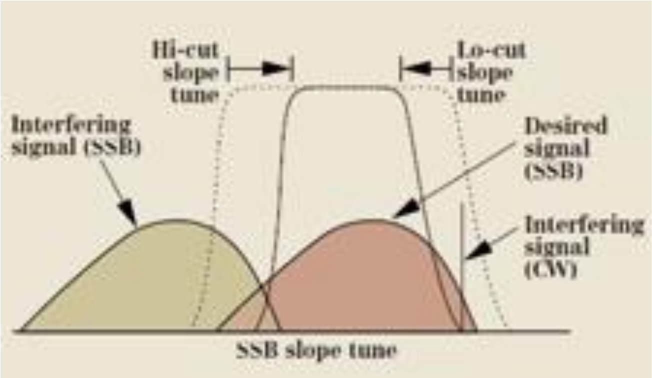
IF

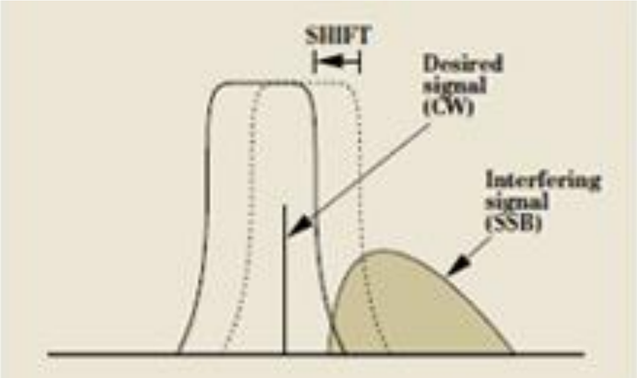


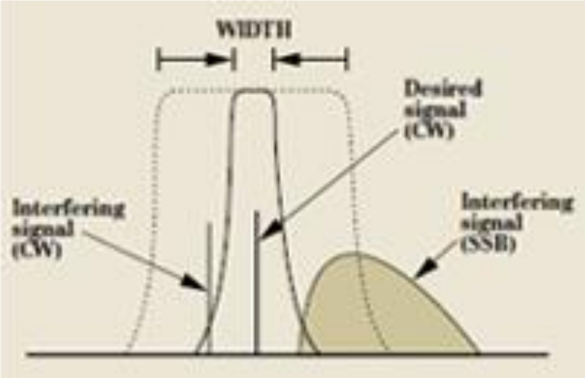
Passband



SSB "slope tune" (high cut-low cut)







Both DSP and analog notches can be wide or narrow

IF offset (another example)

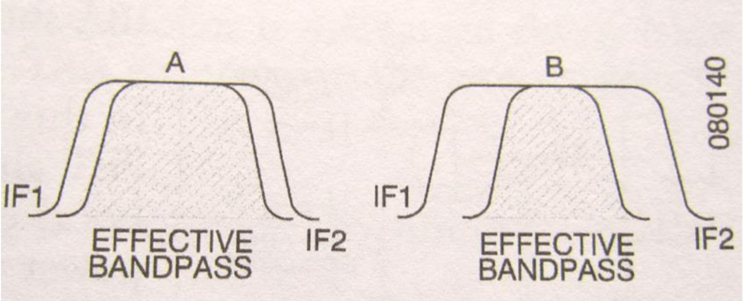
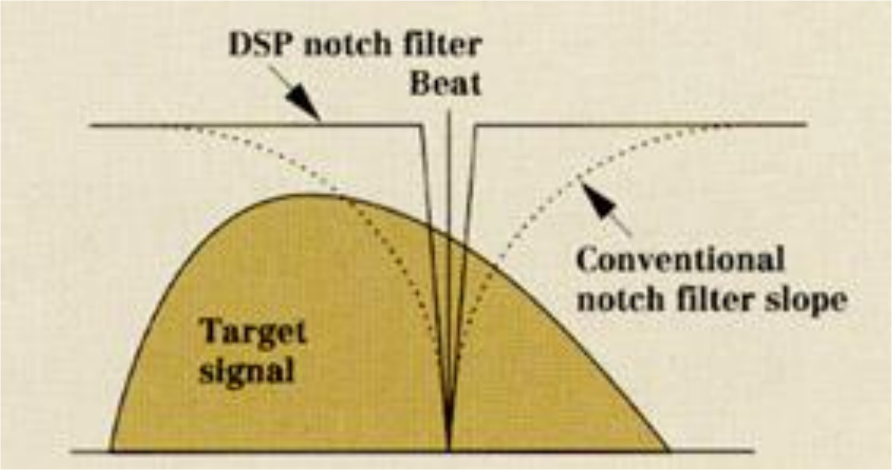


Fig 8-9



"Autonotch" vs. manual notch

Multi vs. single autonotch

Audio vs. IF autonotch

Internal receiver noise (independent of antenna)

-usually dependent on "front end design"

-mainly noise created in RF amp or first mixer/oscillator

-limits weak signal detection (sensitivity) and copy

-low current devices are the quietest (diode or FET mixers)

Sensitivity: minimum signal giving a 10dB S/N ratio

-in a modern HF receiver this is about 0.13μV@50Ω, or -140 dBm @ 50Ω (for SSB, CW, FSK). For very narrow modes detectable sigs are lower. WSJT modes: sigs copyable down to 26dB below noise.

-alternatively in HF, the MDS, or "Minimum Discernable Signal" (a CW signal you can just barely copy) can be used

-MDS is about -140 dBm

-spectrum gets quieter as frequency goes up

-RF amplifier only used if really necessary

-under low band-high noise, also insert Attenuator

-continuous noise readable on the S-meter reduces dynamic range

AGC/AVC (automatic gain or volume control)

-negative feedback to give both strong and weak signals about the same audio volume out.

-fast attack/slow release (usually adjustable)

-useful for most modes

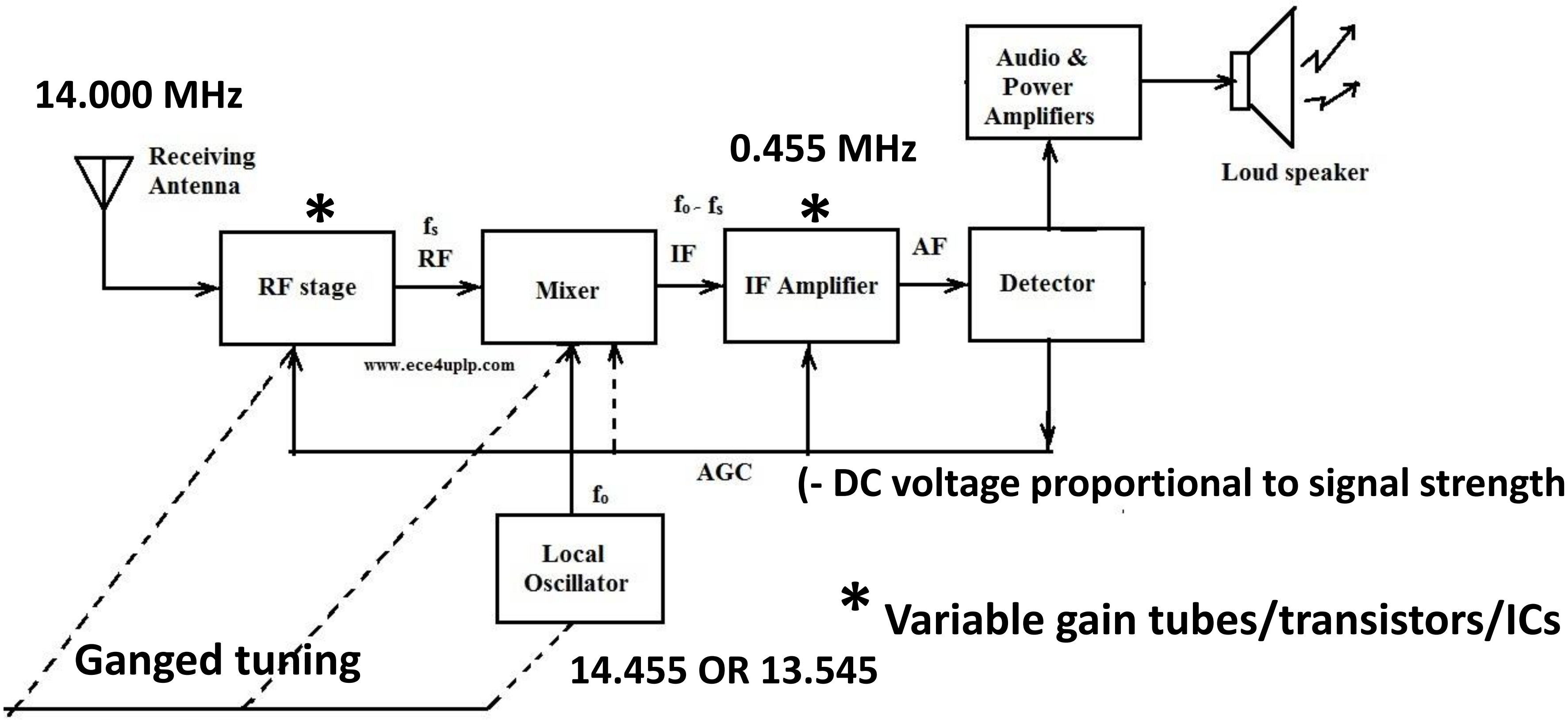
-control DC voltage usually rectified from IF signal voltage, or occasionally from audio signal voltage

-weak signals → no AGC voltage produced → RX at full sensitivity

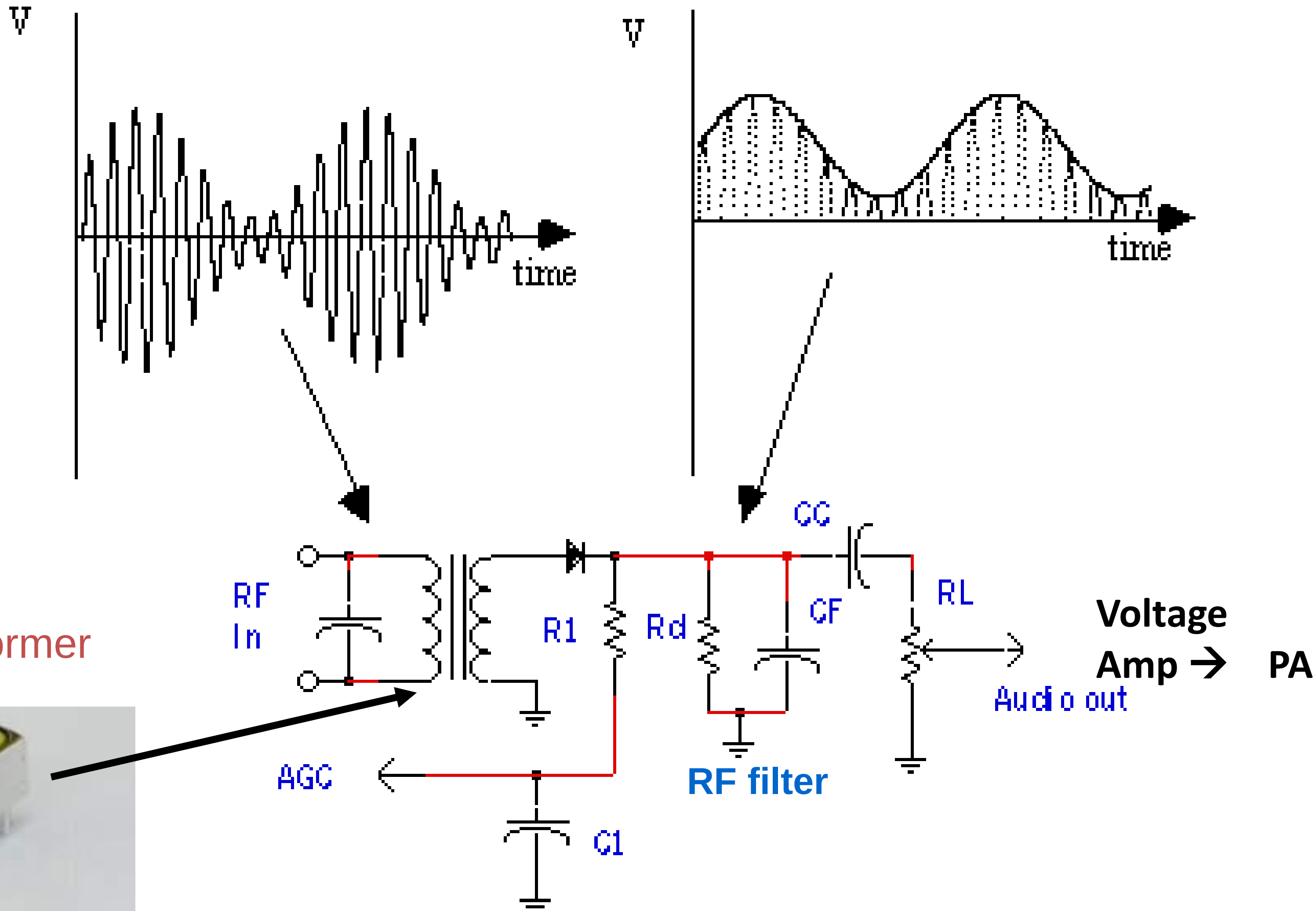
-above some threshold signal strength, AGC voltage produced and RX sensitivity reduced

Conventional Superhet Automatic Gain Control

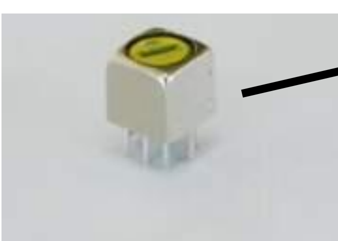
- later designs almost never control the mixer
- diode in/near detector rectifies signal to produce (-) voltage proportional to input signal strength
- negative AGC voltages reduces gain of RF and IF amplifiers
- "fast attack – slow release" response best for voice
- "fast attack--fast release" best for CW, RTTY, data



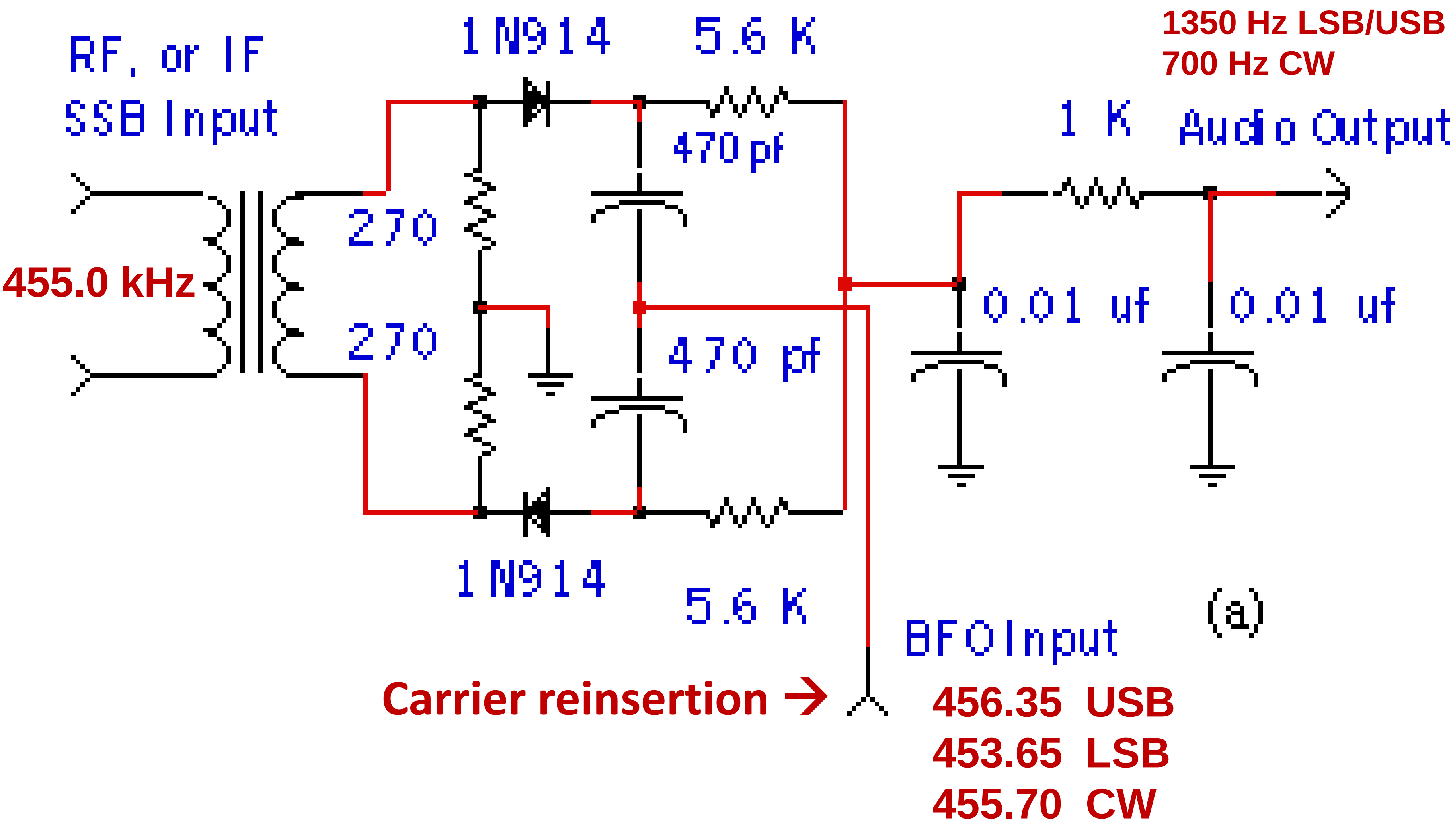
AM Demodulation (diode detection)



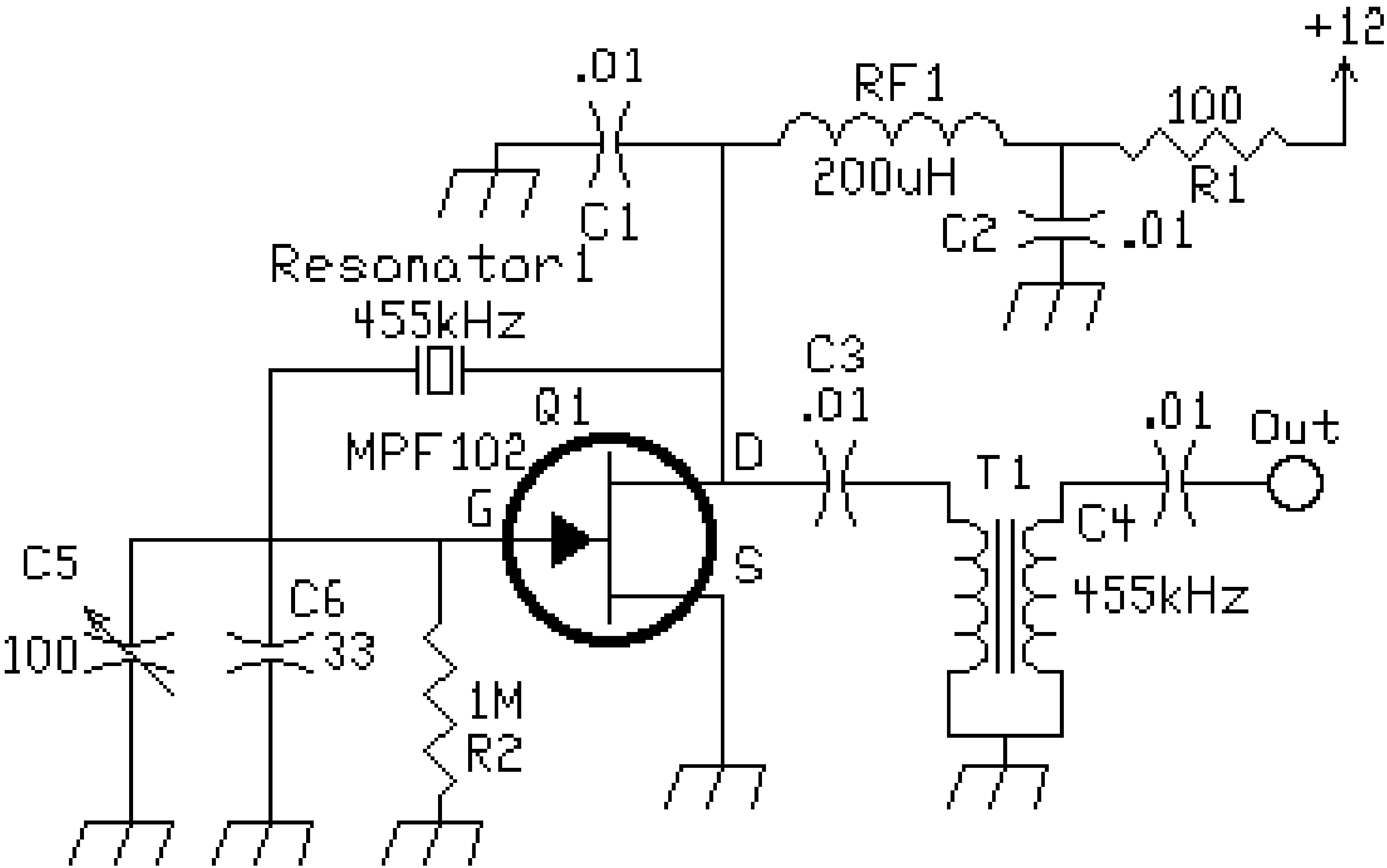
IF Transformer



Product Detector (really a mixer)



Beat Frequency Oscillator



Balanced diode ring product detector

High BFO level injected at T2
BFO usually needs buffer to provide enough energy + stability

BFO frequency removed, but BFO 2nd harmonic is present and must be filtered out

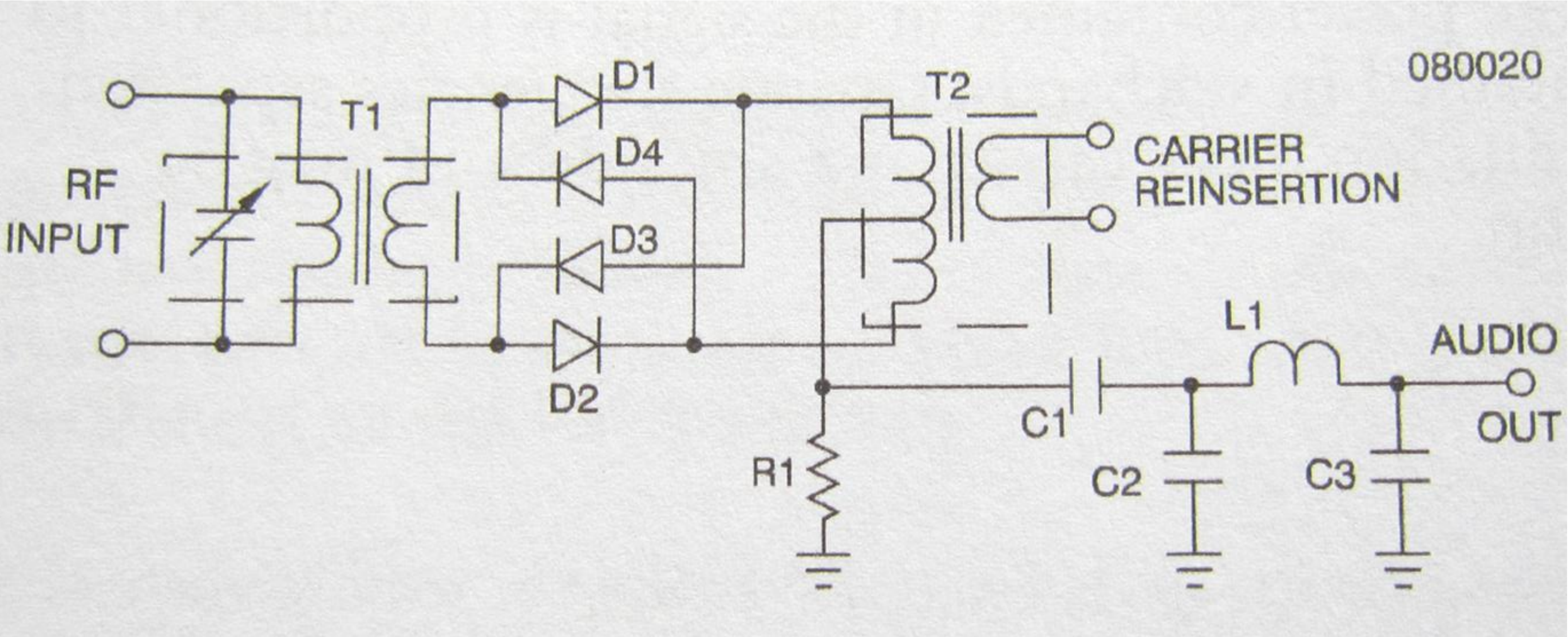


Fig 8-12

MC1496: double-balanced product detector/mixer in a chip

-adjustable to fine-balance cancellation of signal and carrier (BFO) RF
-no tuned circuits or transformers
-great for ham projects!
-has gain, so more audio output than diode designs

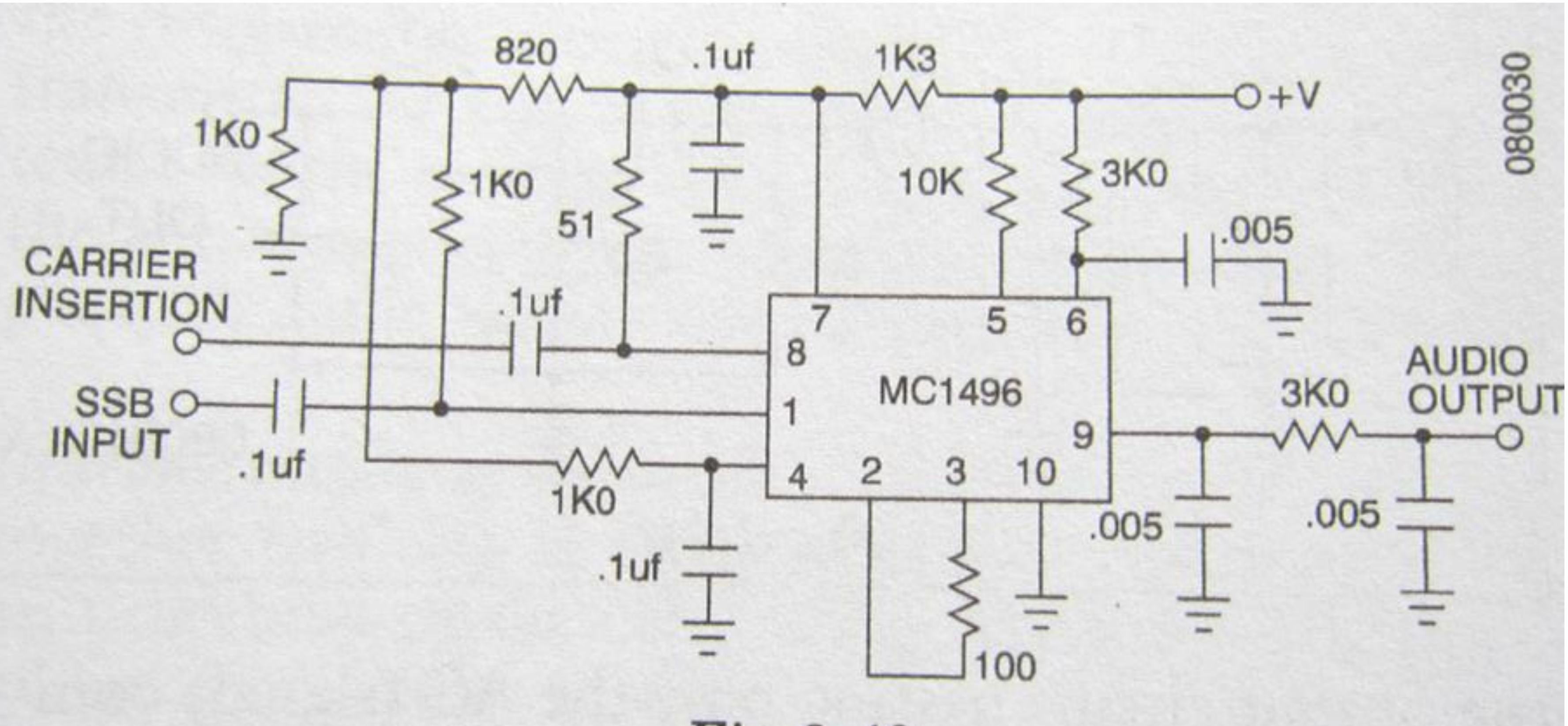


Fig 8-13

Audio section of RX can include the following:

-voltage amp. + power amp (PA)

-audio frequency response shaping

-noise limiting ("clipper" or "limiter")

-noise blanking

-squelch

-audio-derived AGC

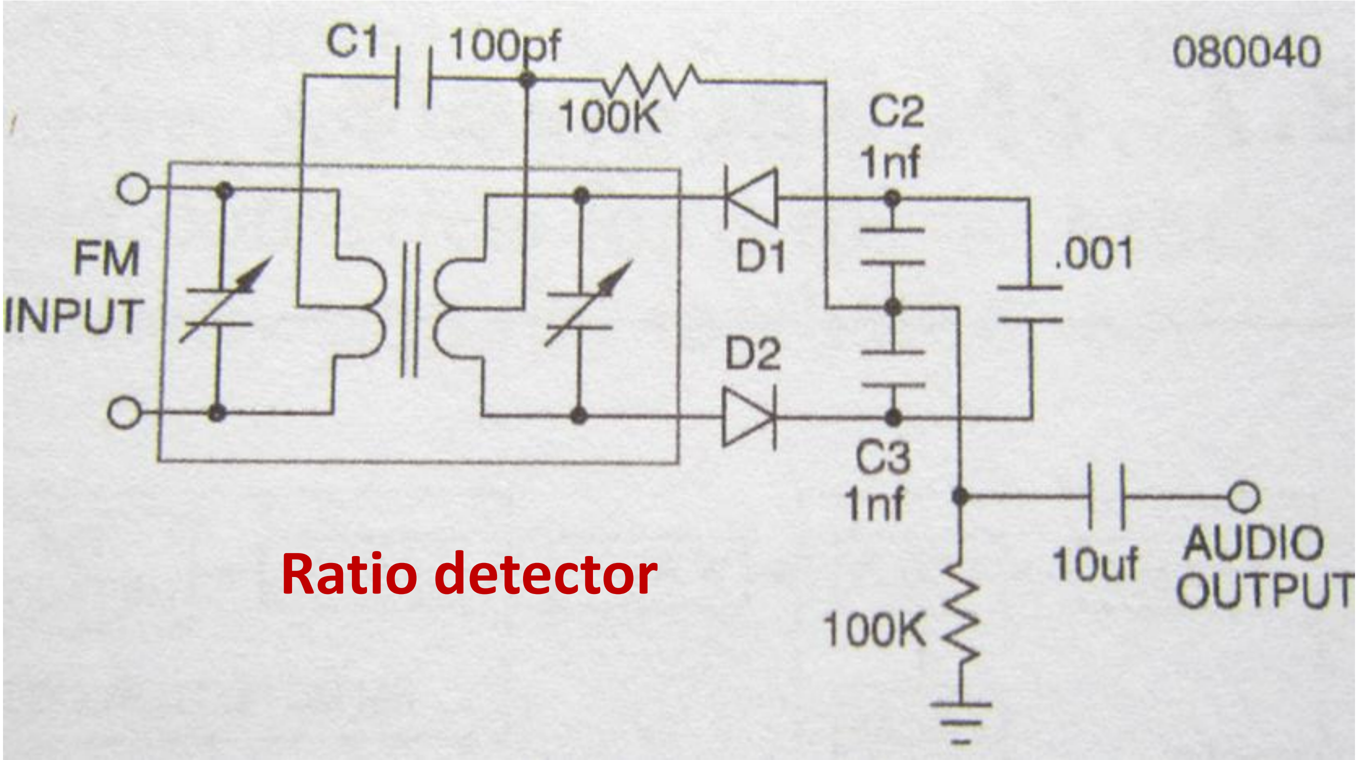
-DSP processing (de-noiser, auto-notch, band-pass filters)

-FM de-emphasis

FM Detectors: the ratio detector

Converts small frequency variations in signal frequency into audio amplitude variations.
Speed of amplitude variations becomes audio output frequency.

Very insensitive to AM noise.
Precision detector transformer is expensive, so ratio detectors not popular.

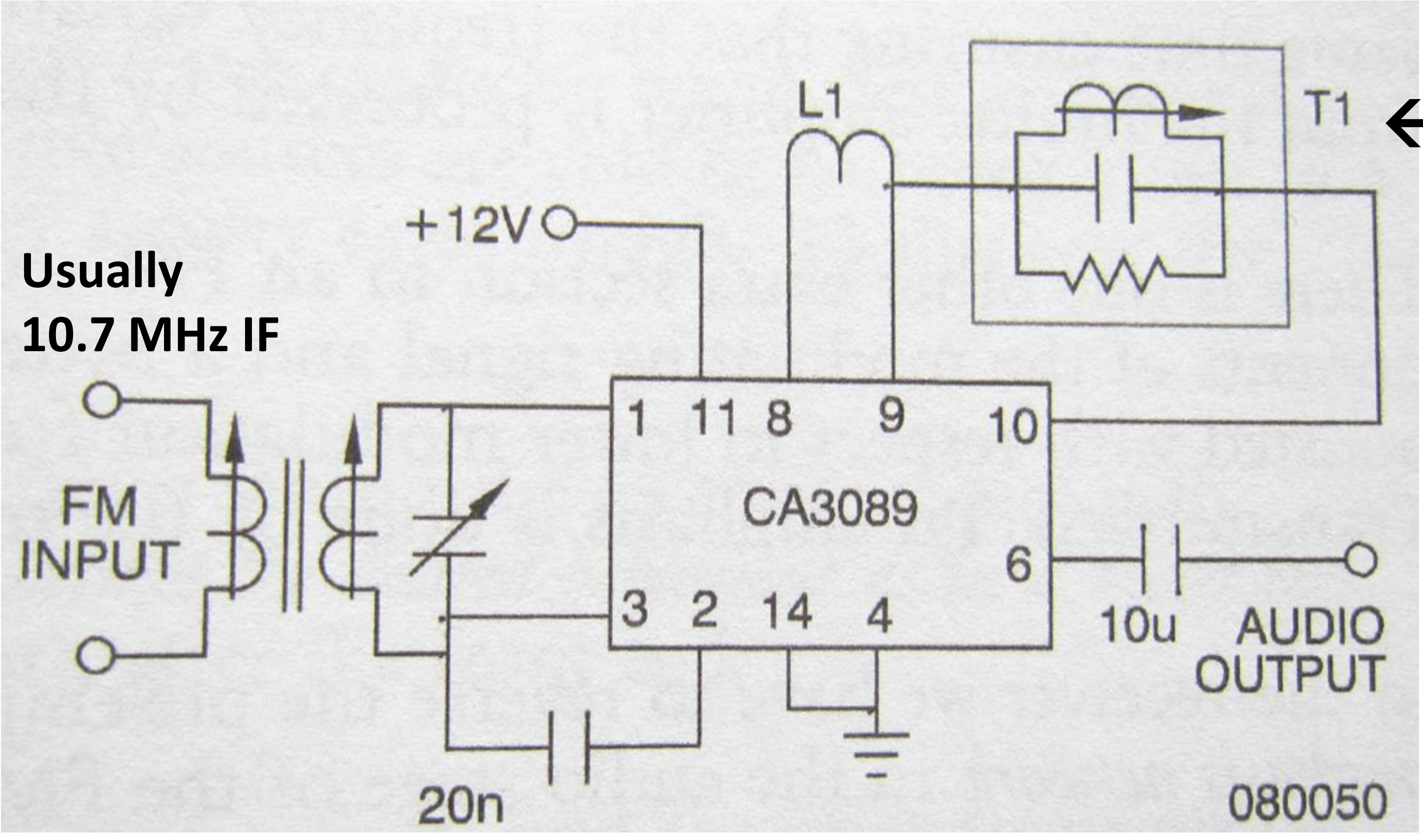


Ratio detector

FM quadrature detector

CA3089 chip detector contains amp, limiter, squelch, tuning meter, etc. (big parts count reduction)

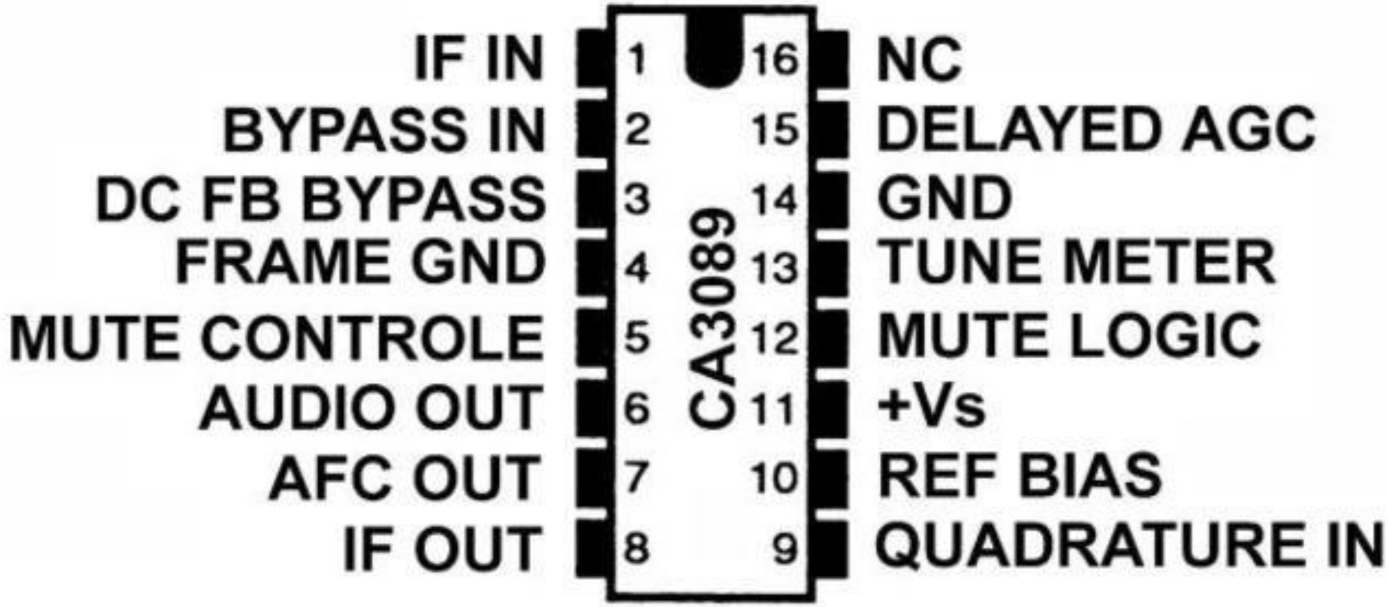
Today: complete FM system on chip most common



←quadrature coil

FM-IF System

Type	I_S Max mA	V_{IL} (Typ) µV fo = 10,7MHz	Specifications at T_A = +25°C and +VS = 12V α_{AM} dB Min	T_{HD} %	S_{NR} dB	AF_{out} mV Min	Supply Voltage V_S Min	Max
CA3089E	23	12	45	1	60	300	8,5	16



> FM ZF-Verstärker mit automatischer Rausch-unterdrückung, Quadratur-Demodulator, Abstimmanzeige, verzögerter AGC Regel-spannung, AFC-Spannung für Scharfab-stimmung, und Muting

CA3089E
PDIP-16

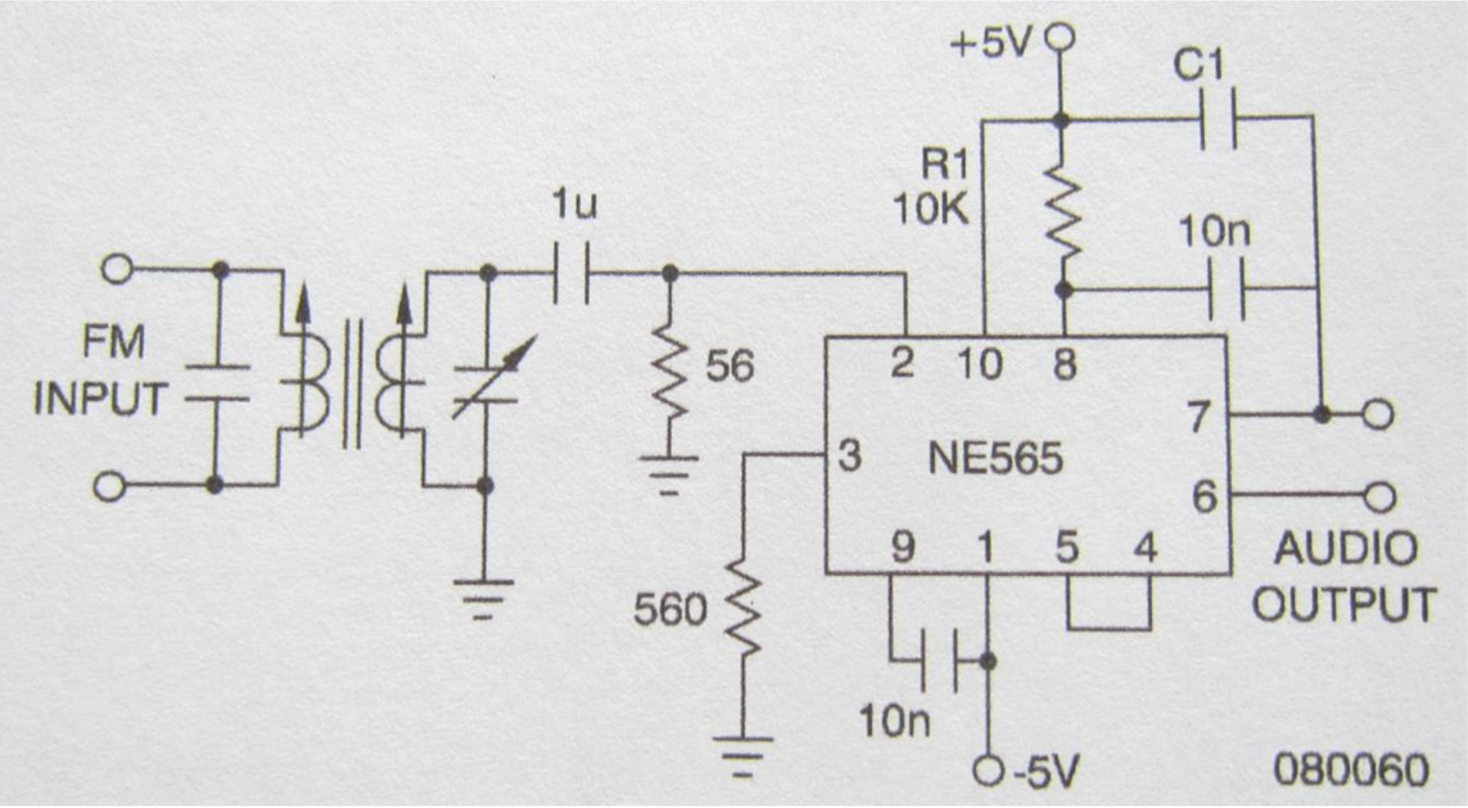
Fehler und Änderungen bei technischen Daten, Abmessungen und Preisen bleiben vorbehalten.

PLL FM detector

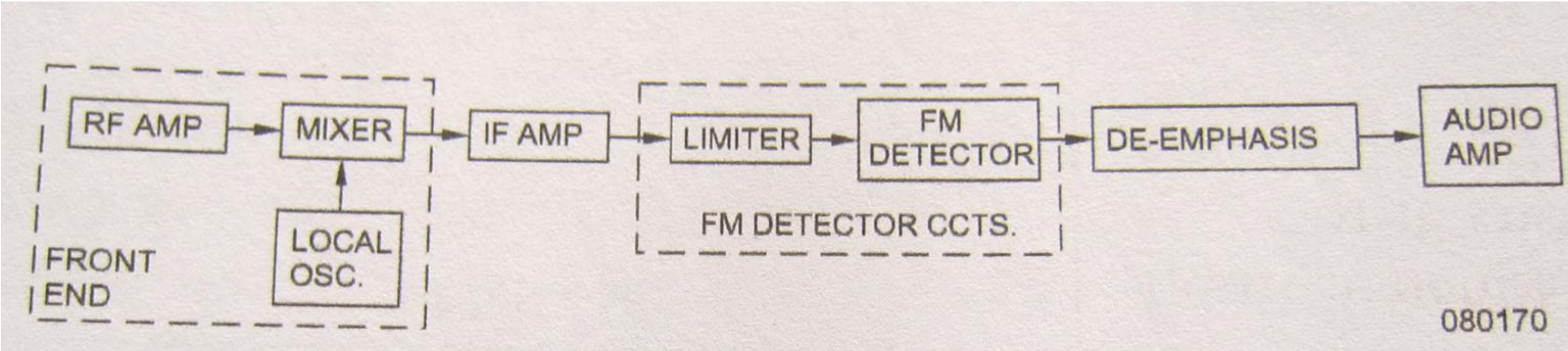
No inductors needed: uses <u>free-running osc</u>. and <u>phase detector circuit</u>

-phase detector circuit control voltage will follow freq. change in the signal.

-control voltage will therefore be a replica of the original modulation audio.



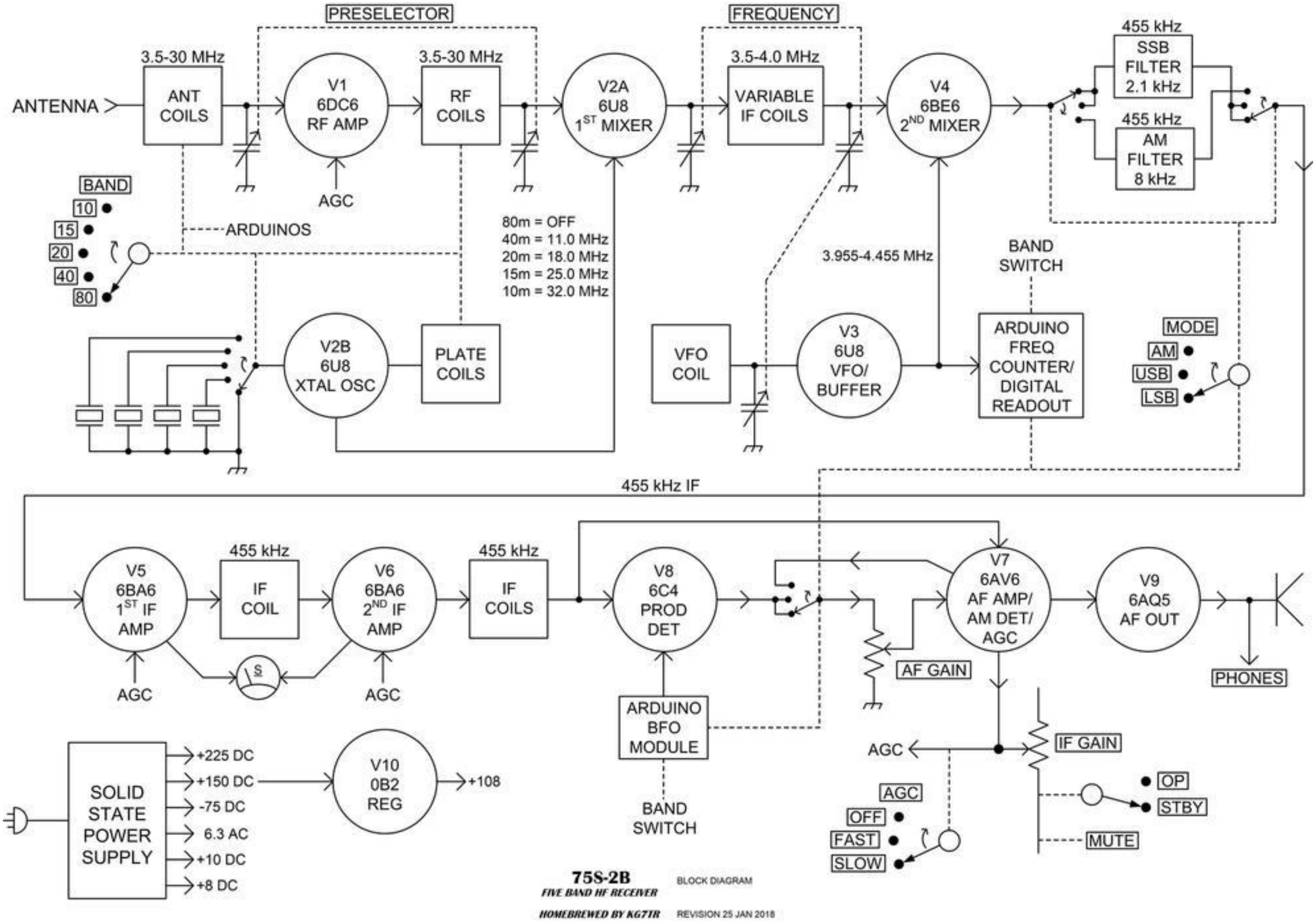
FM receivers



-High-gain IF followed by limiter amp. → constant amplitude signal, except with very weak signals
-LO usually contains frequency multipliers
-AM noise of all sorts is eliminated

-at TX high audio freqs. are boosted: <u>pre-emphasis</u>
-at RX the highs are <u>de-emphasized</u> to restore normal sound balance

Fixed converter, variable IF superhet



Intermodulation distortion (IMD): occurs in RX front end

-can occur everywhere there is rectification or a "non-linear conductor" and 2 or more signals
-corroded, dissimilar metals act as diodes/non-linear conductors

When two or more strong RF signals "received" by metal structure or objects MIXING can occur.

Result: many mixer sums/differences => => more mixing => => lots of spurious signals!!

Common in : old plumbing, rain gutters, rusty masts, rusty towers, especially when ferrous metals were originally galvanized.

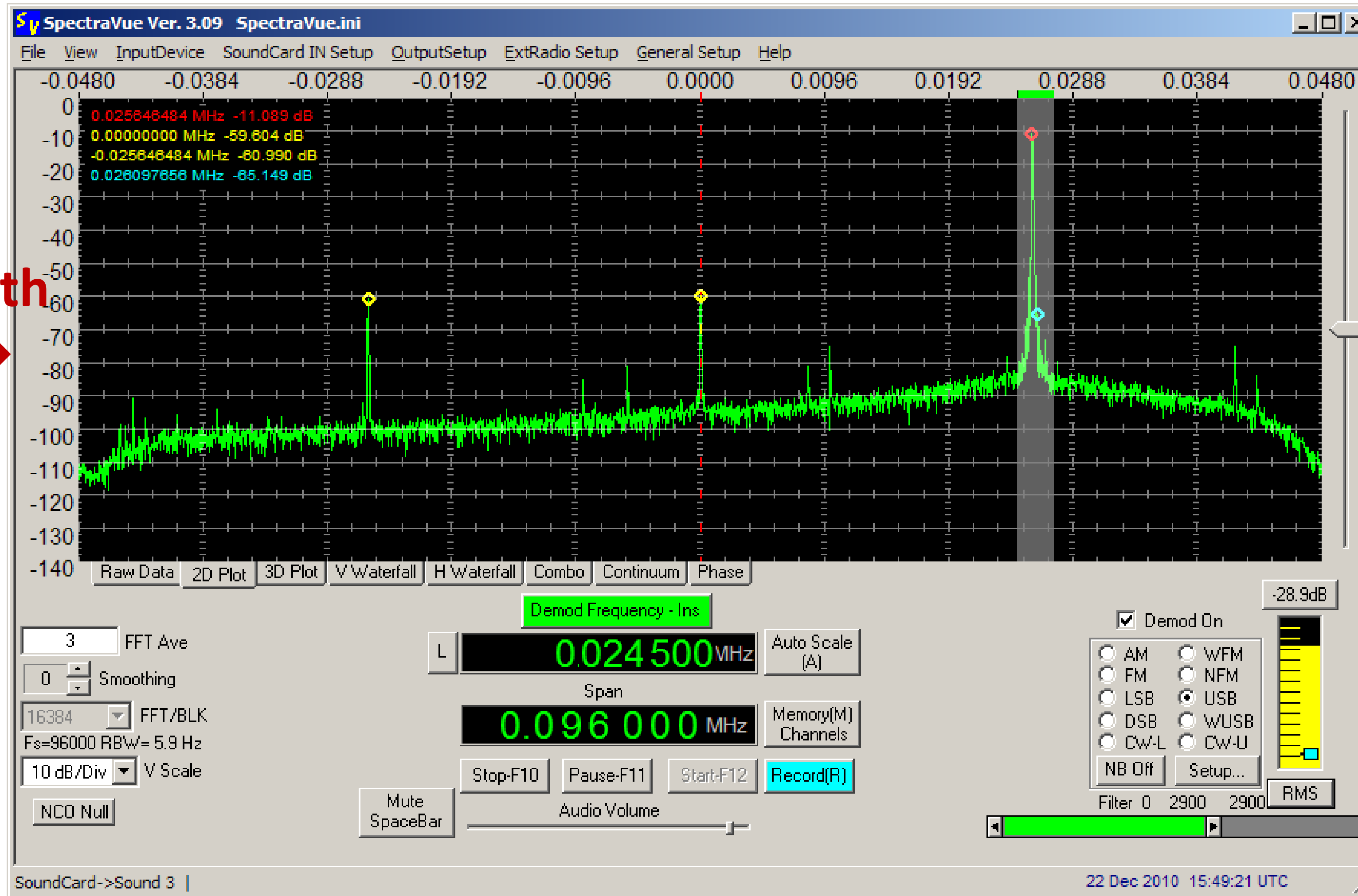
Fun Cube Pro+ Dongle SDR ($200)

100kHz to 2.0 GHz

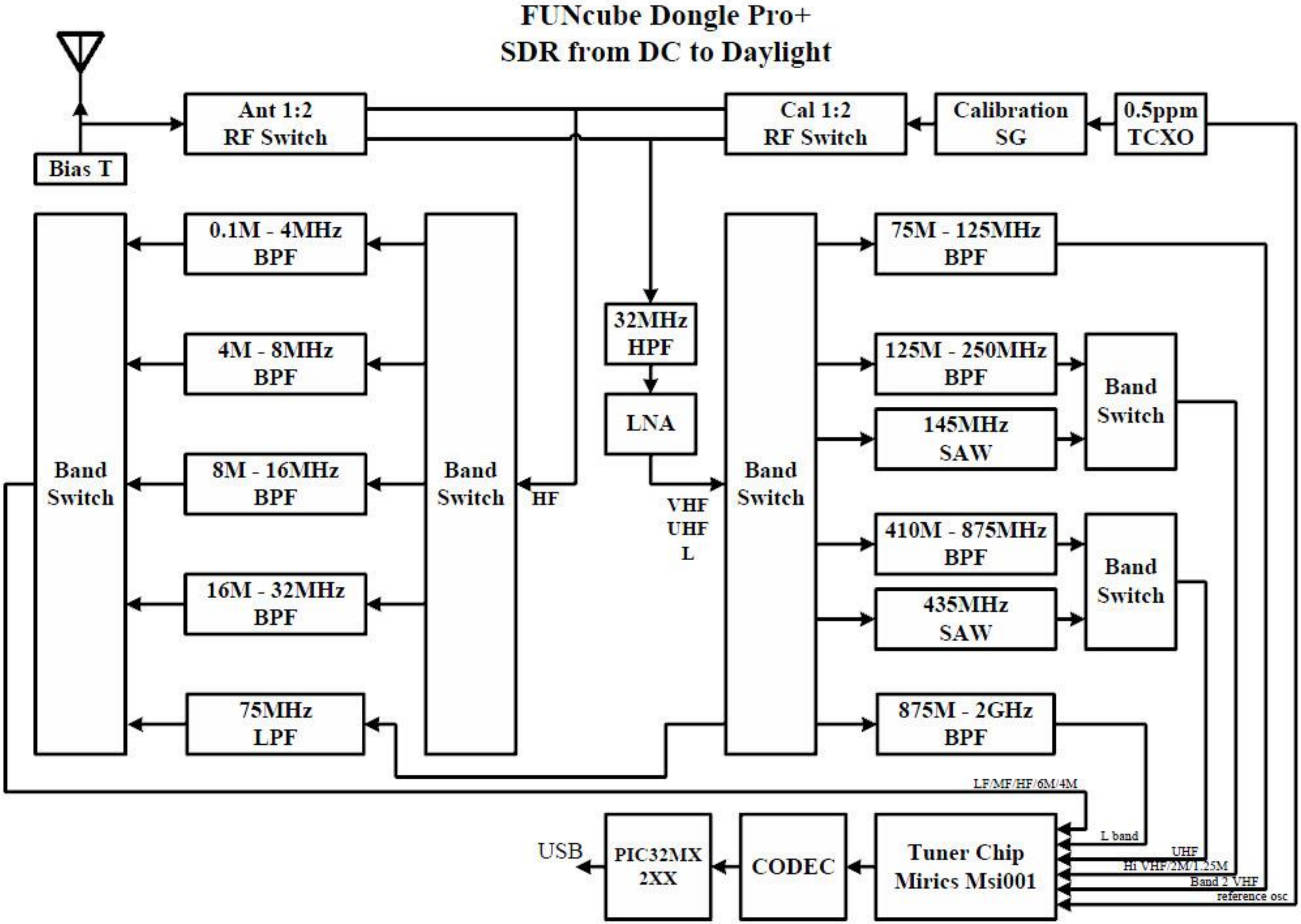
-computer provides digital power

GHz →

Signal strength in dB →



True digital RX!



End of Receivers!