Advanced Course Ch. 7 Oscillators

de VE1FA 2019

Oscillator: - an amplifier circuit that generates a periodic signal

- an oscillator periodic signal is a continuous wave (CW)
- amplifier circuit with a gain greater than 1
- amplifier with positive feedback
- in addition to a fundamental frequency, harmonics, other frequencies, and noise usually produced

- heart of every radio transmitter and audio oscillator
- for stable output frequency, need a frequency-selective (+) feedback loop

You want: frequency stability, purity, and accuracy in a practical oscillator

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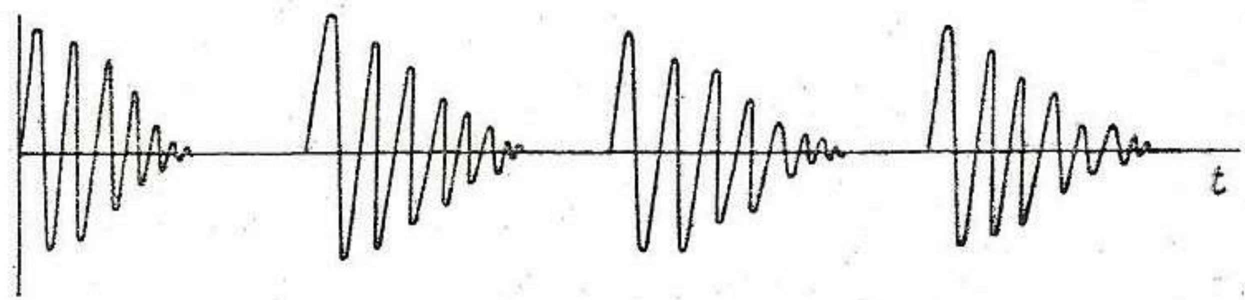
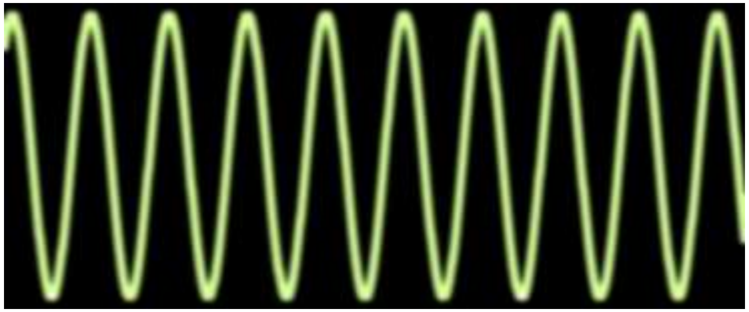
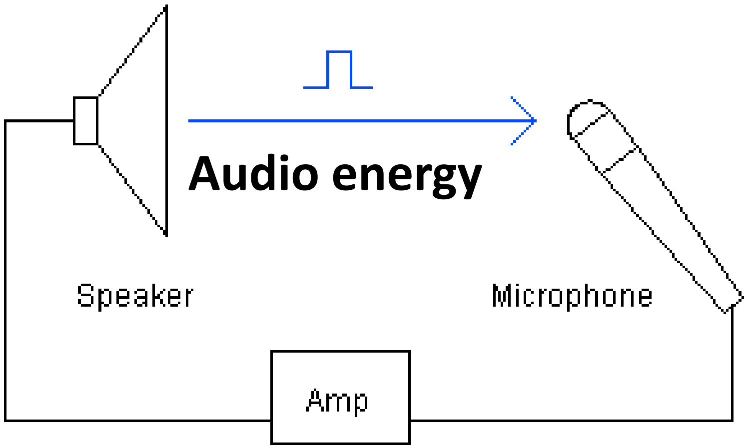
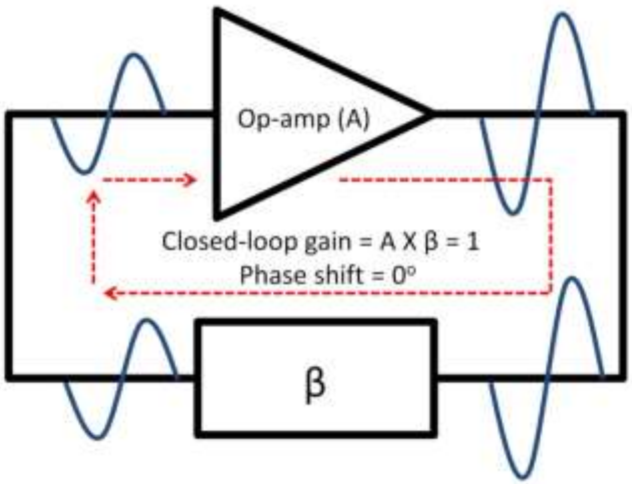
Damped wave "DW" or "plain spark" used 'til 1920s ➔



Modern TX continuous wave "CW" requires oscillator ➔







Positive feedback = oscillation

β: phase shift, or frequency-selective, or simple resistive

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Spark (damped wave) radio technology: beginning to 1920
CW (oscillator-based) technology: 1920-now

E. H. Armstrong invented the following:

Oscillating amplifier tube: -the basis of modern radio transmitters.

Regeneration (high-gain, near oscillation) as the basis of sensitive receivers. Patented 1914

Superheterodyne radio circuit : Patented 1919

FM radio system: 5 patents 1933

FM doppler radar + moonbounce: 1946

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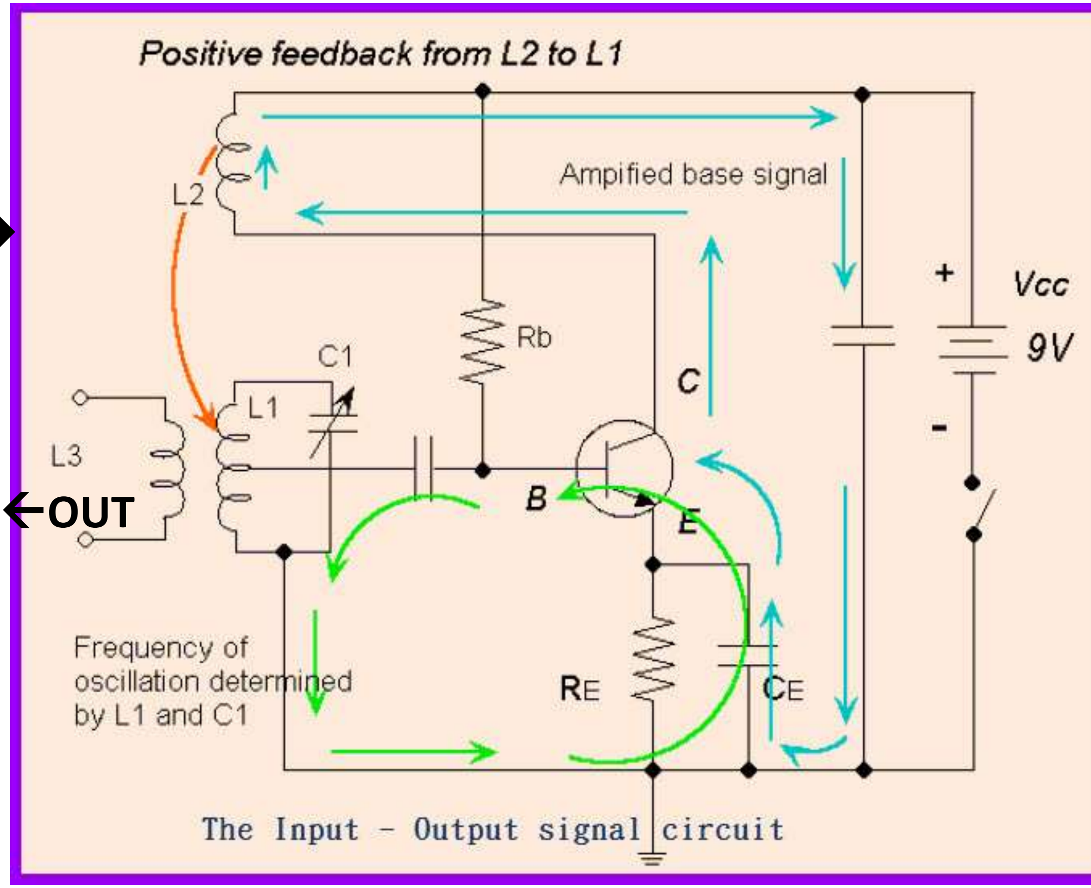
Armstrong oscillator circuit

Positive inductive feedback→

Continuous wave
RF output across L3→



C1-L1 sets output frequency

Variable C1 makes this a VFO

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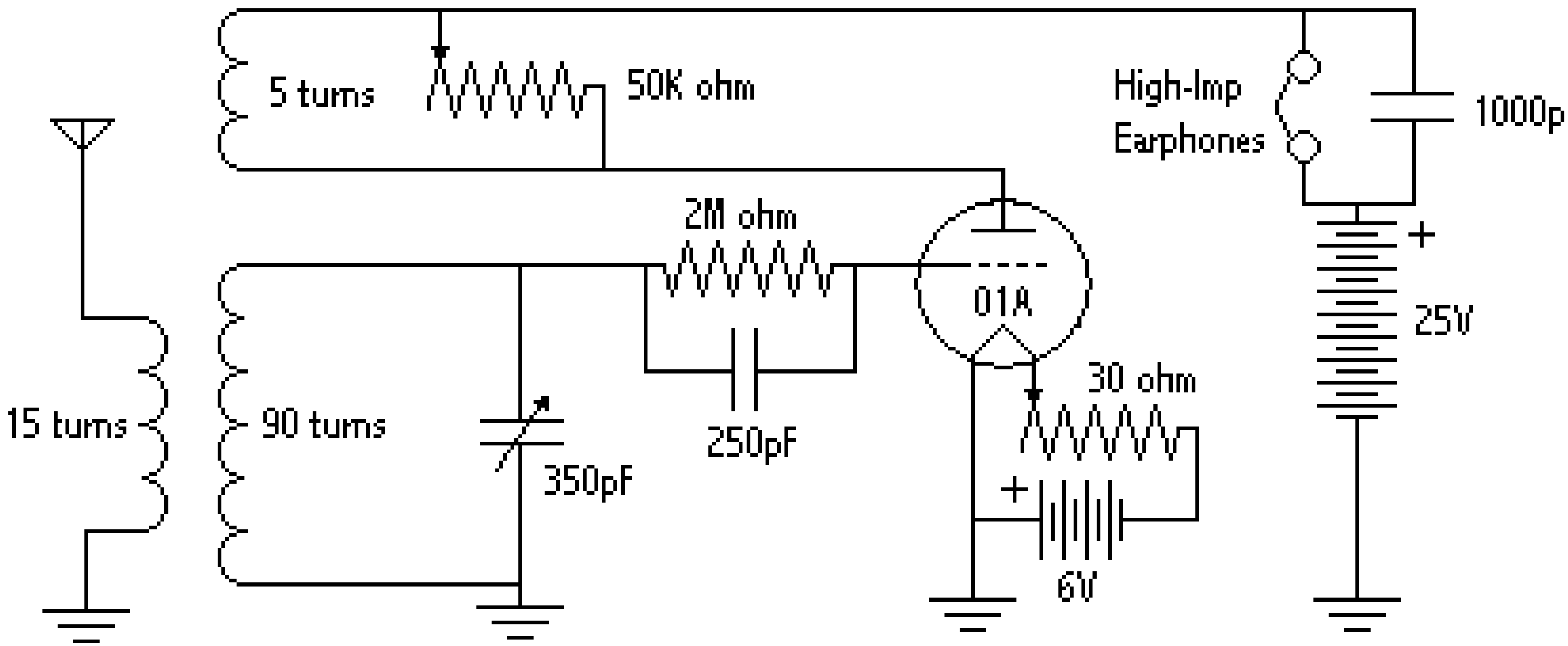
Regenerative/oscillating receiver of E.H. Armstrong, 1918



This was early commercial + amateur version

The first real DX receiver!

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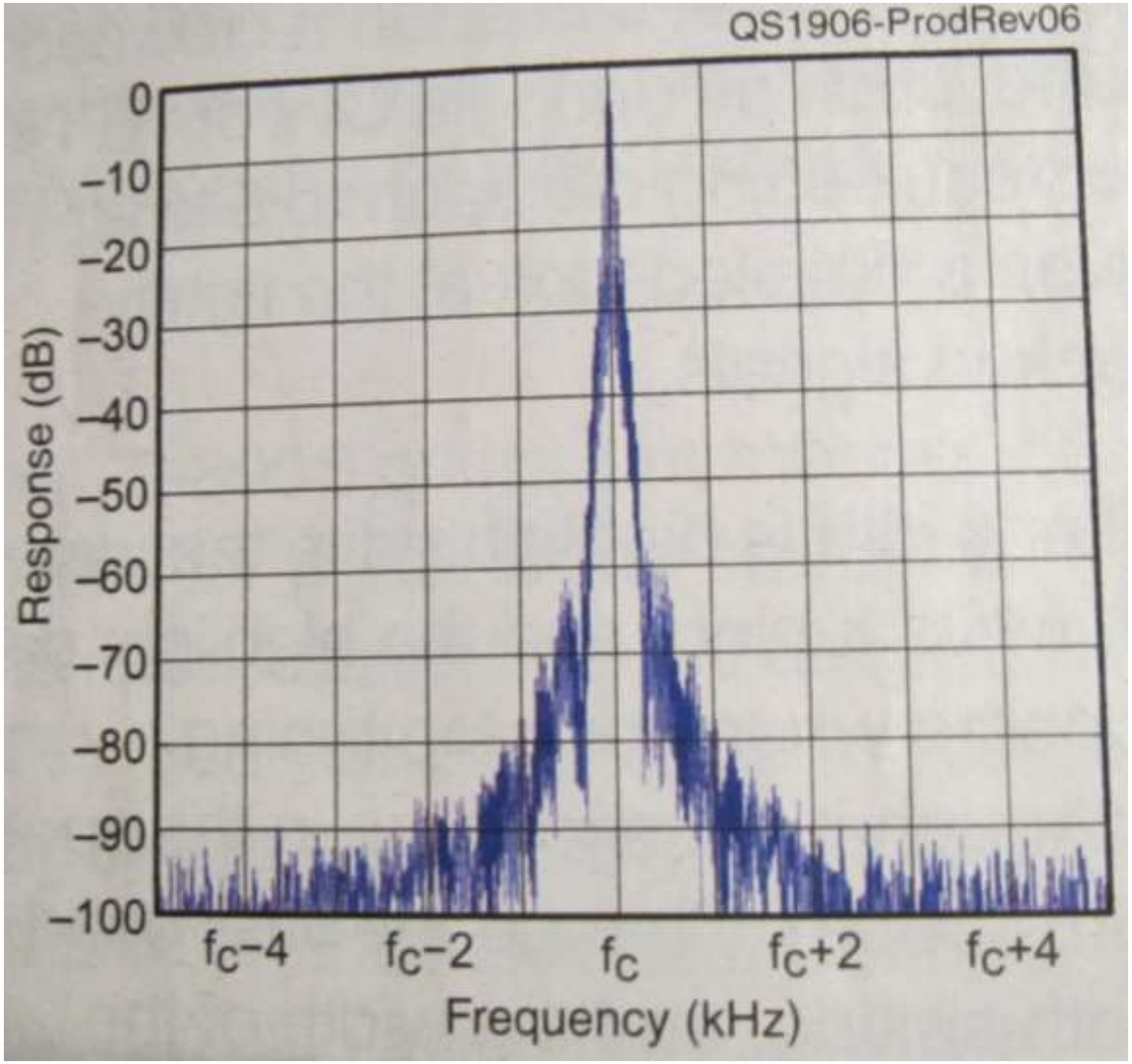
Oscillator RF purity: determines purity of IF signal, transmitted signal, number and amplitude of spurious mixer emissions



TS-890 Spectral purity

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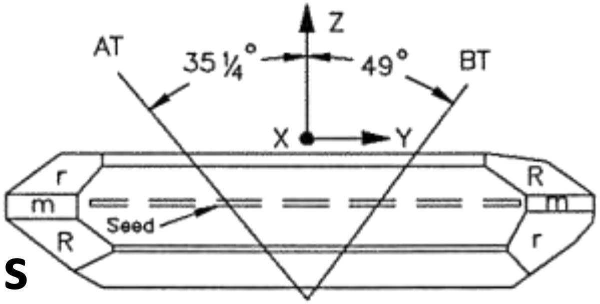
Quartz Crystal Oscillators



-"AT" or "SC" cut for most crystals

SiO4

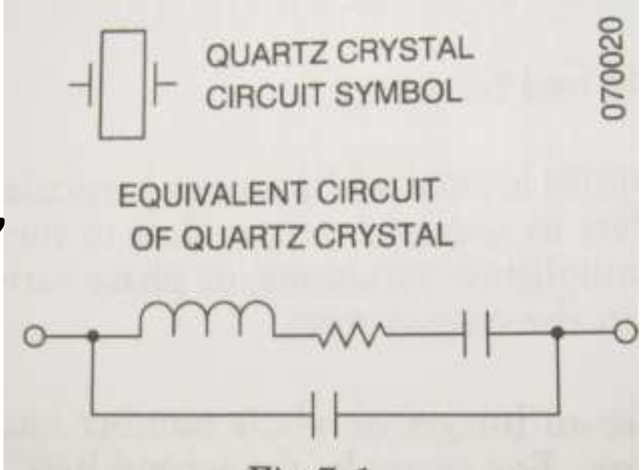


Fig 7-1

<u>Compared to LC oscillators:</u>

-very stable to mechanical vibration
-temperature + time stable
-only useful very near fundamental frequency, or harmonics of it (very limited VFO range)
- high Q, low noise
-very high frequency stability, if circuit is well-designed and ovenized

-"overtone crystal" can be ground specifically for certain harmonic of its fundamental

Raw crystal, crystal blanks, and crystals ready for mounting →

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Pierce oscillator

Crystal placed between control and output electrodes

C1 small to minimize loading

180° shift between gate and drain

+180° shift between sides of crystal

Equals in-phase (positive) feedback to gate!

Therefore: oscillation!

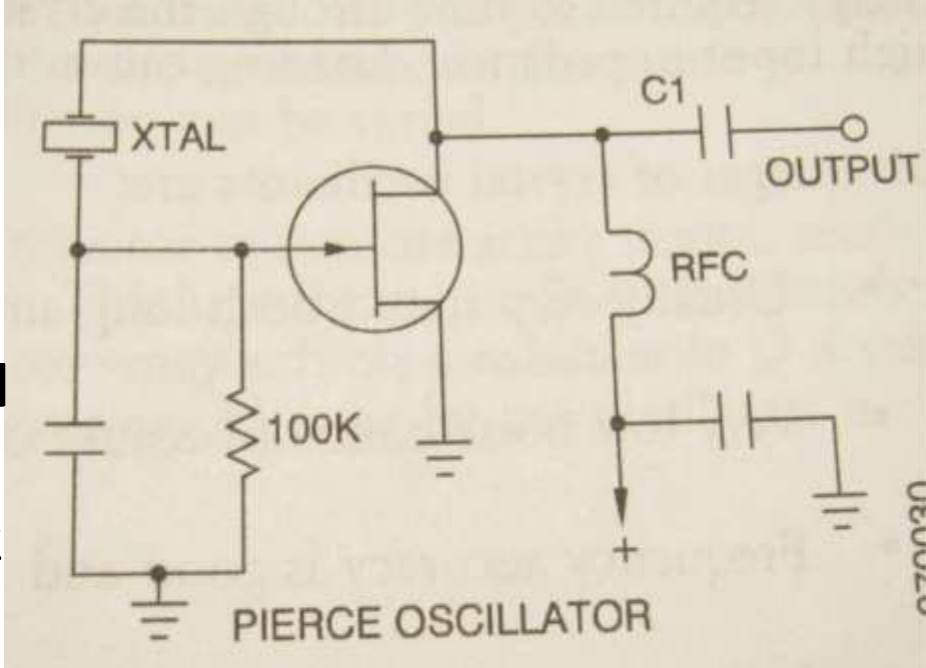

Fig 7-2

Q: Why is each component in the circuit??

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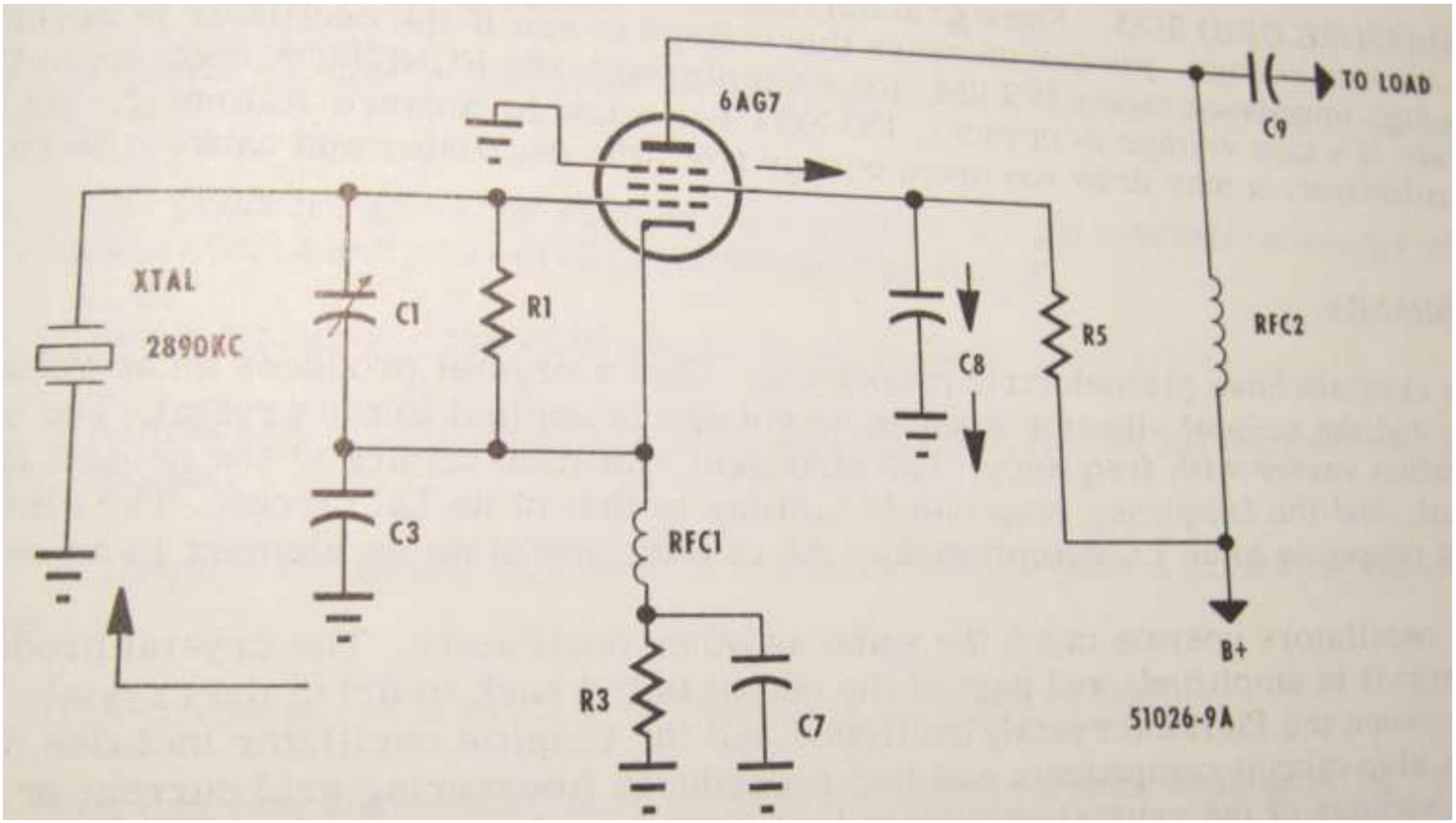
"Electron-coupled " tube-type Pierce circuit

Compared to previous transistor circuit:

- -provides fine tuning of oscillator frequency
- -provides better load isolation for crystal



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Colpitts Crystal Oscillator

C1 + C2 split the RF voltage across the crystal and Q1. Some is used for + feedback, and some provides the output.

CS trims the frequency to the one wanted

Colpitts especially stable

Often used for LC VFOs

C3 should be small

C1 + C2 + CS may be low temp. coeff. types to maximize frequency stability (eg. NPO)

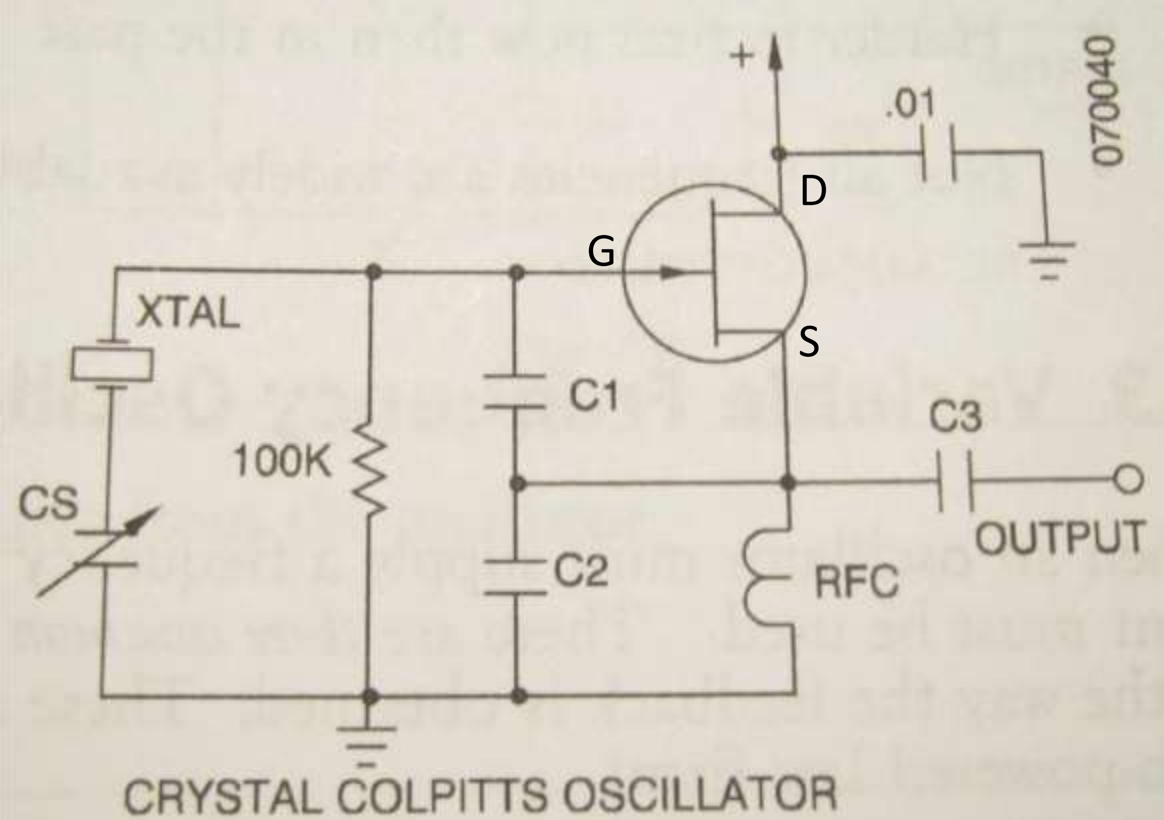

Fig 7-3

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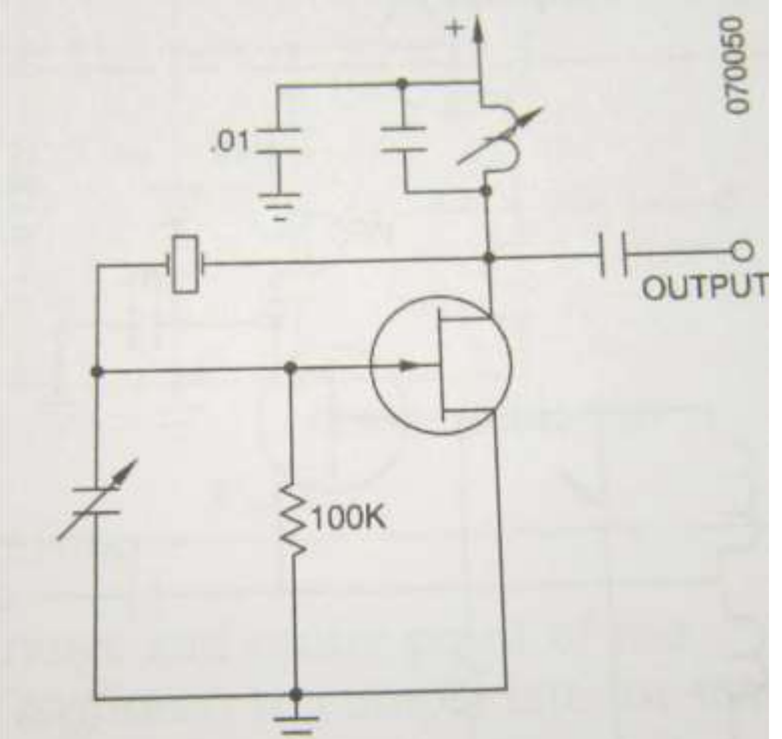
Overtone oscillator: forces crystal to oscillate on odd harmonic

LC tuned circuit on drain tuned to 3rd, 5th, 7th or 9th harmonic of crystal fundamental.

Only works on odd harmonics.

Overtone crystals specially cut.

FETs especially good for crystal oscillators, as high base Z means low current and cool crystal



OVERTONE CRYSTAL OSCILLATOR

Fig 7-4

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Hartley variable frequency oscillator (VFO)

3 common VFO types: Hartley, Clapp, and Colpitts

-analog VFOs becoming rarer in commercial radios

-Hartley has tapped inductor to provide (+)feedback

-RFC should have an XL of several thousand ohms at the oscillator frequency

-where does bias come from?

-effective Q = circuit Q x FET's gain

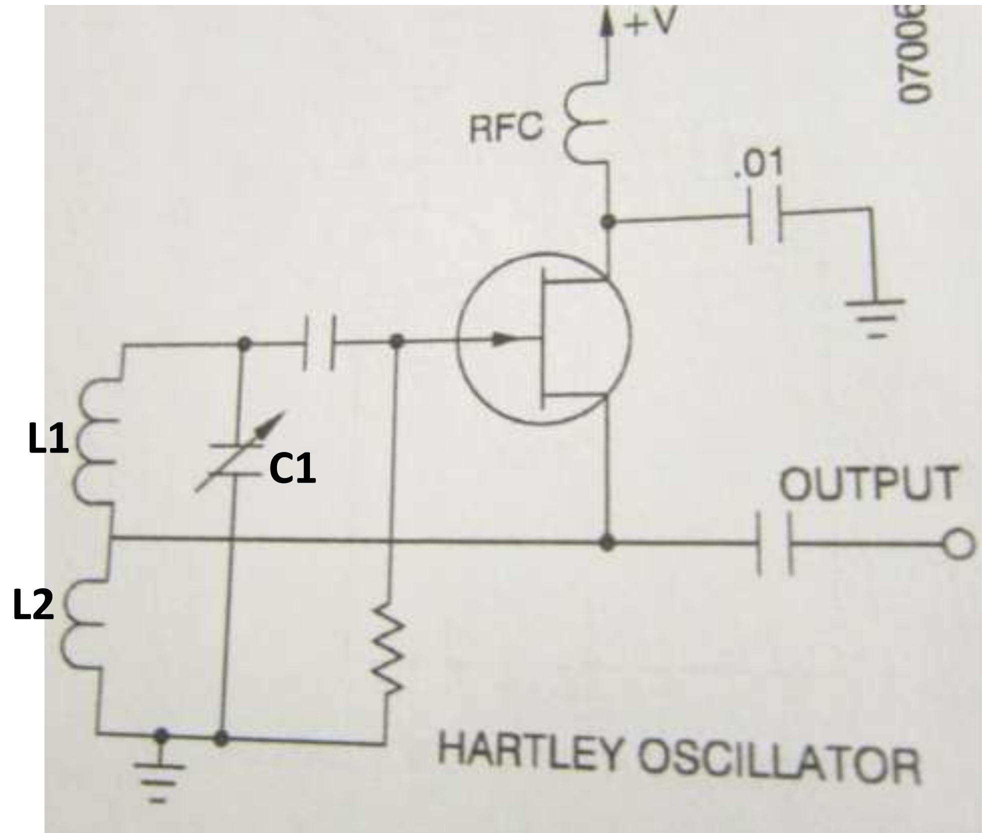

Fig 7-5

$f = 106/2\pi\sqrt{LC}$

-where f = resonant frequency (kHz), L = µH, and C = pF

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Colpitts VFO

-Split capacitor, instead of split inductor to tap off output and to provide positive feedback.

-C 1-4 all determine the VFO frequency.

-Popular VFO circuit due to its Stability.

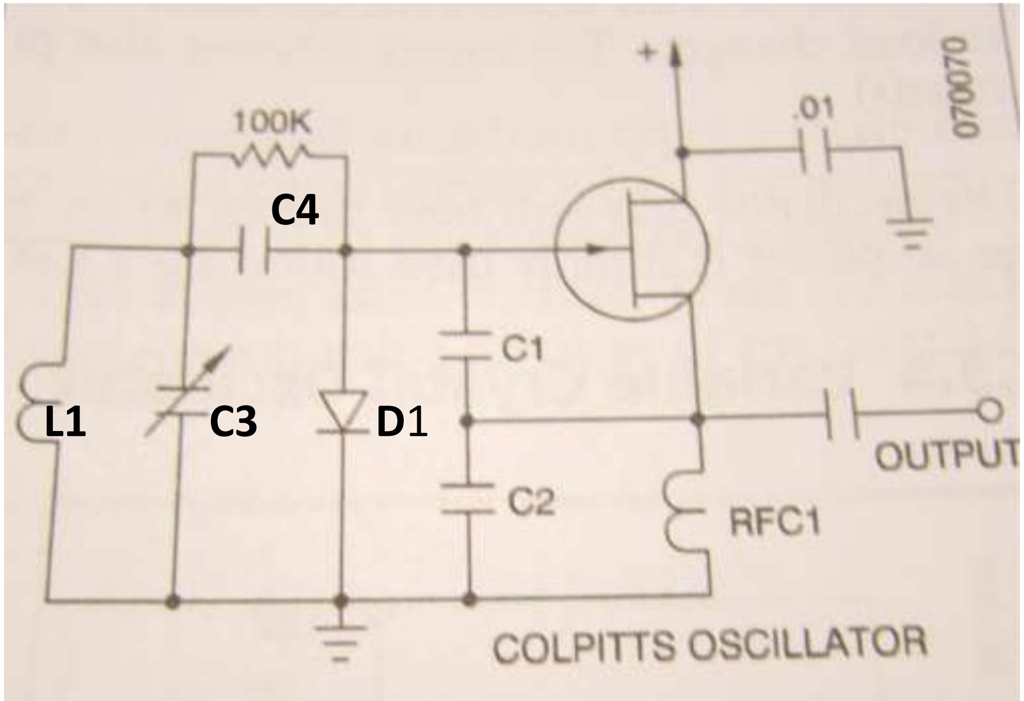

Fig 7-6

-D1 aids in producing negative bias on gate

-RFC should be low Q

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Clapp VFO

-series tuned version of Colpitts

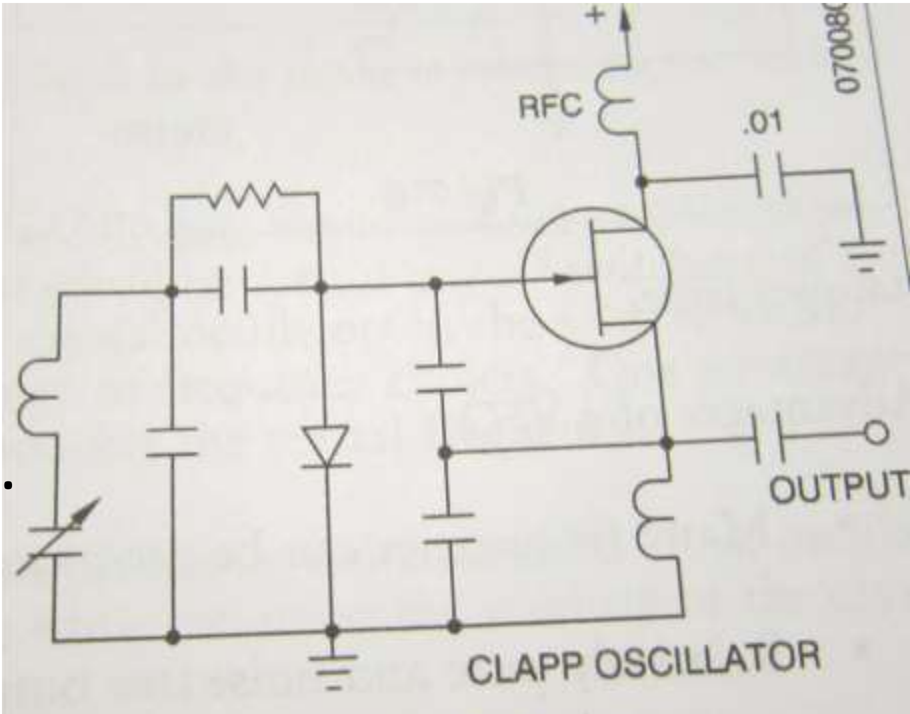

Fig 7-7

<u>Stable VFO (of any type) stability requires:</u>

1. Rigid mechanical design.

2. Low thermal expansion coefficients (ceramic + teflon much better than phenolic). Invar much better than Cu, Al, or Fe.

3. Low temp. coefficient inductors and capacitors.

4. Temp. compensating capacitors.

PTO (permeability tuned oscillator) uses variable L instead of C
-can be designed for very linear tuning

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Crystal VFO: varying the capacitance in series or parallel with a crystal changes its frequency a little

e.g.: a crystal cut for 7040 kHz, may shift from 7038-7042 kHz.

-if the crystal is “pushed” too far it will stop oscillating.

-used to move crystal-controlled radios off an occupied frequency.

-also used to set an oscillator on an exact frequency.

-the master oscillator in a modern TRX can be precisely set by zero beating with WWV on 2.5, 5.0 10, 15, or 20 MHz.

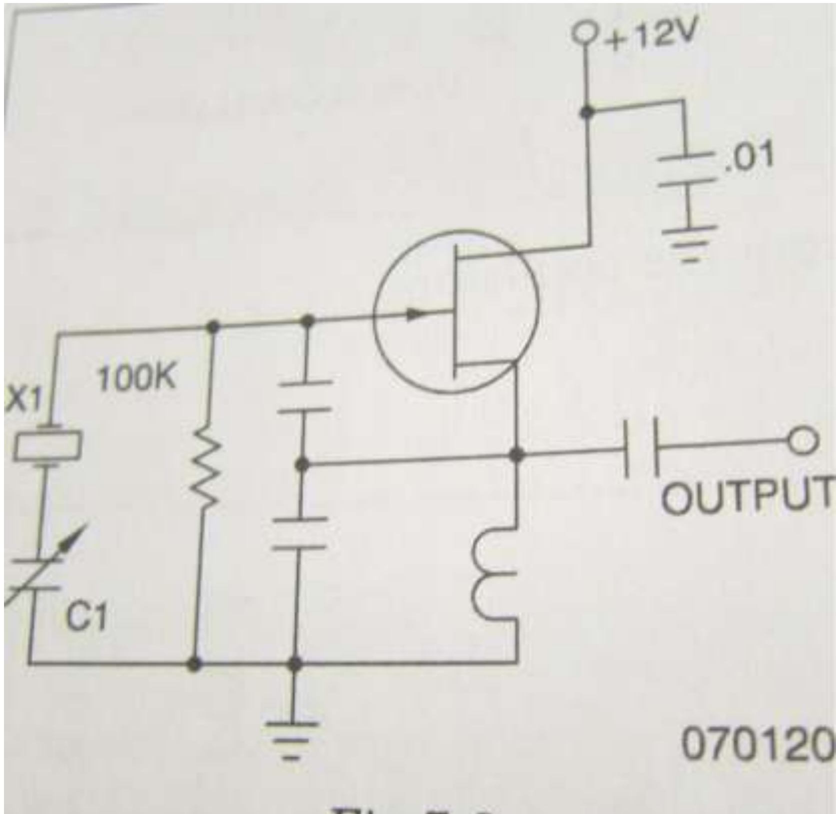

Fig 7-8

-if heavily coupled to another oscillator close to the same frequency, an oscillator can be pulled and lock on to the other oscillator’s frequency.

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GPS Disciplined Oscillator (GPSDO): a way to make your oscillator/radio as accurate and stable as GPS or NBS

-oscillators can be pulled by a nearby tuned circuit close to that circuit's frequency

-GPS signal → very accurate time, frequency, and near-perfect stability

-will lock transceiver or other master oscillator to GPS signal

-easy to implement with most modern radios, especially if MO is 10 or 20 MHz

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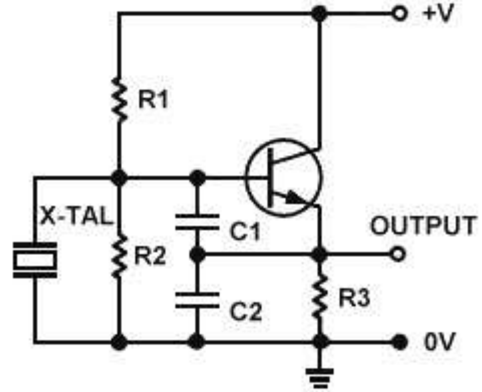
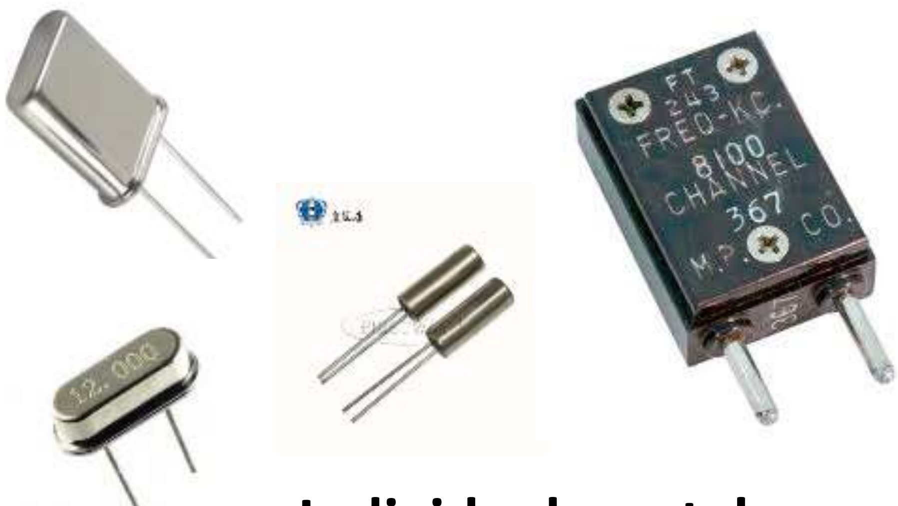
Sealed unit oscillators

+/- 0.5 ppm

Unit osc. circuit



Opened oscillator



Individual crystals

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"TCXO": -temperature–controlled crystal oscillator

-often set to 60°C

-reduces total drift of current Kenwood HF radios from 5.0 ppm to 0.5 ppm

-5 ppm = +/- 70 Hz at 20m

-0.5 ppm = +/- 7 Hz at 20m

For best crystal oscillator stability:

1. Constant temperature (above highest operating temp. of radio).
2. Regulated (constant) supply voltage.
3. Well buffered (constant load) output.
4. High quality close tolerance crystal.
5. Well-designed oscillator circuit.
6. Re-check over months/years for crystal drift due to aging.

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Digital oscillators

-Phase-locked loop (PLL) (hybrid between digital and analog)

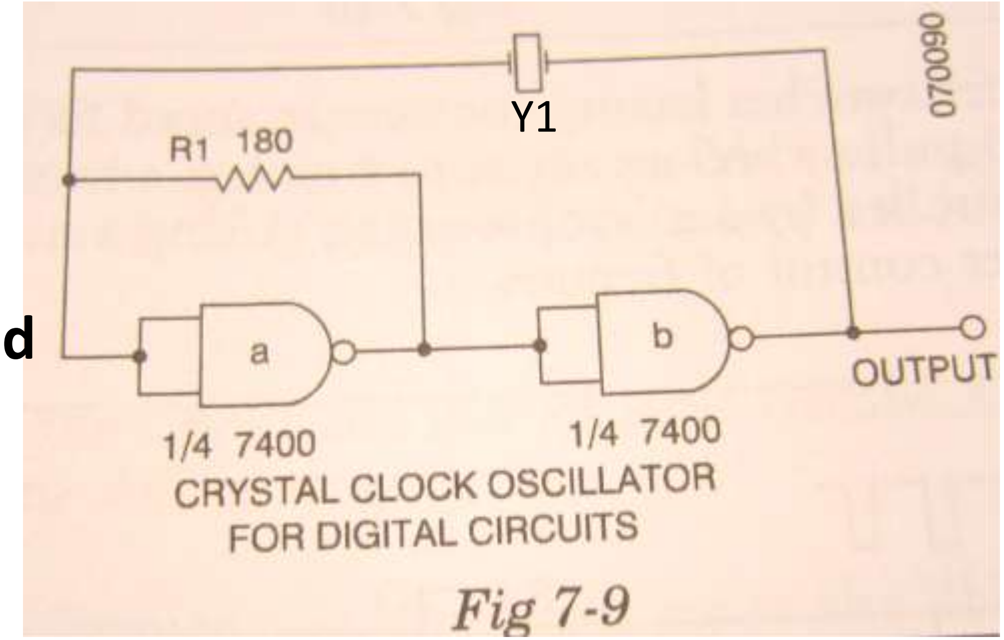
-Direct digital synthesis (DDS) (true digital generation)

Advantage of digital: stability of signal equals the controlling crystal while remaining tunable

Clock oscillators: xtal controlled

- -generate square waves
- -accurate

7400 a+b: NAND gates connected as inverters ("TTL" technology)



R1 holds 7400a in linear part of off-on shift needed to start oscillation.

Y1 shifts signal 180°

-third section of IC could be buffer amp (gain = 1).

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Clock oscillator : stable

-crystal osc. always used with digital frequency gen., because frequency change shows up as errors or phase noise in output.

VCO (voltage controlled oscillator), usually controlled by voltage applied to a varactor diode

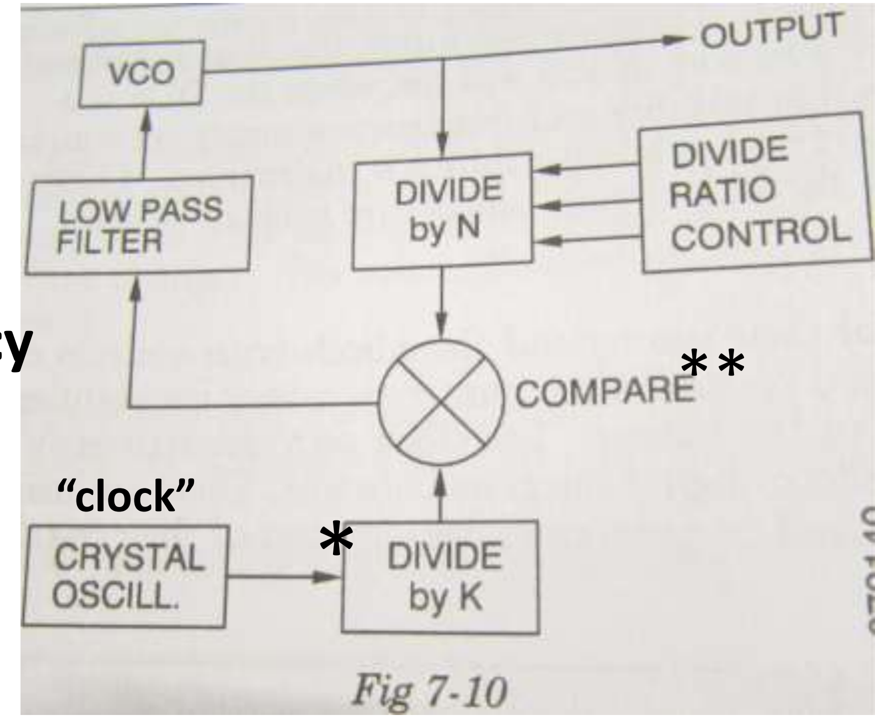
-not inherently stable, but kept very stable by correcting tuning voltage

Programmable digital divider →

VCO output kept in constant, precise relationship to the reference frequency

* = "reference output"

** VCO: clock osc. compared to VCO



PLL frequency generation

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Implementation of PLL generator

"Loop filter" output produces correction voltages for VCO

Only a <u>finite</u> <u>number</u> of frequencies are available i.e., there is a <u>minimum step size</u> for VCO control.

<u>Steps obvious + annoying when you tune on a strong signal</u>

Input from divider chain (N) →

Reference output to PLL→

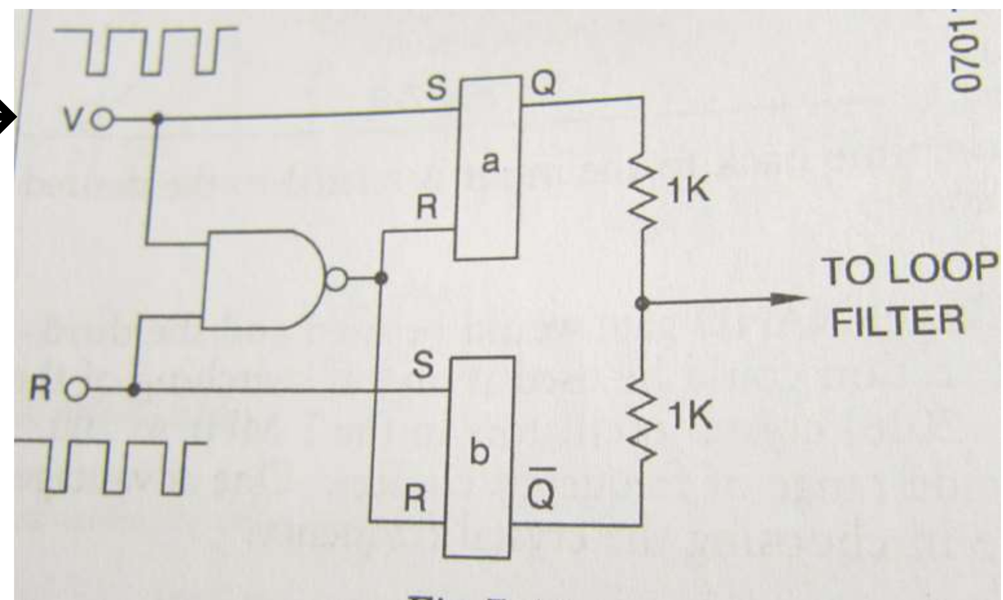

Fig 7-11

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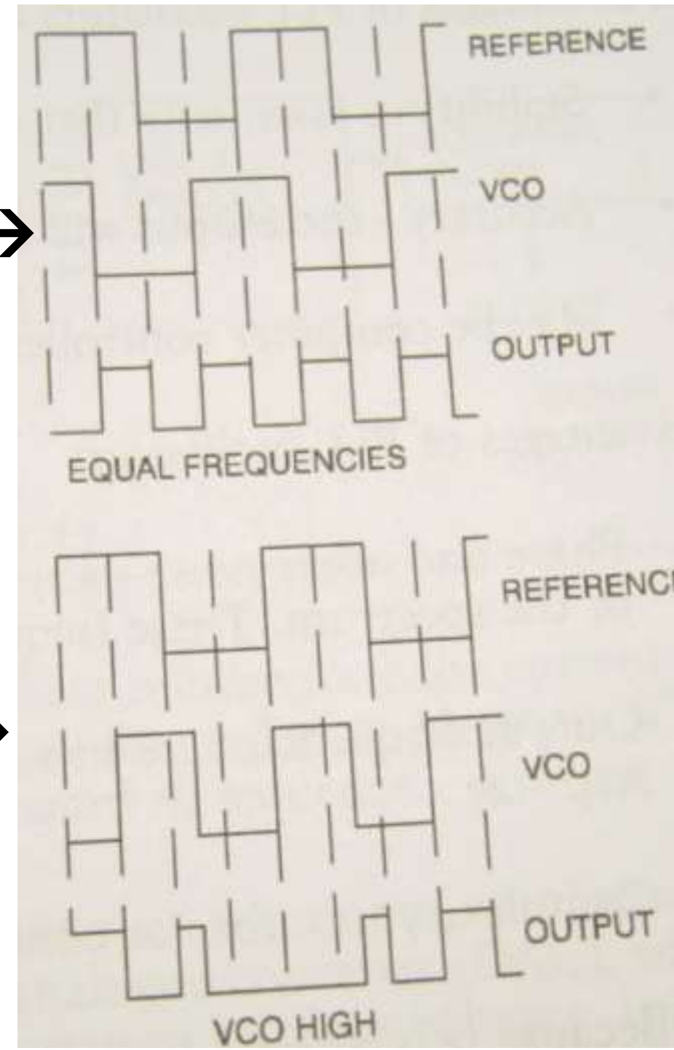
PLL: circuit keeps VCO on the closest possible frequency to the desired frequency

If minimum step = 100Hz, VCO corrected to nearest 100 Hz

VCO locked in to desired output →

VCO not corrected by reference →



Time →

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Direct Digital Synthesis (DDS): pure digital circuits functioning as a VFO

-good modern DDS types are almost indistinguishable from good analog VFOs (no audible "steps"!).

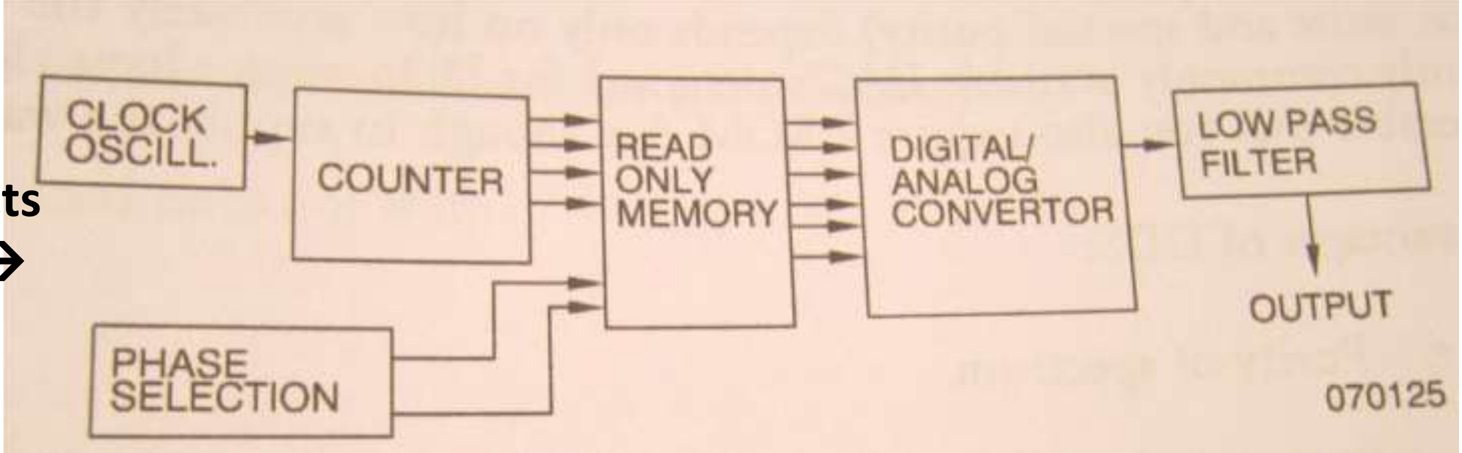
1. Step-free tuning and clean (low phase noise and distortion) output
2. Can be far more accurate and stable than analog VFOs.
3. DDS can produce clean sine, or any other arbitrary waveform.

-creates waveform 1 step at a time: the more steps per cycle, the higher the DDS operating frequency must be.

-uses DAC (Digital to Analog Converter) and ROM circuits.

-high, complex HF waveforms need UHF or GHz DDS frequencies.

How DDS constructs a frequency →



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DDS frequency synthesis

Minimum number of data points/cycle = 2

More data points = waveform is more accurate

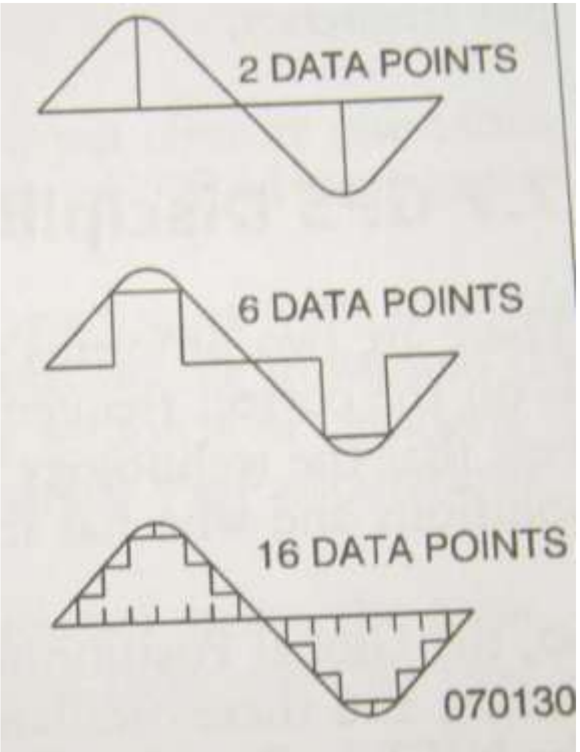

Fig 7-14

DDS Advantages

1. Stability equals the clock crystal
2. Output exactly what is set by dividers
3. Can be computer-controlled

DDS Disadvantages

1. Phase noise, other noise may occur
2. Output frequencies are in steps. Steps determined by the smallest division the circuitry will allow
3. Complex, but this reduced by large-scale integration
4. Difficult to troubleshoot and fix.

PLL used in receivers + transmitters as far back as 1969

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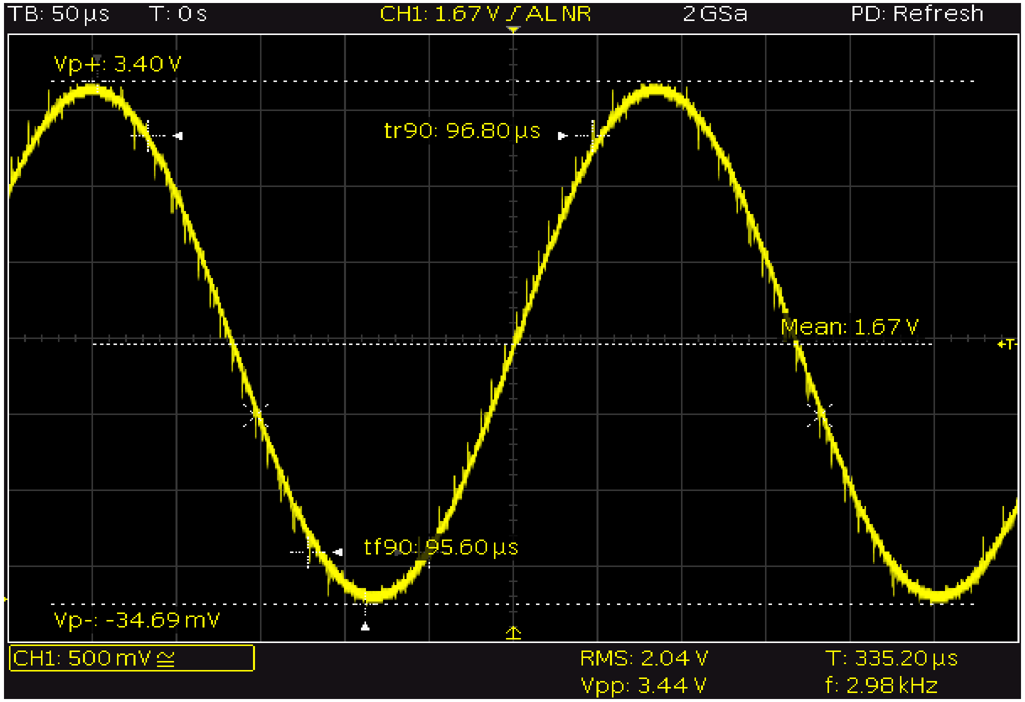
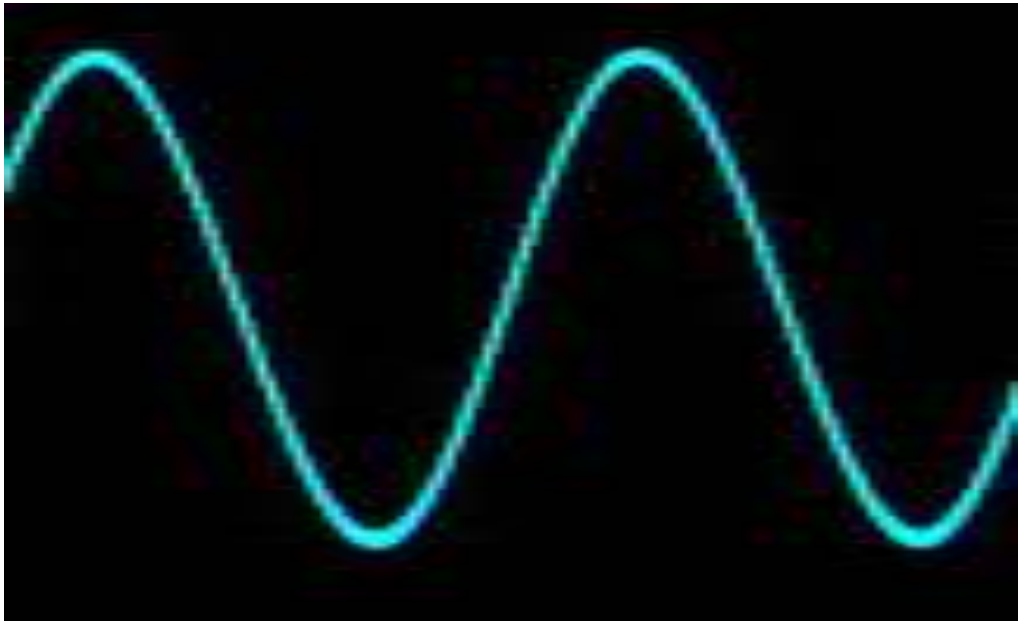
DDS generated “sine” wave



Analog generated sine wave



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DDS board of Kenwood TS-850 HF transceiver (1990 technology)

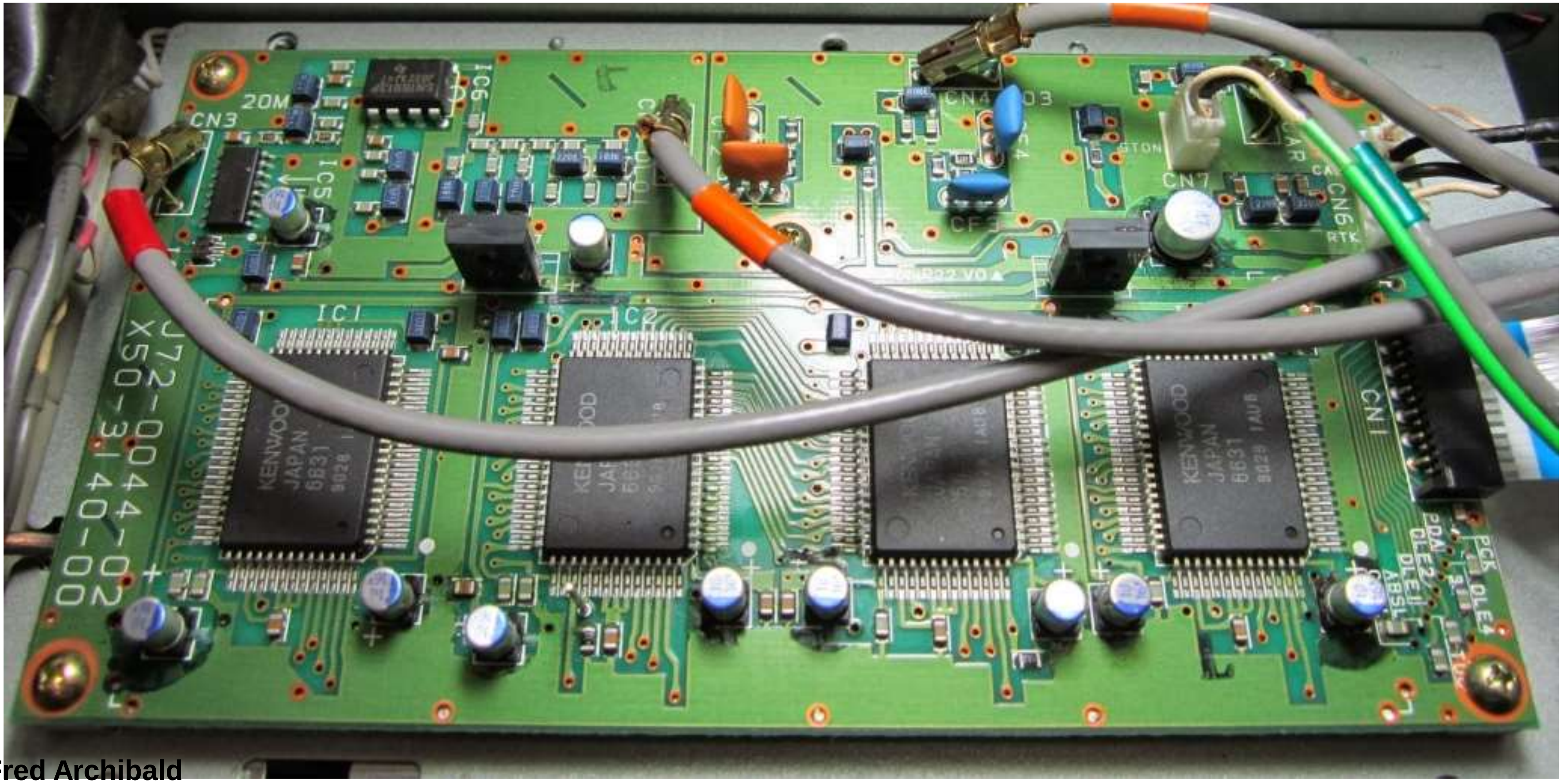
Starting with master oscillator frequency:

-3 local oscillator frequencies

-SSB, CW, digital "BFO" frequencies

-main tuning VFO frequencies

-100+ memories



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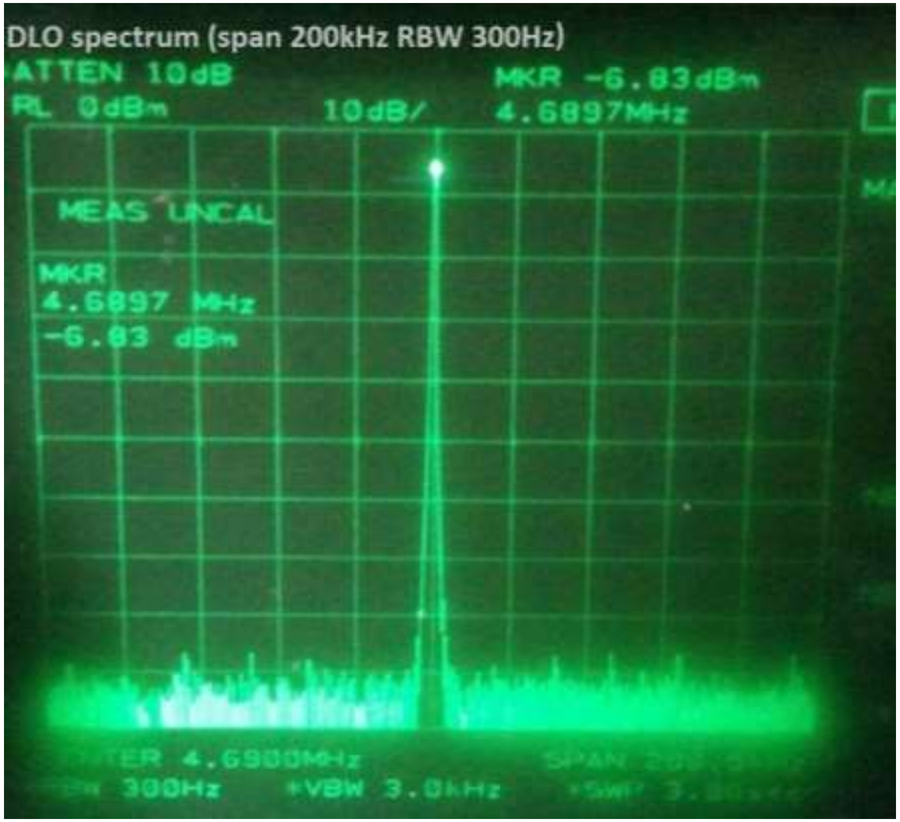

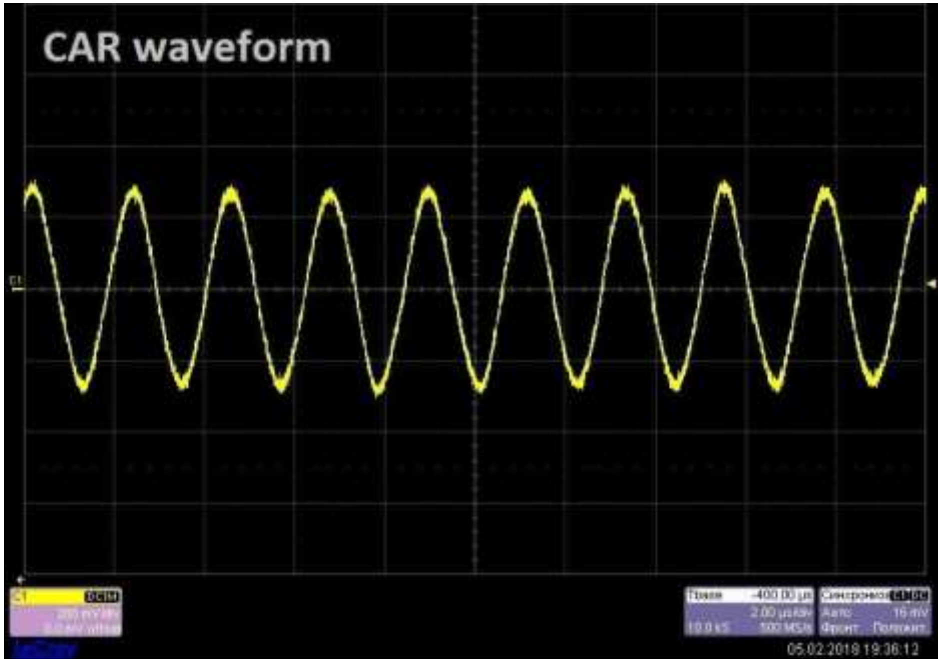

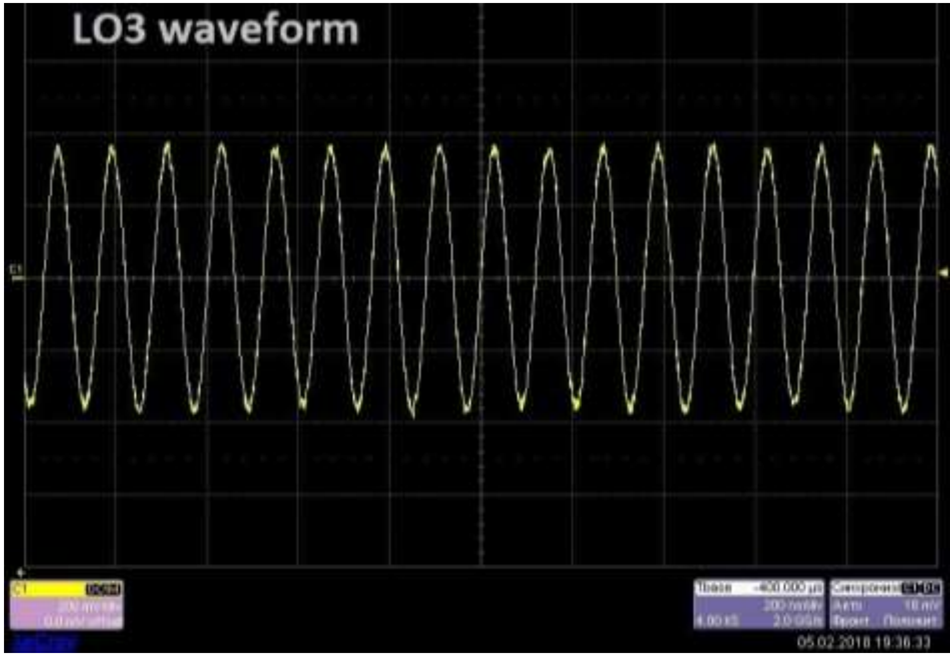

DDS generated LO frequency

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Parasitic Oscillations: unintended oscillations occurring in an amplifier or oscillator circuit

Can be big problem in home-brew + older gear, especially power amplifiers

Neutralization: negative feedback applied an amplifier to improve stability and kill parasitics

-high gain amplifiers most susceptible

-stray capacitance within and around active device may allow positive feedback, leading to instability and oscillations

Cbc –stray unintended capacitance

CN- neutralization capacitor, tuned to exactly cancel parasitic or instability

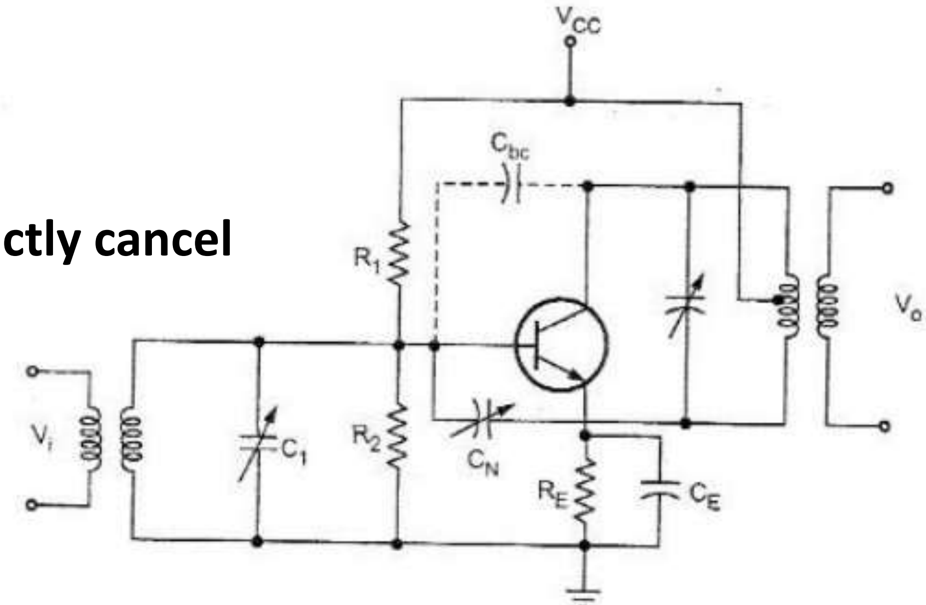

Fig. 3.36 Tuned RF amplifier with Hazeltine neutralization

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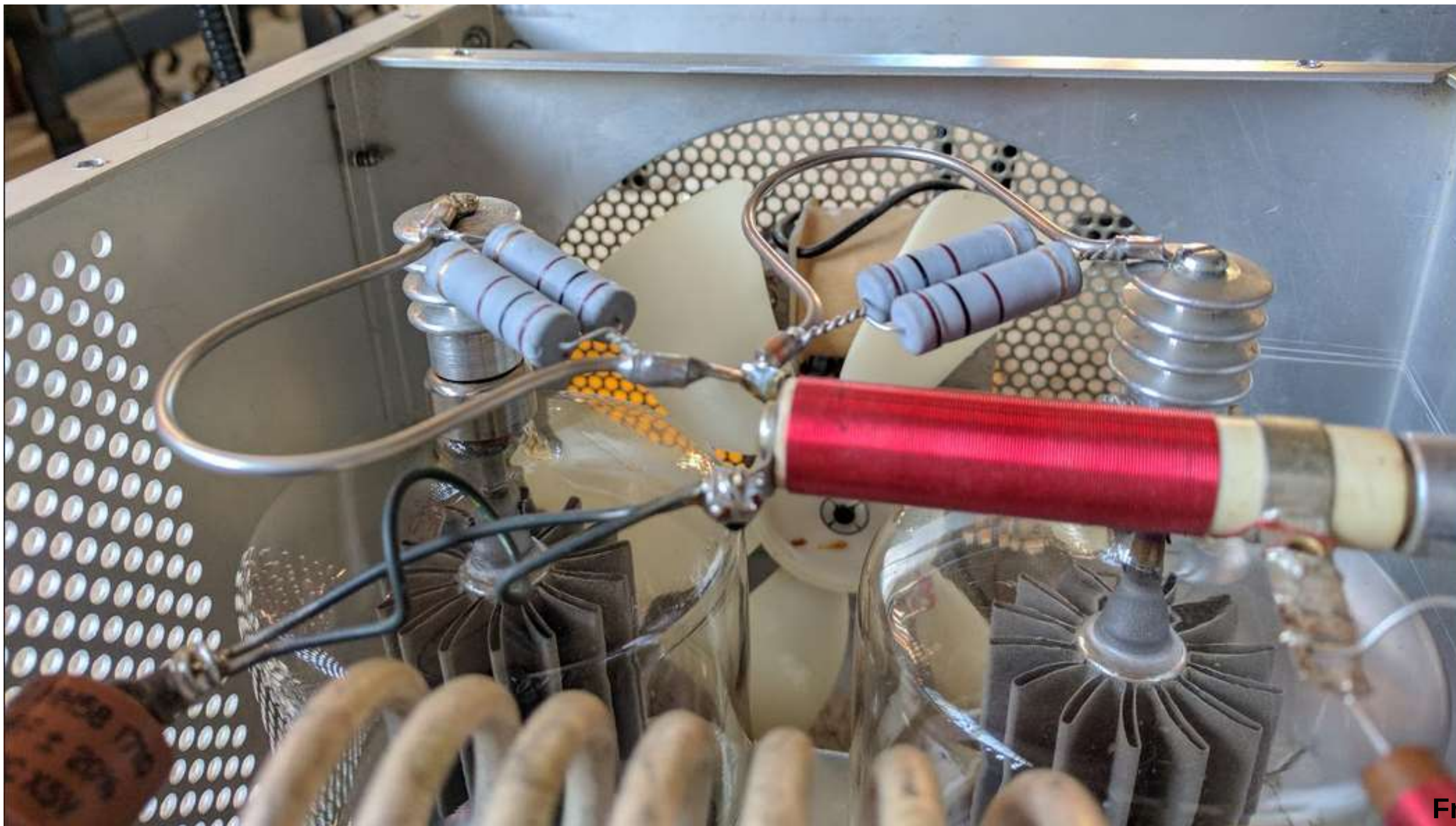
Parasitic suppressors for big tube linear amplifiers

Tinned copper wire/carbon
resistor (old style) →

Nichrome wire-metal film resistor (new) style



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End of oscillators!