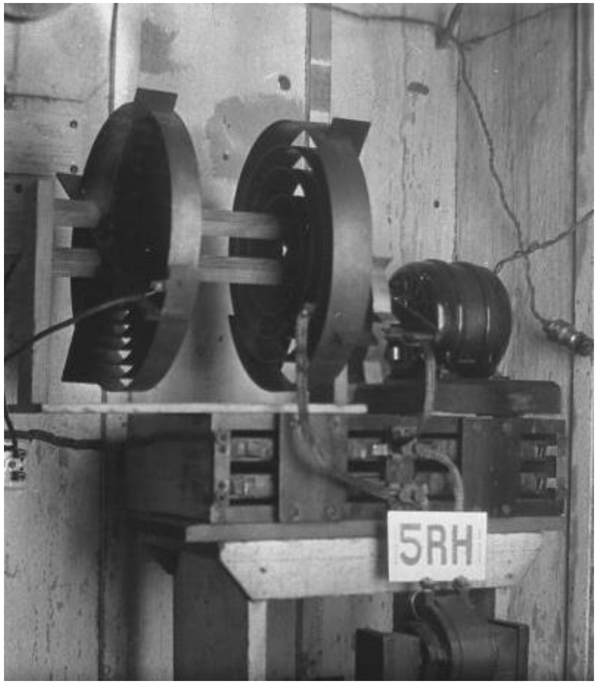
Advanced Course Ch. 9 Transmitters

de VE1FA, 2019

1915



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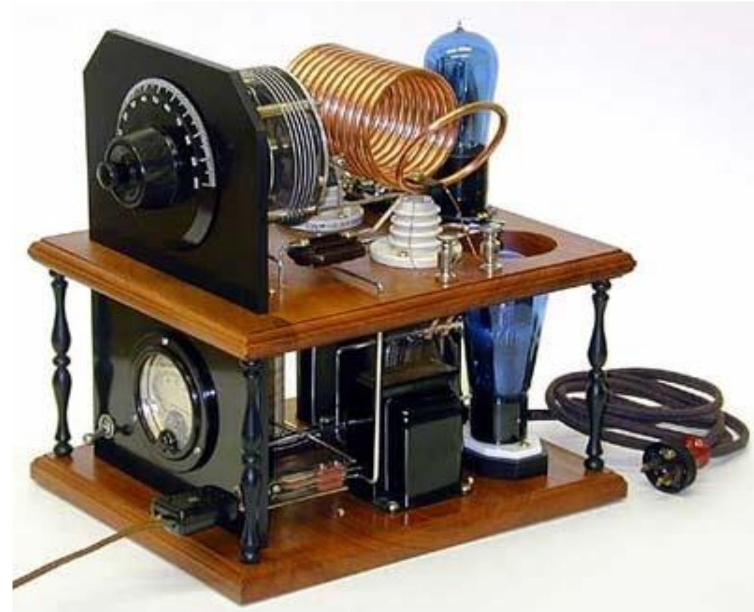


A reproduction 1929 one-tube Hartley transmitter for 80 Meters by Rick Weber, W9QZ.

1952

1990s

Untangling RF power terms

Carrier power = PEP (peak envelope power) = average power in steady carrier modes, like CW, FM, FSK, RTTY, JT-9, JT-65, but not in varying carrier modes like AM and SSB.

RMS power = 0.707 of PEP in steady carrier modes

RMS watts = DC power watts = "power company watts"

PEP: highest envelope power supplied to Z-matched TX-line delivering complete undistorted cycles.

PEP in 100% modulated AM (DSB + carrier) = 4 x average power

PEP in SSB = 3-10 x average power (varies with ALC, mic used, and voice)

Current Canadian Amateur Transmitter Power Regulations
RBR-4, Issue 2, 22 January, 2014

10. Restrictions on Capacity and Power Output

The transmitting power of an amplifier installed in an amateur station shall not be capable of exceeding by more than 3 dB the transmitting power limits described in this section.

10.1 Amateur Radio Operator Certificate with Basic Qualification

The holder of an Amateur Radio Certificate with Basic Qualification is limited to a maximum transmitting power of:

(a) where expressed as direct current power, 250W to the anode or collector circuit of the transmitter stage that supplies radio frequency energy to the antenna; or

(b) where expressed as radio frequency output power measured across an impedance-matched load,

(i) 560W peak envelope power for transmitters that produce any type of single sideband emission, or

(ii) 190W carrier power for transmitters that produce any other type of emission.

10.2 Amateur Radio Operator Certificate with Advanced Qualification

The holder of an Amateur Radio operator Certificate with Advanced Qualification Is limited to a maximum transmitting power of:

(a) Where expressed as direct-current power, 1000 W to the anode or collector circuit of the transmitter stage that supplies radio frequency energy to the antenna; or

(b) Where expressed as radio frequency power output measured across an impedance-matched load,

(i) 2,250 W peak envelope power (PEP) for transmitters that produce any type of single sideband (SSB) emission, or

(ii) 750 W carrier power for transmitters that produce any other type of emission.

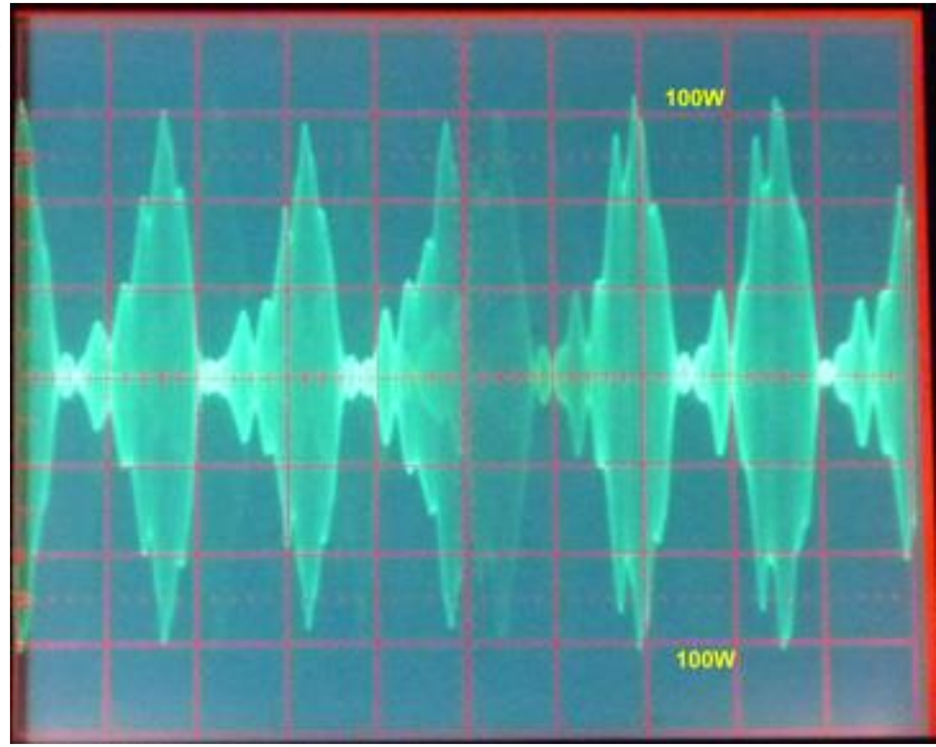
In US: "Extra"-class ops allowed 1500 W PEP in ALL modes. (FCC Part 97)

SO: Advanced Canadian amateurs can use 50% more power in SSB, but only half as much power in CW, AM, FM, RTTY, and many digital modes as US "Extra" class amateurs!

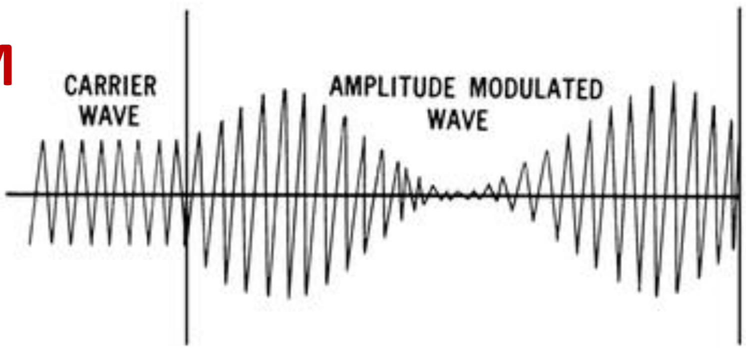
Carrier pwr = PEP pwr = average pwr
In CW + FM, but not in SSB or AM

SSB signal →

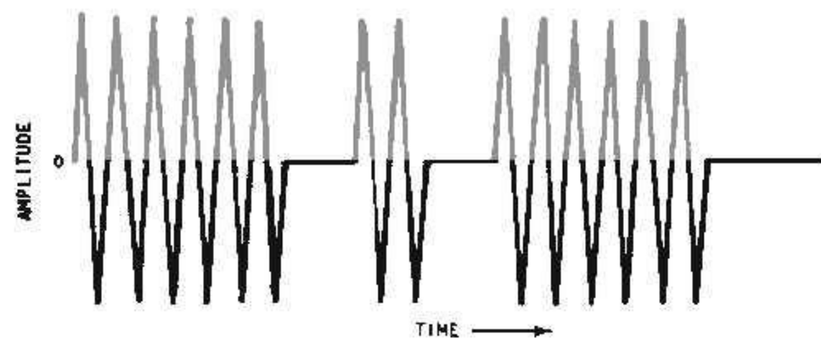
Average SSB pwr = 10-30% of PEP →



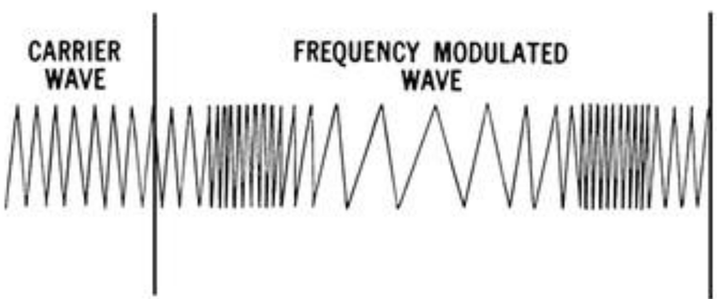
AM



CW



FM



Key properties of a good transmitter (TX)
(from a regulatory viewpoint!)

1. Frequency stability (with varying time, temperature, vibration, changing voltages, T/R change-overs, etc.)

2. Spectral purity: all emissions other than intended frequency should be > 40 dB down. e.g.: noise, RFI, EMI, harmonics

3. Over-modulation protection/limitation built in TX

4. Bandwidth limitation (consistent with modulation mode)
   e.g.: SSB 3.0 kHz; AM 6.0 kHz; CW 0.5 kHz

Basic Transmitter

Osc. → Buf. → Driver (IPA) → Power Amp. (PA) →
output + filter circuits→ Antenna
Modulator

<u>Osc.</u>: creates RF energy: stability, adjustability, purity
<u>Buf.</u> : shields osc. from changing load, may provide some gain

<u>Modulator:</u> Impresses intelligence on RF carrier
<u>Driver</u>: increases voltage and power in modulated carrier

<u>Power Amp</u>.: Raises signal power to desired output to antenna
<u>Output circuits</u>: adjust output impedance (usually to 50Ω) + block DC

<u>Filter circuits</u>: Remove most of the undesired harmonics and other RFI.

The Power Amp. (PA) output

A “pi” (π) output circuit, allowing output Z adjustment and resonating the output “tank” to the desired frequency. →

Function of each component?? →

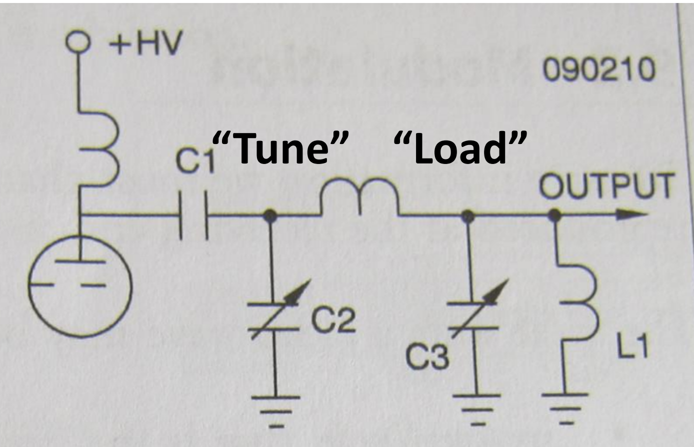


Fig 9-2

Tuned transistor PA matching network →

L2, C1, C2 form resonant matching network

Z matching PA transistor adjusted by L2.
Z to load adjusted by C1:C2 ratio

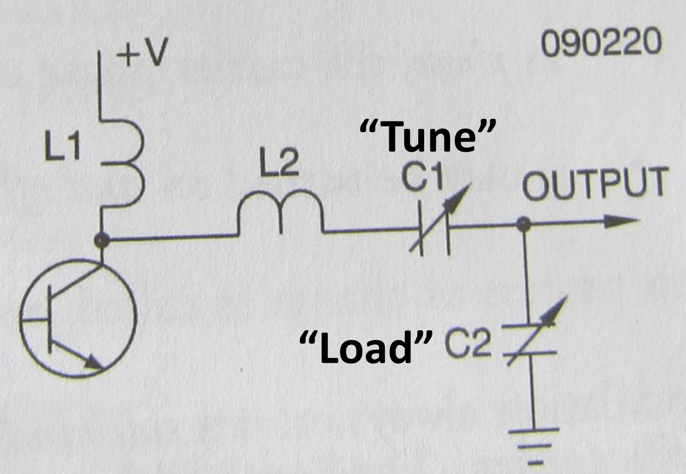


Fig 9-3

“Hybrid coupler” used in higher power transistor amps

L1+L2+L3 form hybrid coupler (a broadband untuned matching circuit)

L1 + L2 are <u>bifilar pair (2 twisted wires)</u>

Must be followed by a low-pass or band-pass filter

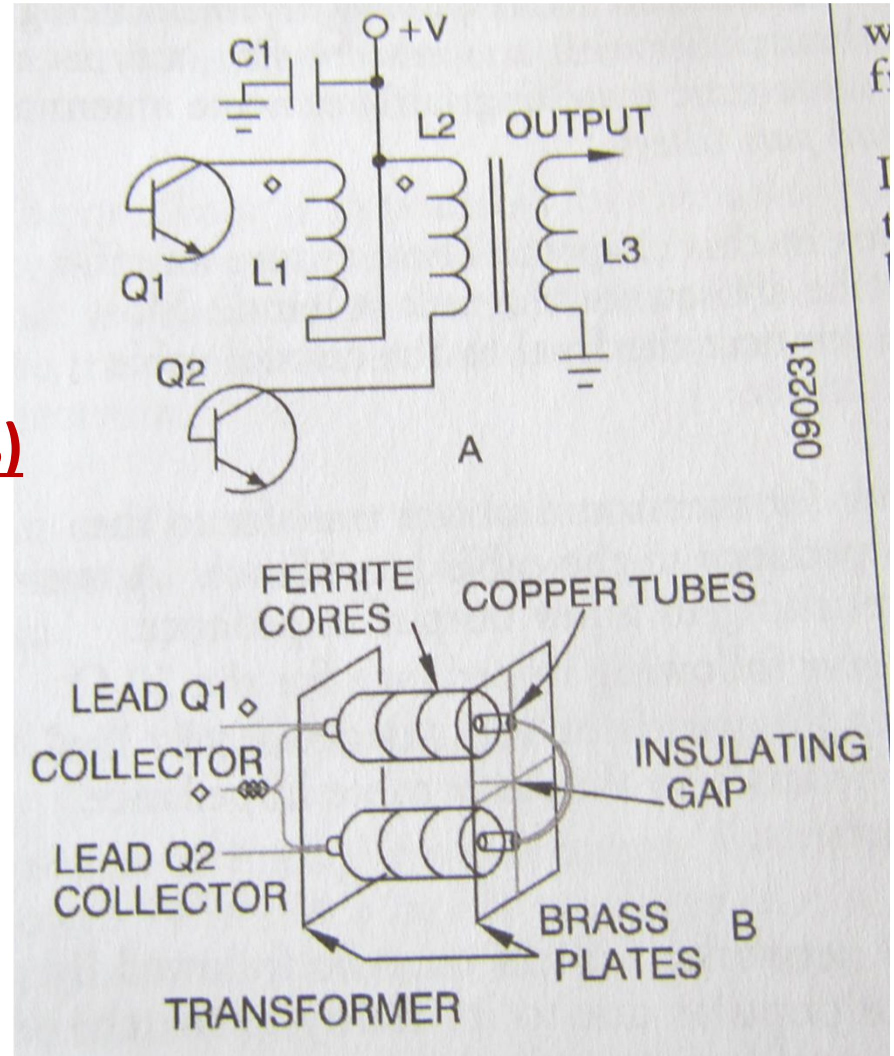


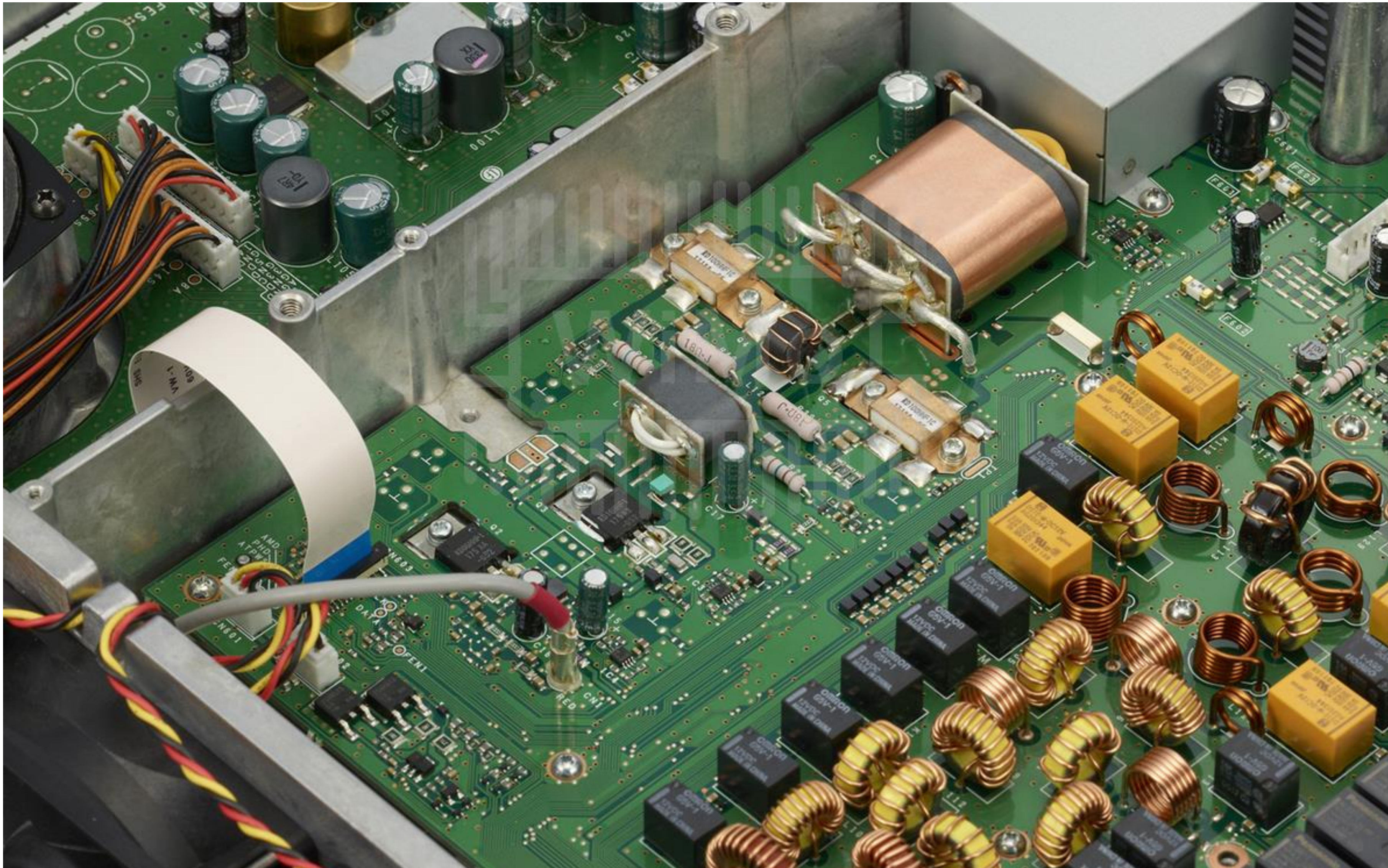
Fig 9-4

Modern 100W 1.8-60 MHz Transceiver Power Amplifier

-push-pull 175W MOSFETS, broadband RF transformers

-massive aluminum heat-sink with fan

Kenwood TS-590SG (2014)



TX Modulation

-via amplitude (AM, SSB)
-via frequency (FM, FSK)
-via phase (PM)
-carrier ON-OFF (CW)

Modulation always creates sidebands, as modulators are mixers

Amplitude modulation (AM)

-impresses audio power on RF carrier
-constant carrier as long as TX is on
-modulation (and carrier) power vary
with audio signal entering modulator

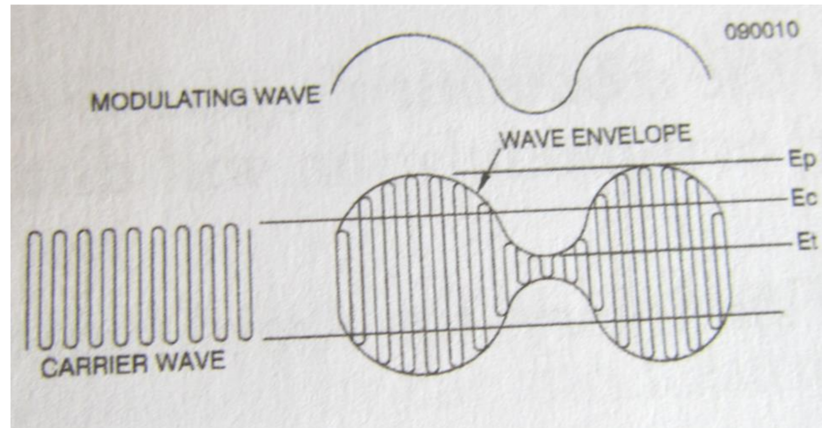


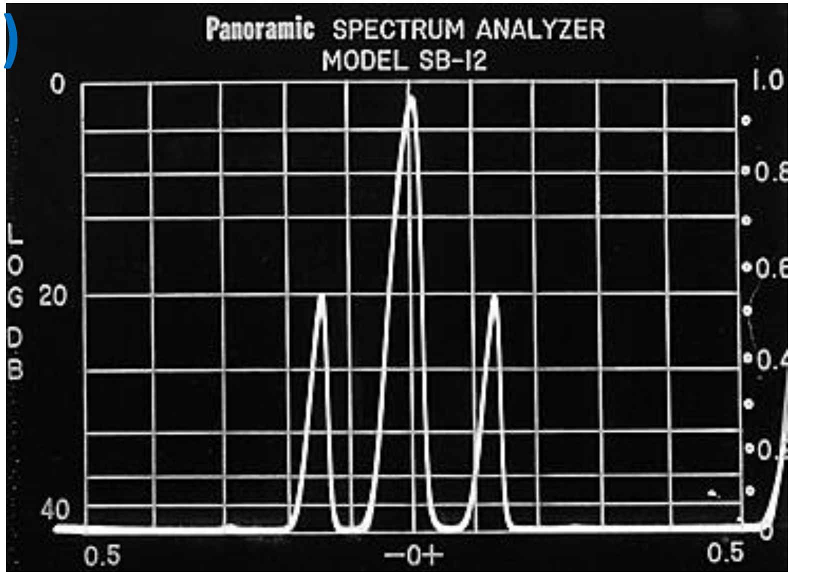
Fig 9-5

% modulation = $E_P - E_T / 2E_C$ x 100%

% modulation = $E_C - E_T / E_C + E_T$

$E_P = E_{PEAK}$
$E_C = E_{CARRIER}$ (constant amplitude)
$E_T = E_{TROUGH}$

1 MHz carrier amplitude modulated (AM) with 1 kHz audio (DSB with full carrier)

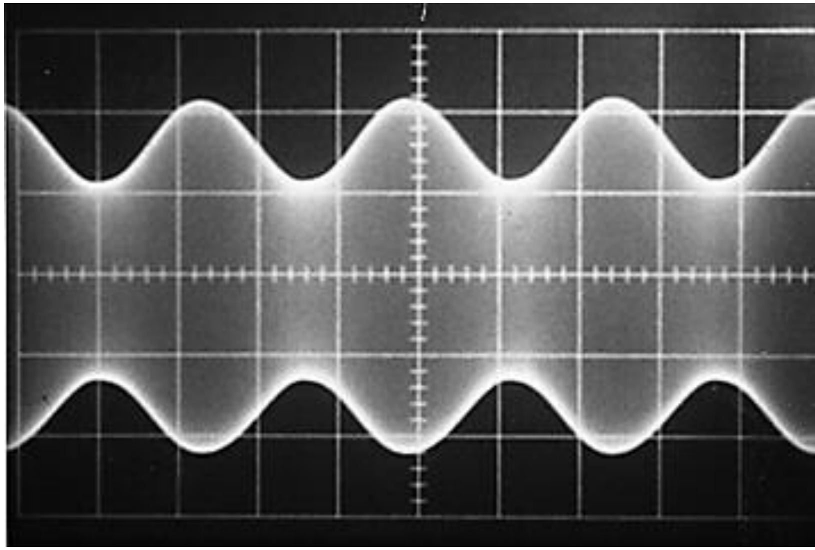


What would change if 1 kHz tone replaced by voice?? →

Frequency →

High-level "PA" AM modulation

-high audio power applied to PA
-50W mod. applied to 100W PA to produce 100% modulation
-total signal power = 150W P-P
-allows the PA to use efficient class C bias



Low-level "grid" AM modulation

-low power audio mod. applied to pre PA stage
-PEP out same as unmodulated carrier
-PA must run as linear amplifier (B or AB)
-used in all modern ham transceivers
-lower efficiency and output compared to high level mod.

Time →

Modulation and Power (AM mode)

-sideband amplitude (voltage) determines % modulation
-power (W) = amplitude (voltage)^2

Therefore, 100% → 50% modulation cuts signal power by 2^2 or 4!

Remember,
-at 100% modulation , carrier power is 2x total sideband power

Total Sideband Power (Watts)	Modulation %	Sideband Amplitude (as % of carrier)
50	100	71
32	80	57
12.5	50	35
4.5	30	21
0.5	10	7
0.0	0	0

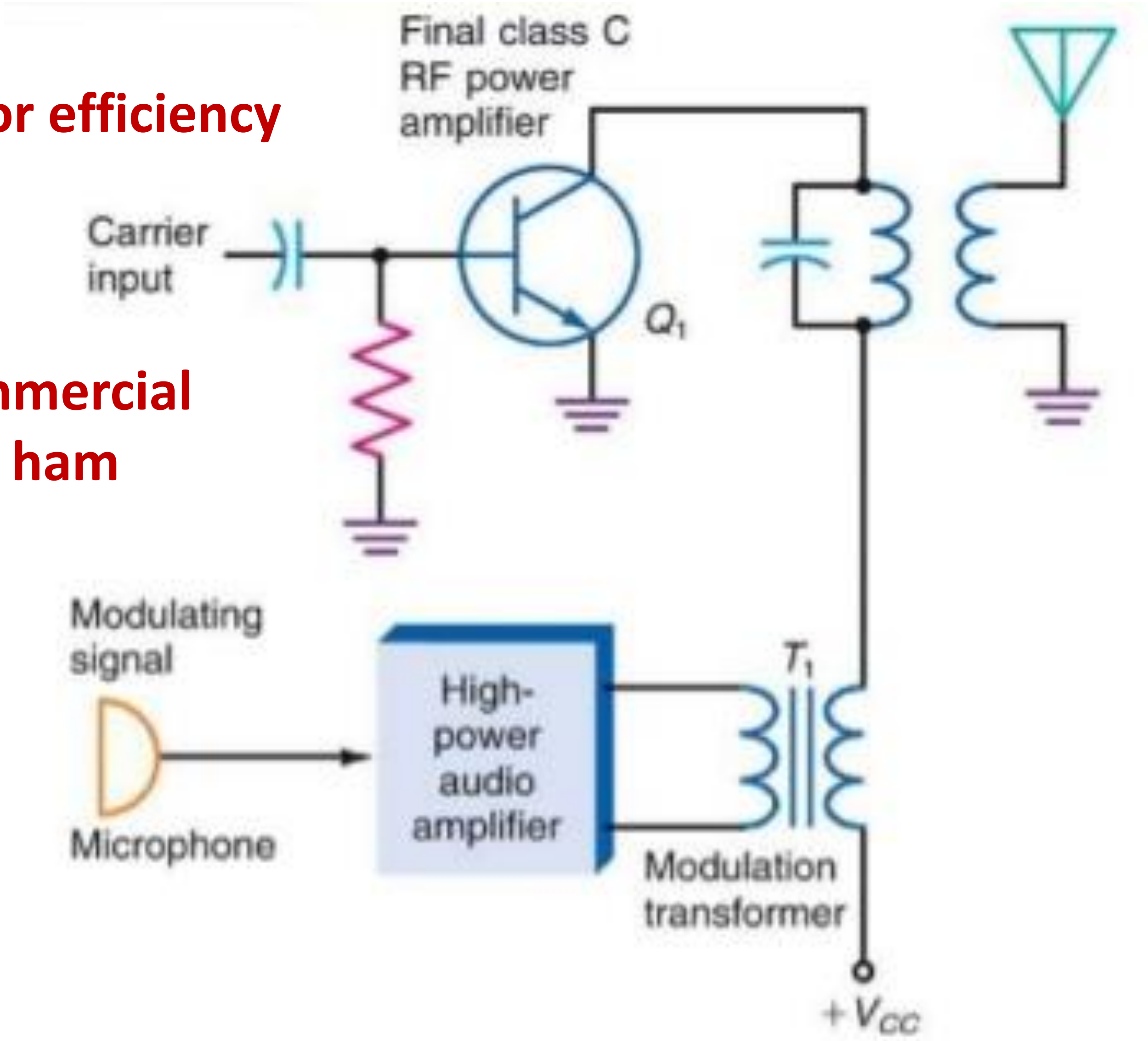
Fig 9-28

High-level (plate or collector or drain) AM modulation

-audio power added to RF power via T1 (the modulation transformer)

Q1 biased class C for efficiency

Widely used in commercial AM stations, older ham gear



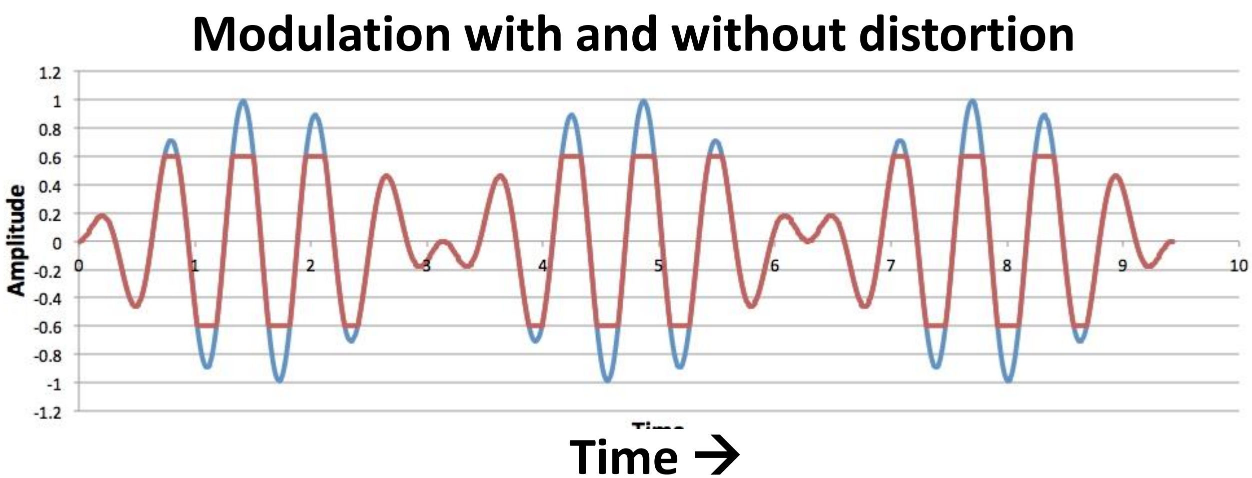
Full AM signal = carrier + upper + lower sidebands

(carrier power does not vary with modulation)

If RF power = 1000W and modulator (audio) power =500W (F1 + F2)

Total power = 1500W at 100% modulation, 1000W at 0% modulation

If AM modulation exceeds 100% : clipping of waveform and distortion, QRMing band!



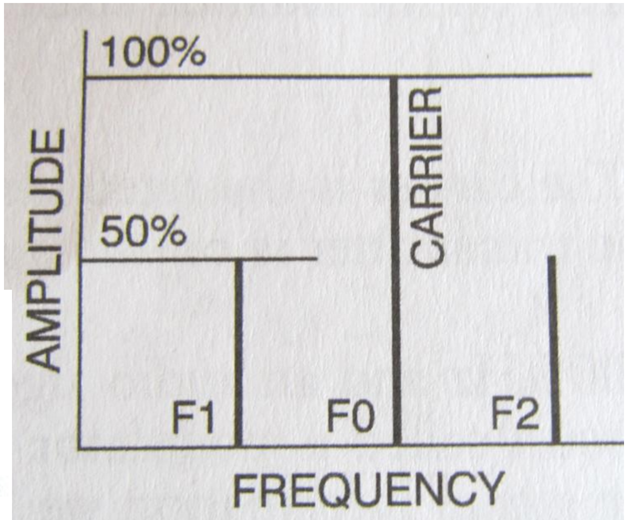


Fig 9-6

AM modulated carriers

(supposed to be sine wave carrier and modulation)

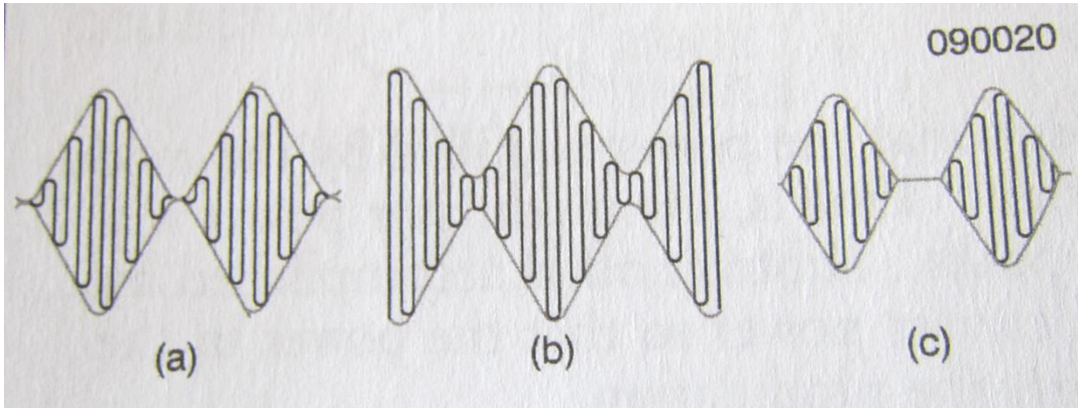


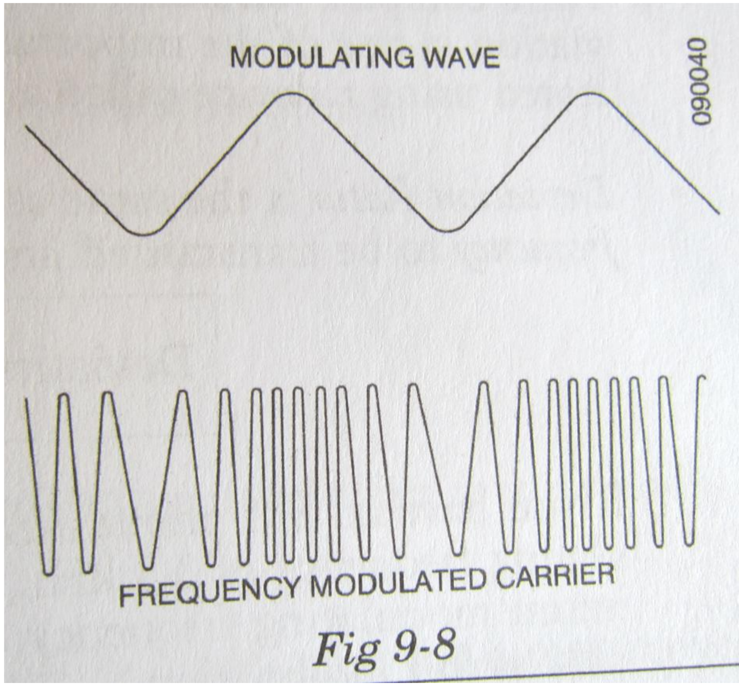
Fig 9-7

a. 100% modulation: most efficient. Any greater modulation will cause distortion.
b. < 100% modulation: low distortion + splatter, but reduced transmitter efficiency (will sound weaker in RX).
c. Over-modulation. Illegal, causes strong distortion, splatter in band.

Whether over-modulation produces clipping (previous slide) or the distortion in (c) above depends on modulator circuitry.

Frequency Modulation (FM) (F3)

Frequency of transmitted signal is varied in master oscillator
-signal (carrier) **amplitude** remains unchanged



Deviation: amount (Hz) of frequency shift
:should match receiver bandpass
:measured with a deviation meter
:needs to be set correctly in FM TX
:carrier +/-5 kHz in most Amateur work (NBFM) bandwidth = 10 kHz

Modulation index (MI) = deviation/modulating frequency ratio
= 10 kHz/2 kHz = 5.0
-for a voice, each voice frequency will have a different MI.

Deviation Ratio = Max deviation/Highest modulation frequency

= +/- 7 kHz / 3.5 kHz = 2.0

Noise suppression capabilities of an FM signal are directly related to the deviation ratio.

Commercial (hi-fi) FM: deviation ratio of 5.0, with max audio frequency of 15 kHz, total swing of +/- 75 kHz (Wide Band FM) (WBFM)-produces high quality audio

Amateur FM deviation: +/- 5 kHz (NBFM) -better use of spectrum

: audio bandwidth 3 kHz

: deviation ratio of 5/3 = 1.67

: narrow signal→ good S/N ratio→ good range

*FM bandwidth: 2 x FM signal deviation (Hz) + f_m (highest modulating frequency (Hz)

*Carson's Rule

Phase modulation (PM) and FM are 2 types of “angle modulation”

-both shift the frequency and phase of the carrier

-PM signals detected by an FM detector will sound funny due to a boost in the higher modulating frequencies

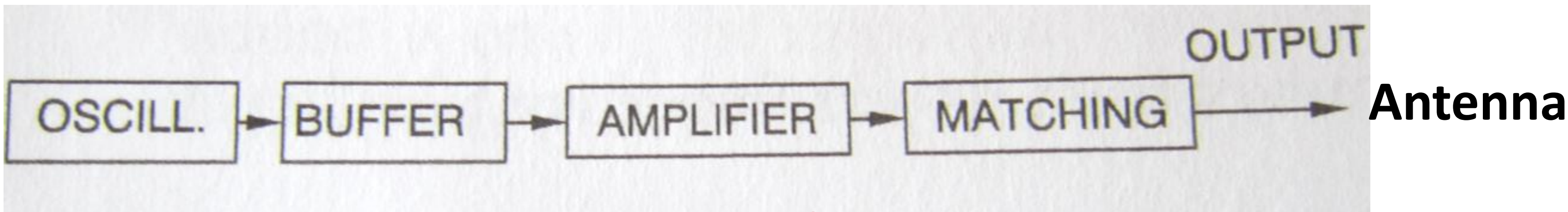
-PM little used by hams

Simple CW transmitter (a “MOPA”)

-simplest possible would be just an oscillator and antenna matching

-popular design for simple “QRP” ham rigs

-osc. can be VFO or VXO or fixed (usually xtal (crystal)-controlled)

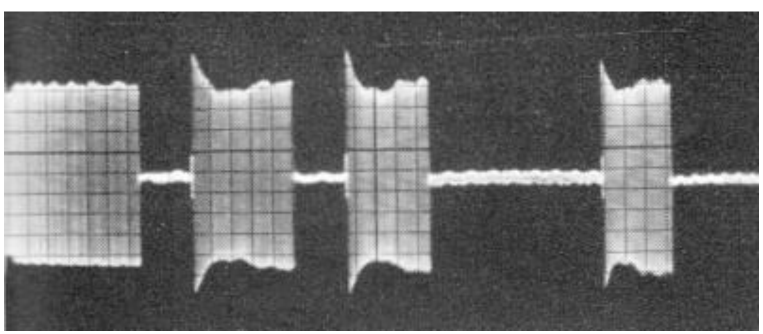


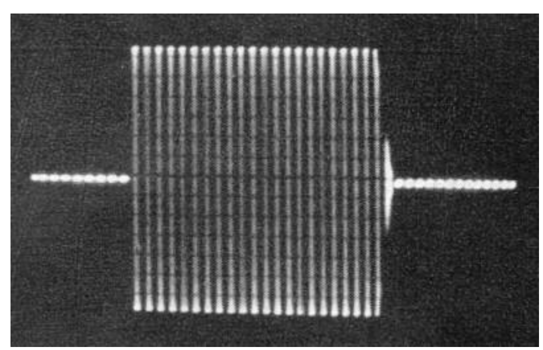
-Keying can be of osc. , buffer, and/or amplifier

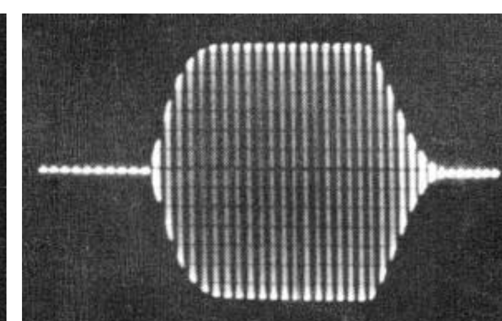
-Keying of some oscs will produce “chirp”: LC oscs are worse than crystal ones. Need good supply voltage regulation.

-chirp: slow arrival of osc. at correct frequency at turn-on

-Key clicks produced by rapid rise time of leading edge of keyed carrier dit or dah.







“Single-stage” crystal-controlled CW transmitter

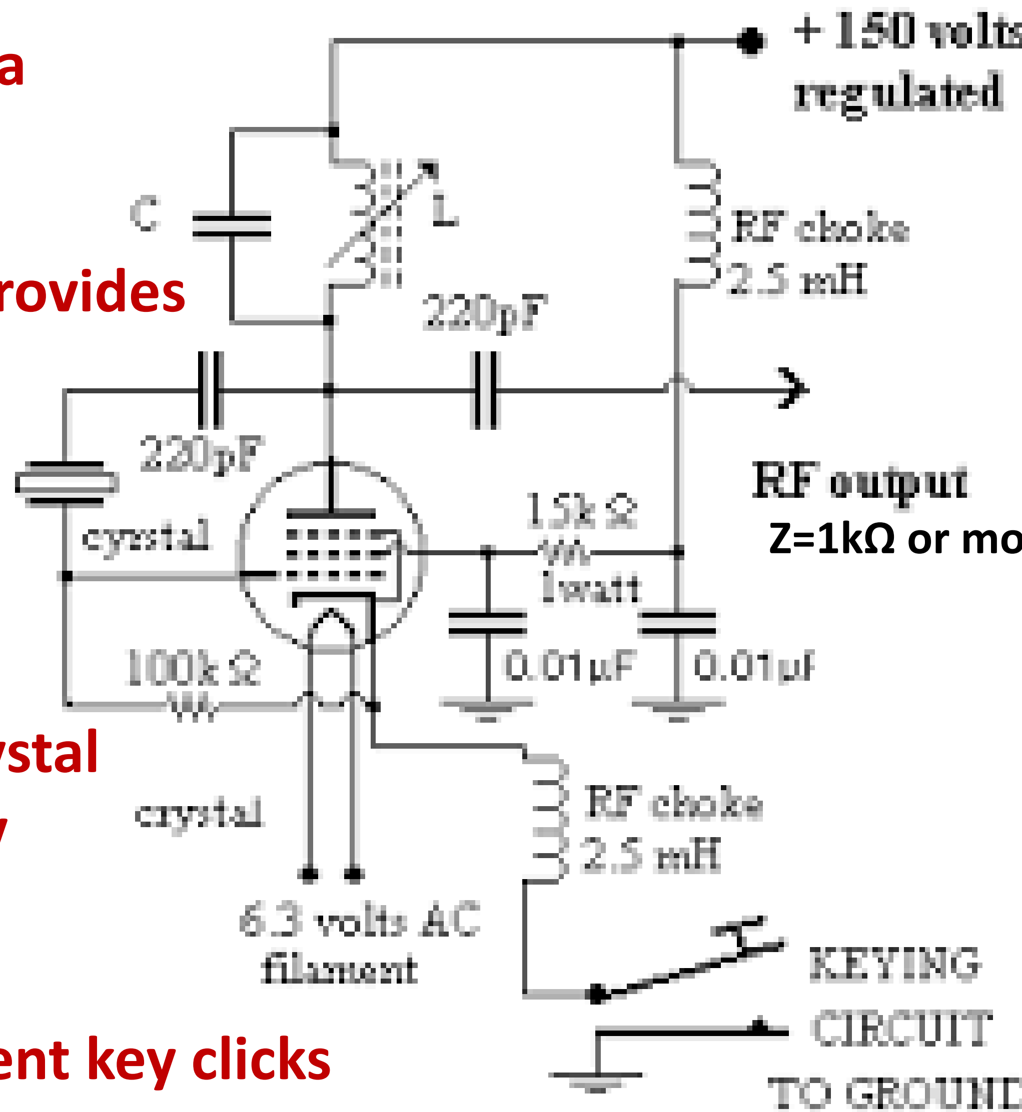
Missing: Z-match to antenna
: power supply

-electron coupling (ECO) provides buffer effect

-screen grid acts as osc. plate in a triode

-regulated B+, ECO, and crystal provide very good stability

-cathode choke helps prevent key clicks



2-stage (MOPA) QRP transmitter based on Pierce osc.

-osc. (Q1) keyed to avoid chirp caused by PA loading osc.

-T1 matches osc. to PA

-Q2 will be class C as no current will flow if osc. isn't running

-C4 is click filter, increases Q1 voltage rise time

-FL1: low-pass filter removes Q2 class C distortion

-RFC2, C6, C7 are P/S filters

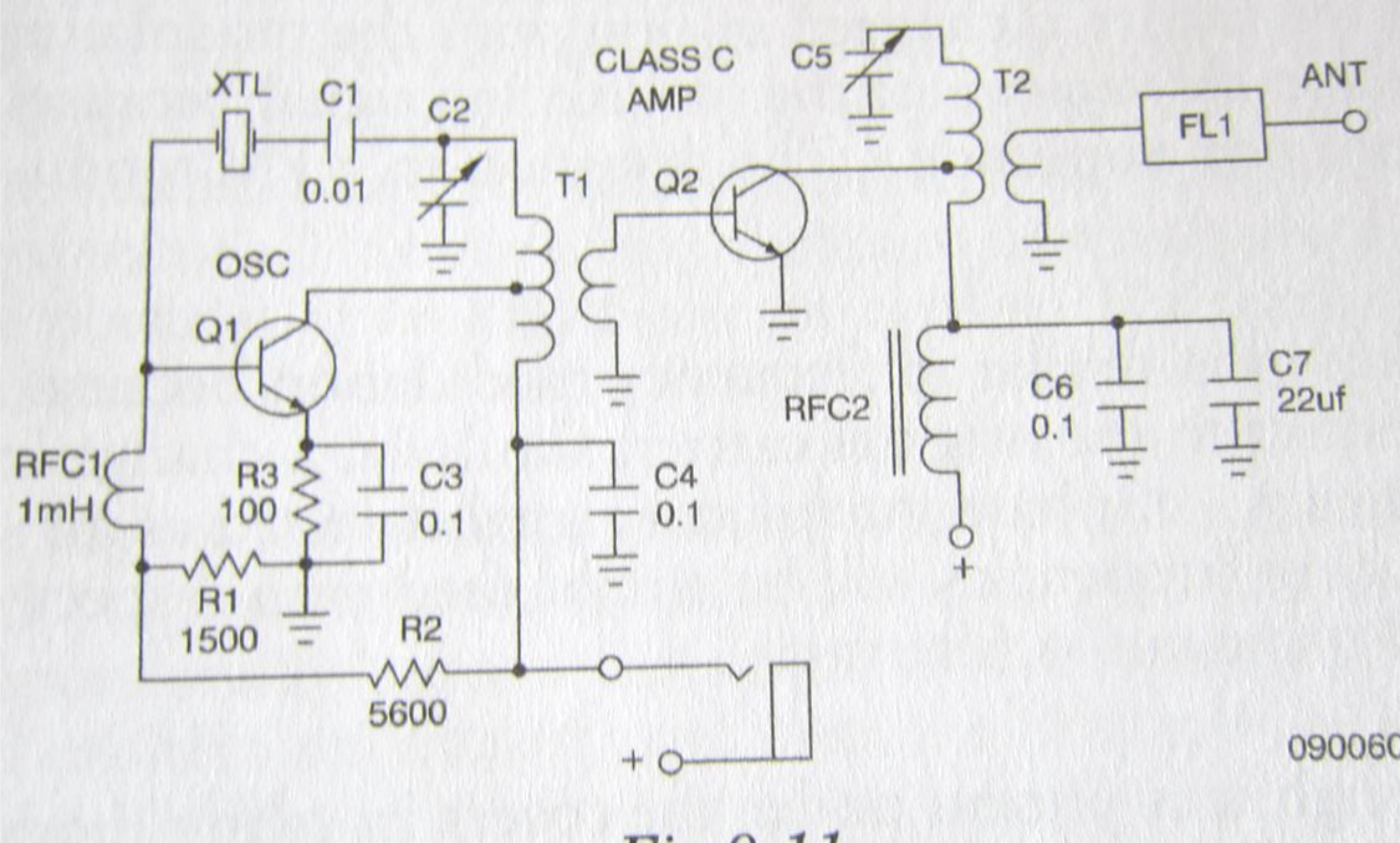


Fig 9-11

Basic MOPA AM transmitter

-modulator must amplify about 300-3000 Hz for Ham AM

-50-5000 Hz for commercial AM

-osc., filter are often identical to CW Transmitter

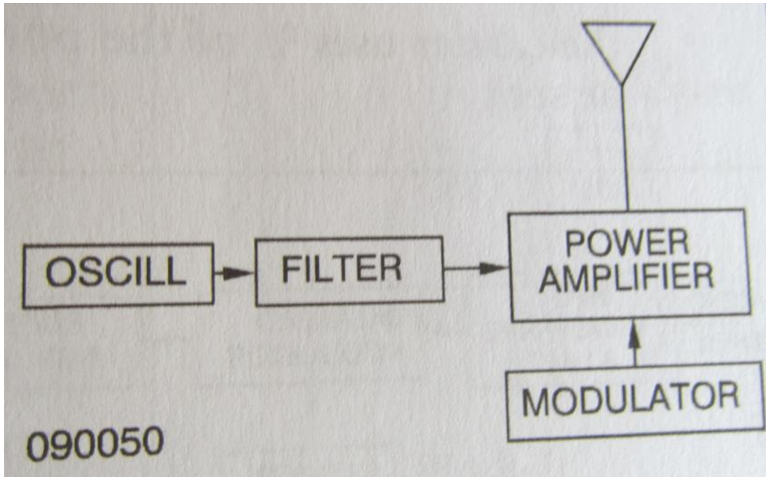


Fig 9-12

-"<u>high level</u>" modulator (like this one)must produce 50% of the power produced by the PA to achieve 100% modulation.

e.g. : PA producing 100w of RF will require 50 W of audio from modulator.

-PA can be class C (efficient)

-"<u>low level</u>" mod uses much less power, but PA must be linear (class A or AB). This is very suitable for modern transceiver producing SSB using class AB.

Double sideband, suppressed carrier (DSBSC) modulation

-In full AM: carrier has 2/3 of the power, but carries no information

-Carrier removed in DSBSC, so all the power goes into the information-carrying sidebands

-Same power produced in TX, double the sideband strength (>4 dB gain in voice strength over full AM)

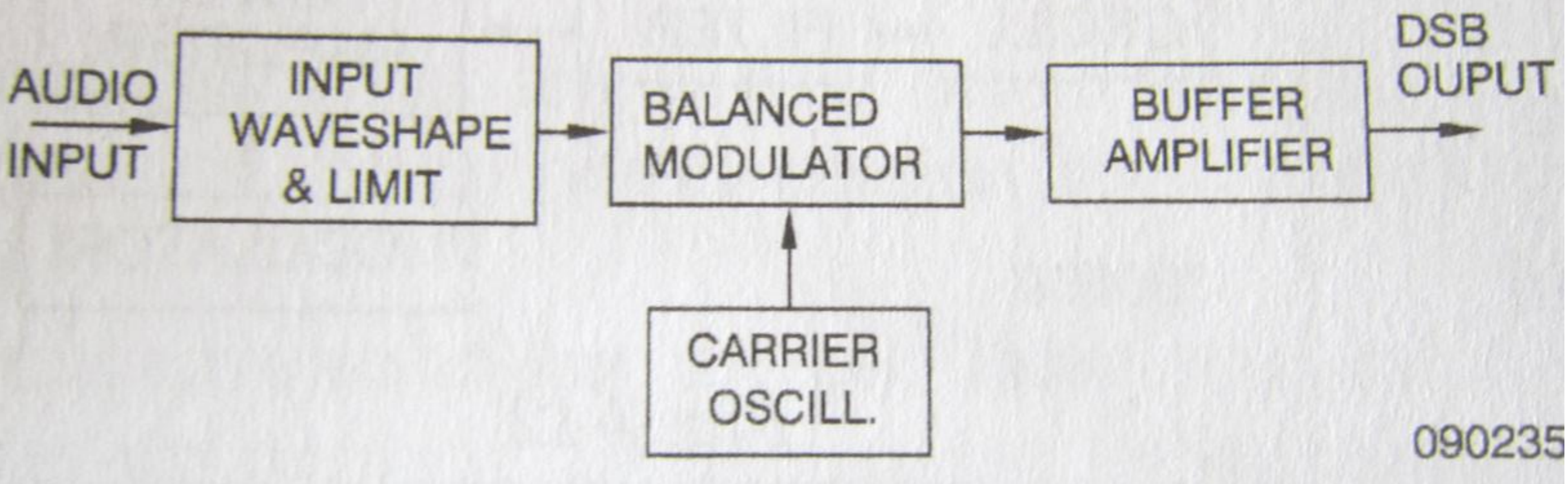


Fig 9-13

DSB always generated at low level, then amplified in linear power amp

Balanced modulators: cancel out the RF carrier

Integrated circuit (I-C) based mixer/balanced mod.

-all subsequent amps must be Class A or AB (linear)

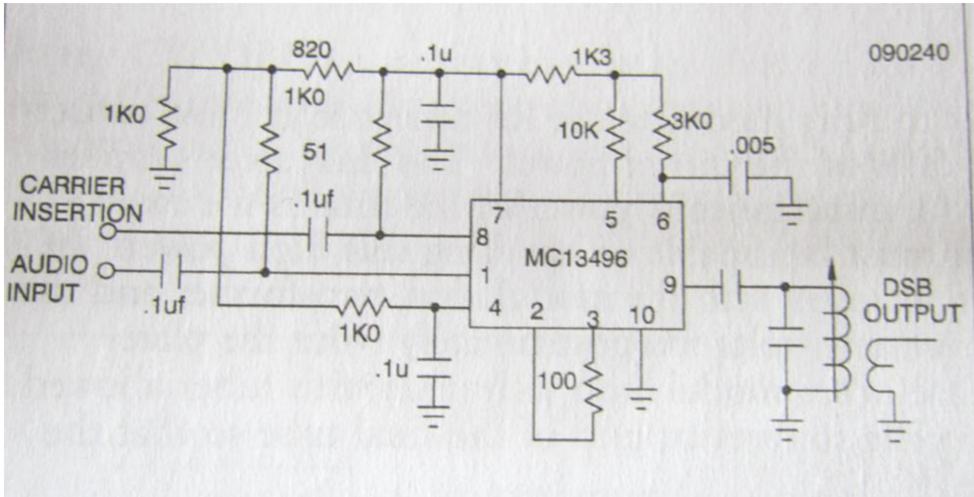


Fig 9-14

Diode ring balanced modulator

Diodes NOT connected as full-wave rectifier

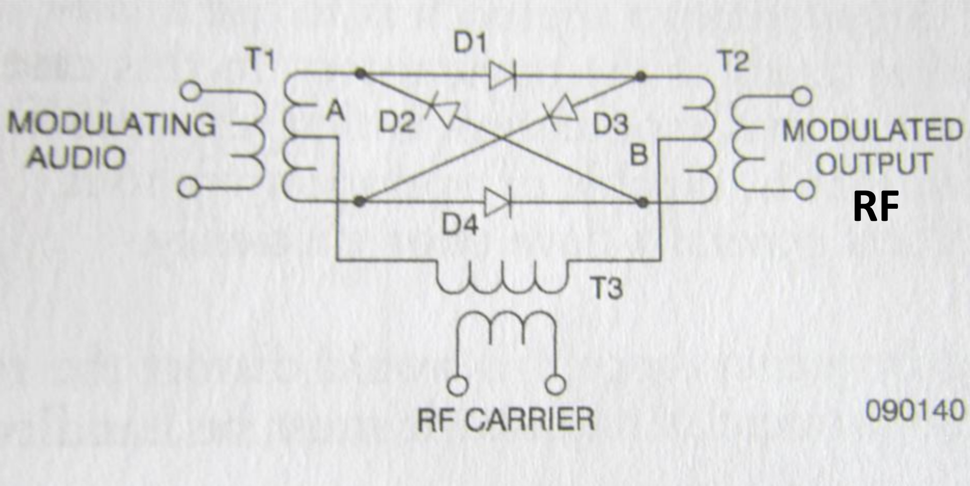


Fig 9-15

Single sideband (SSB)

-both sidebands carry the same information
-remove one and bandwidth fall by 50%
-the power in the remaining sideband doubles if TX output stays the same
-HF convention: USB is used above 10 MHz, and LSB below 10 MHz
-non-amateur users often use USB below 10 MHz

To create SSB, a balanced modulator is used to eliminate the carrier, followed by a sharp crystal or mechanical filter to eliminate the unwanted sideband.

Filters are commonly from 300-1800 to 300-2700 Hz wide.

As with DSB, all following amplifiers must be linear.

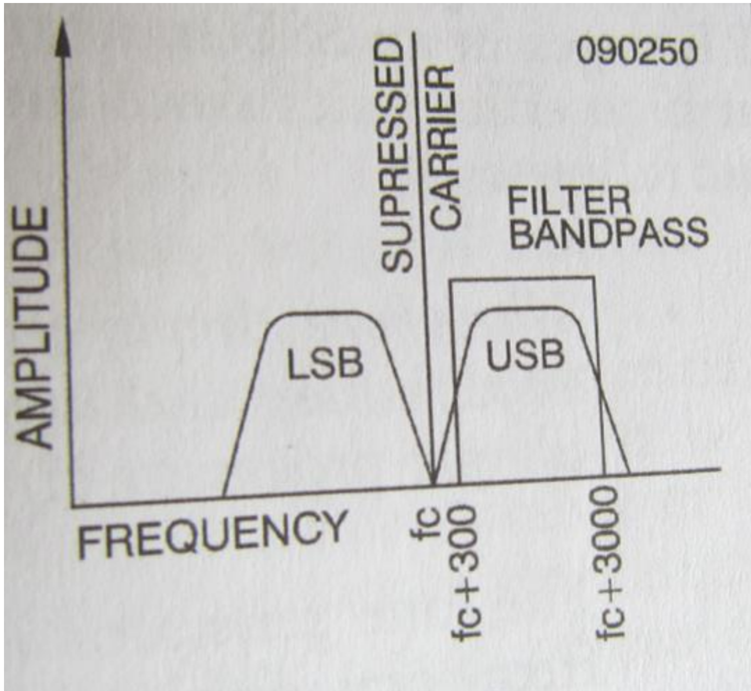


Fig 9-16

Collins mechanical filter

The flatter the passband the better the quality of the voice passing through the filter.

<u>Shape factor</u>: bandwidth at 6 dB down compared to bandwidth at 60 dB down

7 kHz/3.2 kHz =2.2

The lower the shape factor, the steeper the skirts and the better the filter

A very good filter →

Most made for 500, 455, and 250 kHz

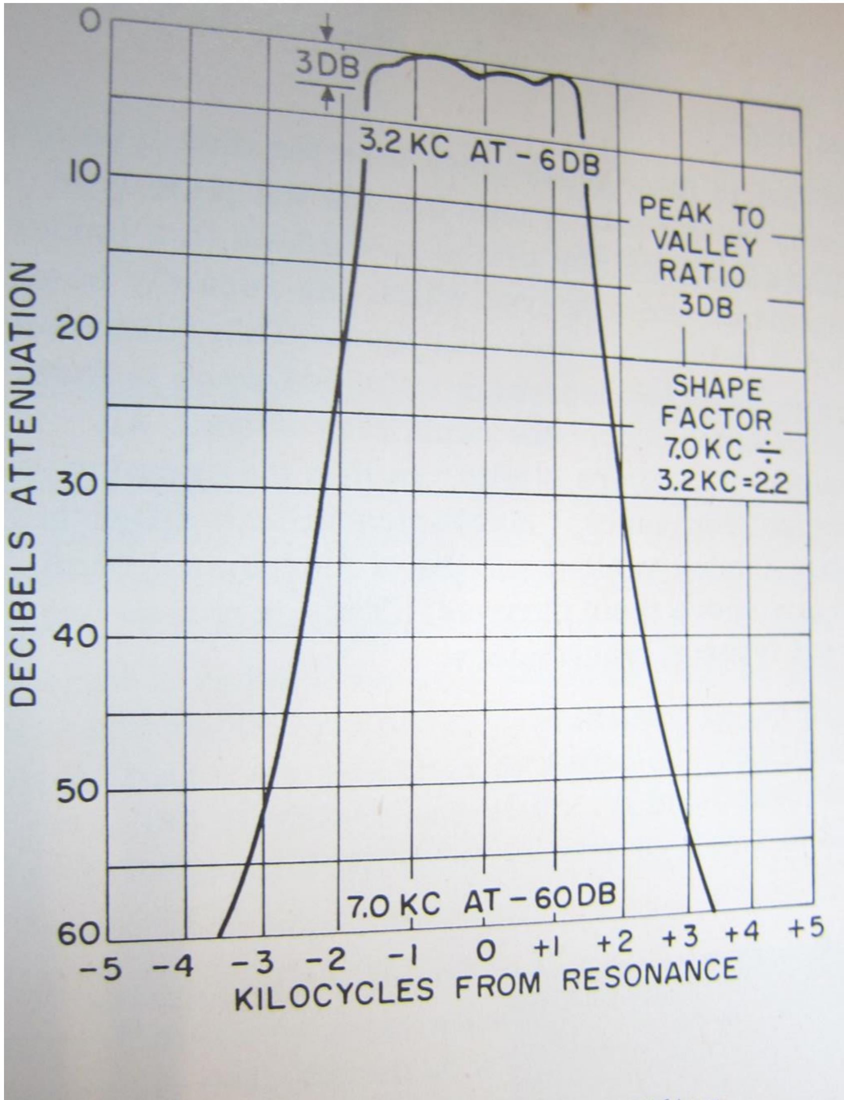
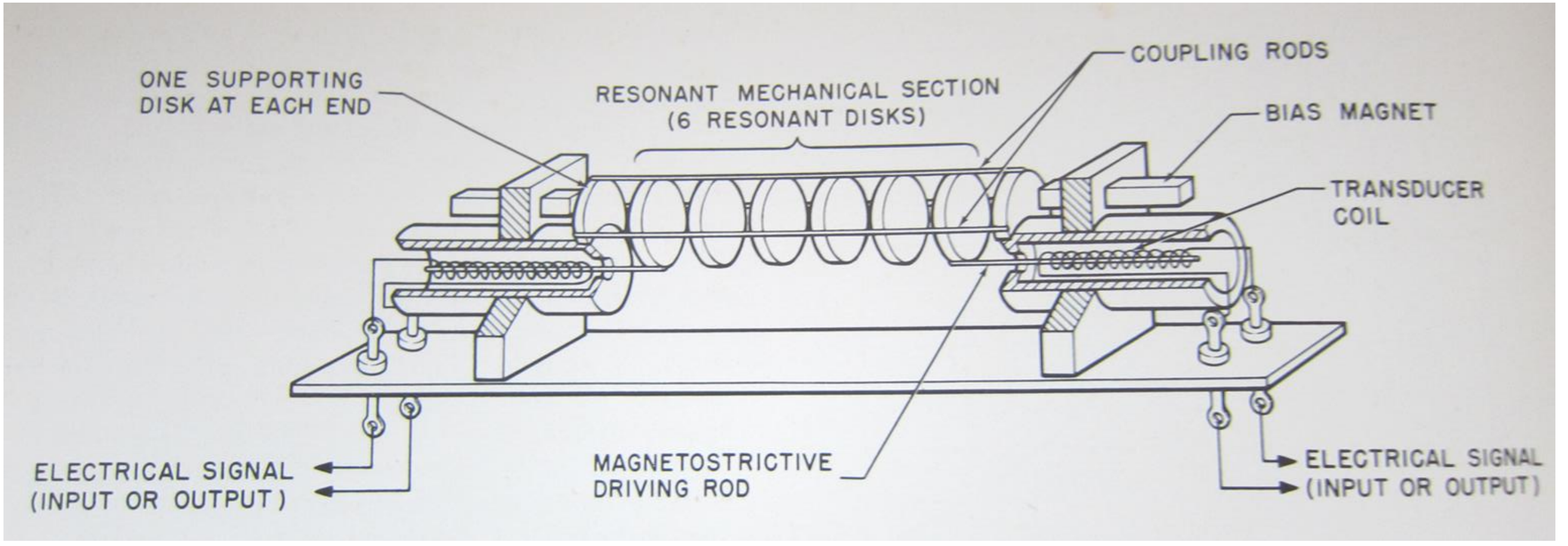


Figure 1-26. Mechanical Filter Characteristic Curve

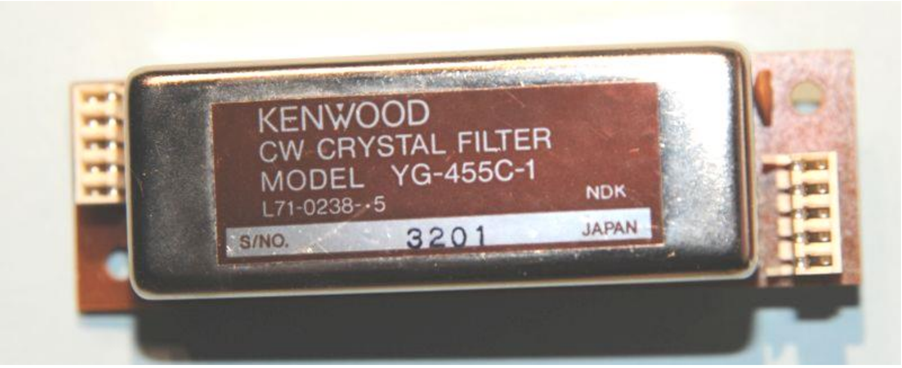
Collins mechanical filter



Disks are nickel alloy ground to frequencies close to band-pass

Compared to crystal filters, mechanical ones have a limited operating range: 100-900 kHz

Are used for CW, SSB, Data, AM, RTTY, etc.



"MCF" = monolithic crystal filter

New, less expensive technology

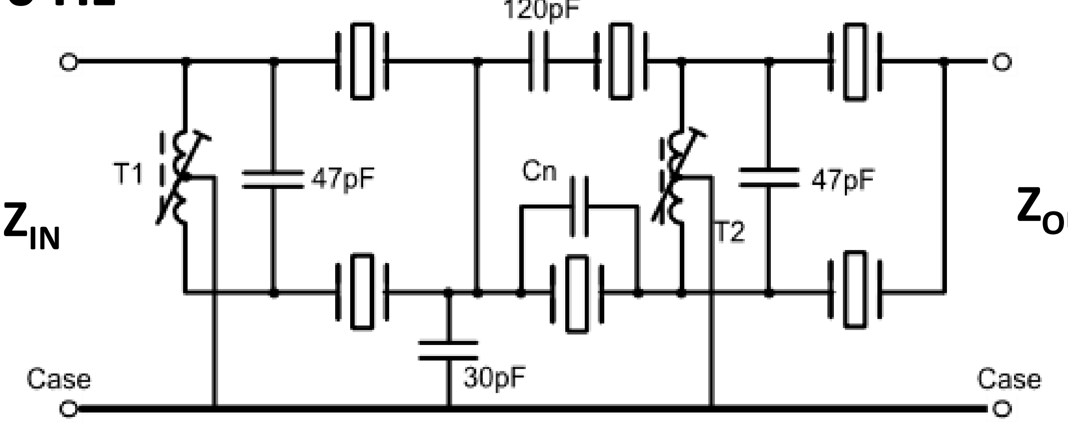
CW crystal filter IF = 455 kHz

Bandpass = 500 Hz

Up to 8 crystals inside

T1, T2 adjustable to optimize passband

A "lattice"-type filter



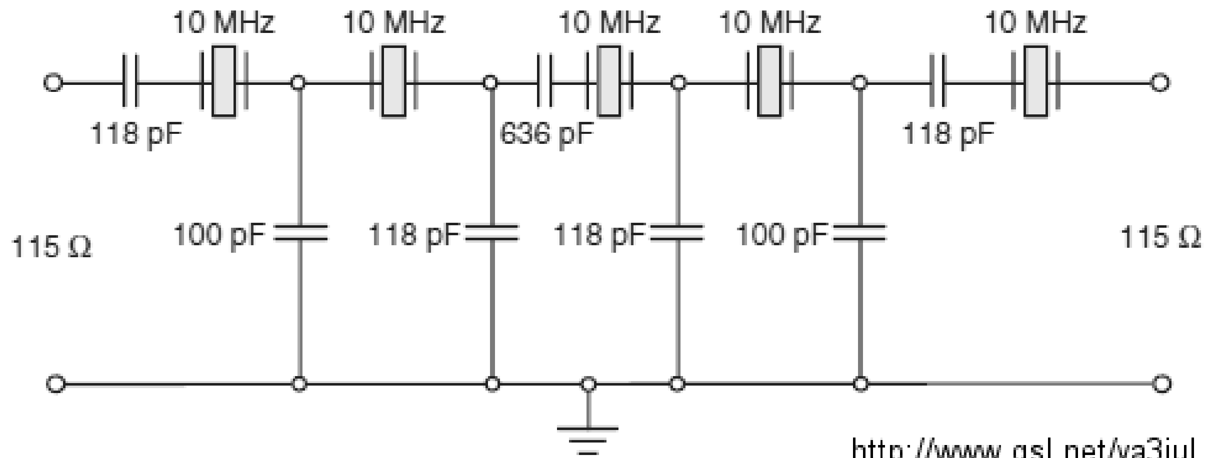
Notes:

1. Crystals are only marked with reference numbers, not frequencies: 3101-1, 3101-2, 3101-3.
2. Cn = neutralising capacitor, typically about 0.47pF - 0.68pF,. Colour coded Brown-Grey-White-Silver.
3. The left most four crystal cases are connected to the case on one side and the remaining crystals to a ground on the other side of the case.
4. Transformers T1 and T2 are mounted in screening cans approximately 0.4inches (10mm) square.

SSB crystal "ladder" filter

Operating frequency: 10.000 to 10.002 MHz

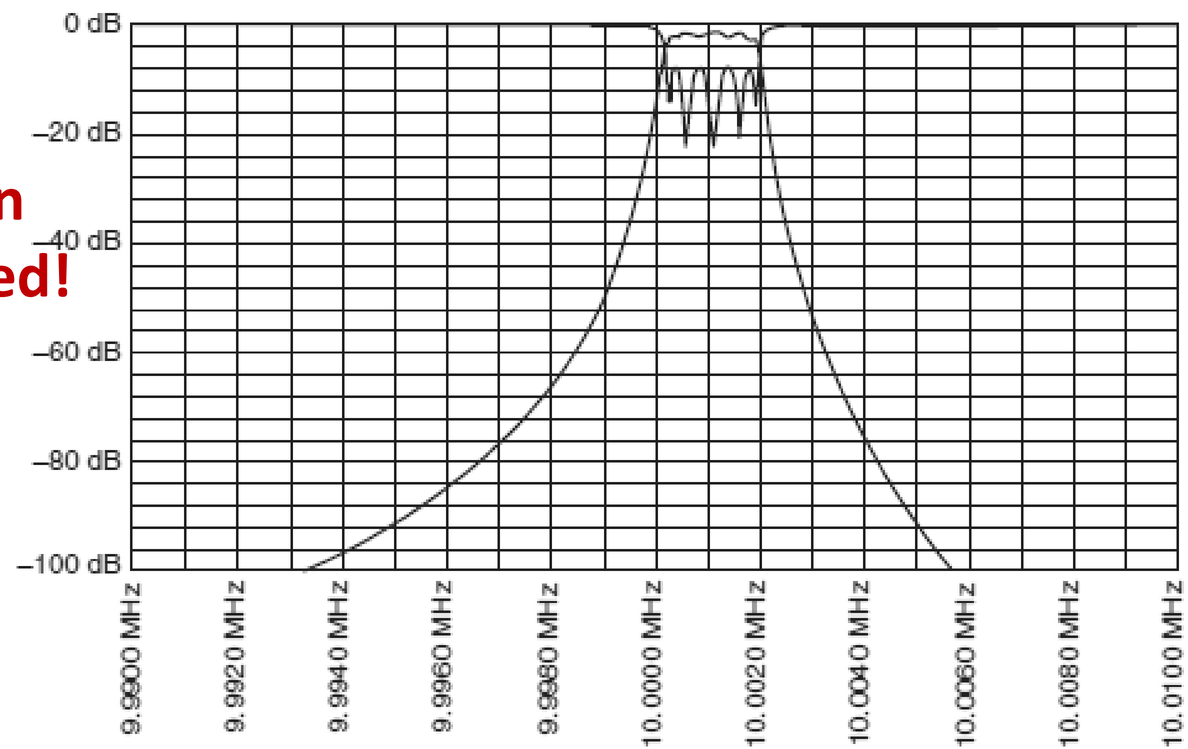
Can home-brew with cheap computer xtals! →



http://www.qsl.net/va3iul

Band-pass 2.000 kHz

Band-pass is smooth when filter is properly terminated!



SSB transmitter

Note: DSP (digital signal processing) filters are replacing crystal and mechanical filters. The best is probably a crystal or mechanical "roofing filter" followed by a DSP filter (in a RX).

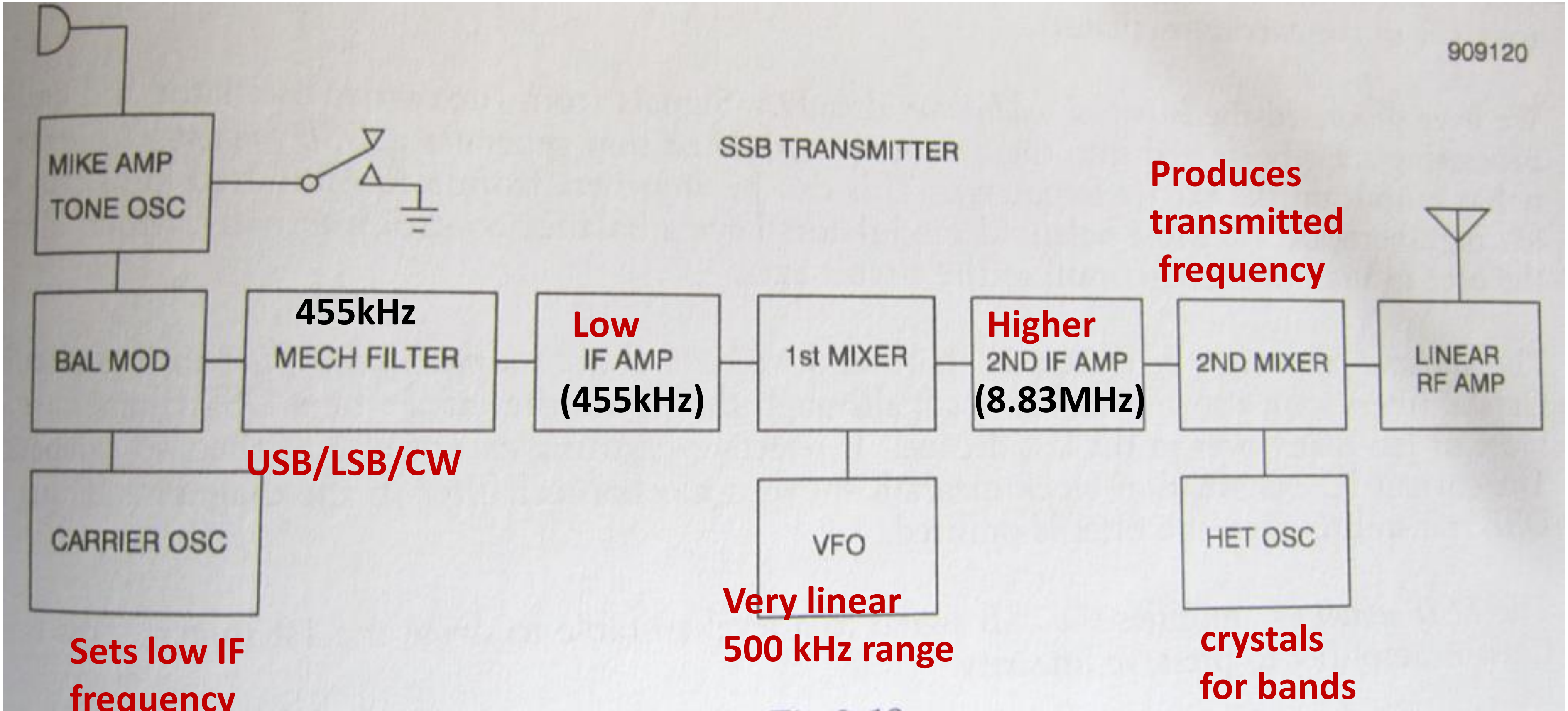


Fig 9-18

Tone osc: for CW sidetone, SSB tuning drive (in some radios)

Today: all freqs derived from one crystal master osc. using DDS system.

-In SSB "average power" meaningless: → no power out unless audio is applied.

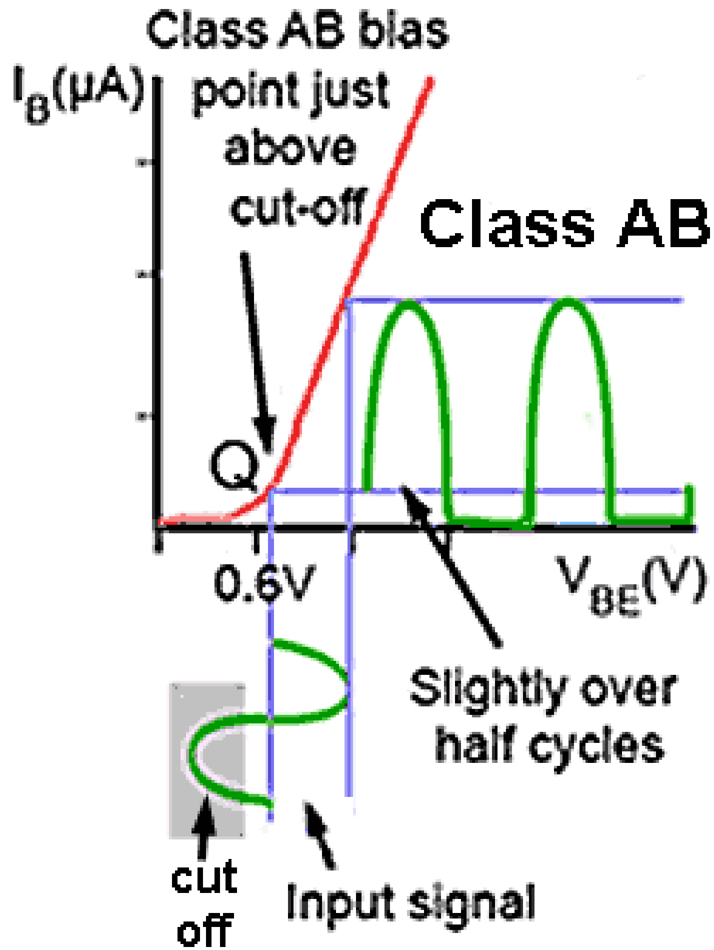
-Peak envelope power (PEP) invented to measure SSB power.

-flat topping: distortion caused when amp driven beyond its maximum power output.

-IF amps are class A in SSB TX to preserve linearity.

PA (final amplifier) whether tube, bipolar, MOSFET is run class AB_1 or AB_2 for good linearity.

Class B bias has high crossover distortion, reducing transmitted SSB quality



FM Transmitters: in the amateur service both FM only and multi-mode transceivers are common

-FM TX is simpler than SSB

-oscillator frequency is shifted at an audio rate for modulation

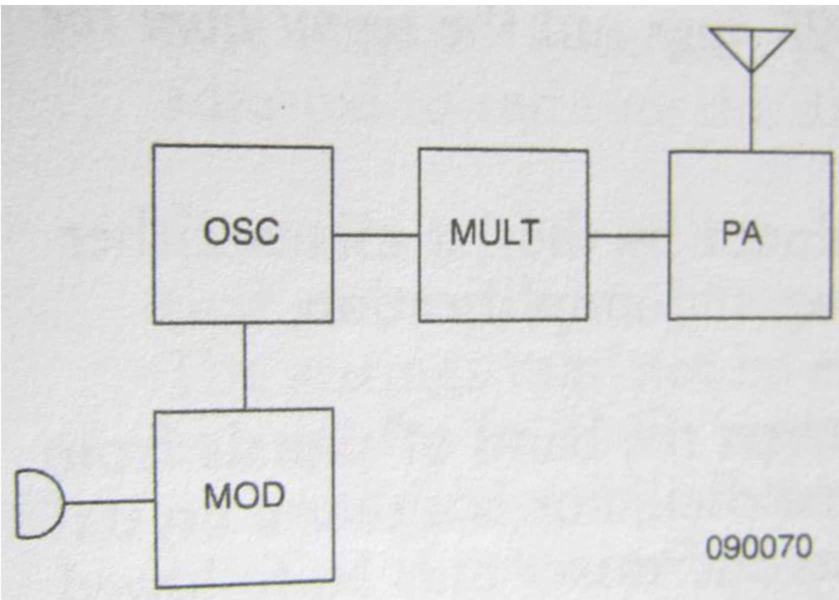


Fig 9-19

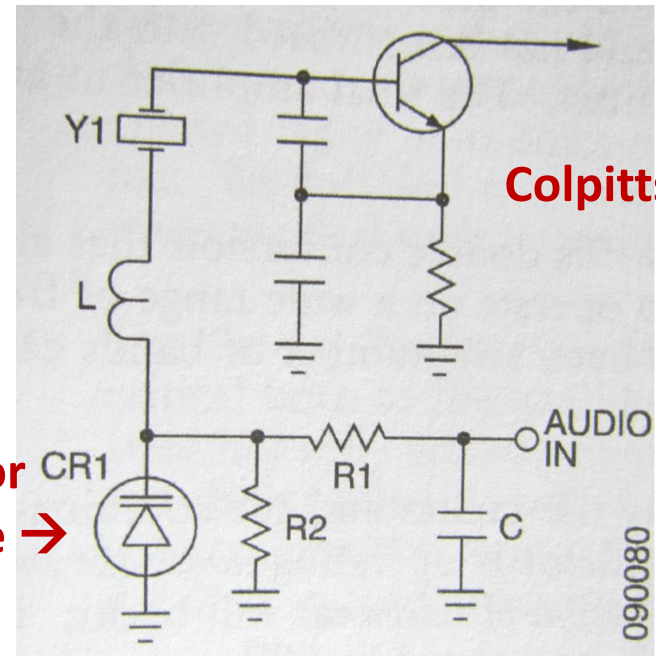


Fig 9-20

-many ways to modulate osc. are available

-here a crystal is pulled +/- by a varactor diode, i.e. changing the crystal's load capacitance at an audio rate.

Phase Modulation (PM) Circuit

Unlike FM, master oscillator not modulated directly

PM generally not used in amateur comms.

RFC1 + C2 control the phase angle of the circuit.

-the audio input alters the phase angle of the RF from the osc.

-the JFET applies the phase shift to the RF signal at C4.

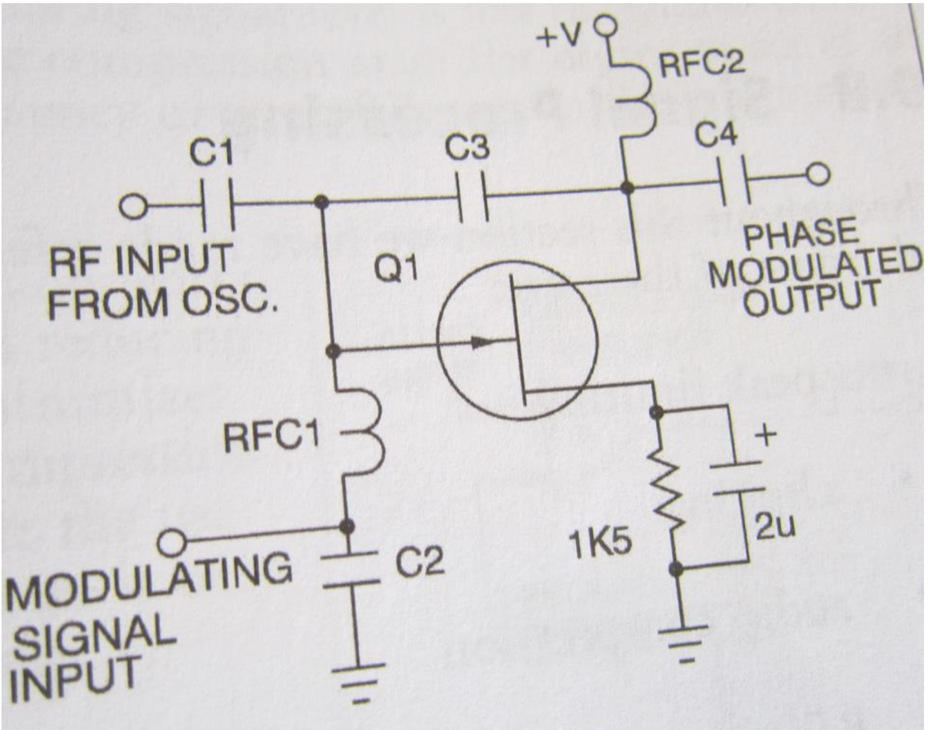


Fig 9-21

-most FM oscillators in the HF range, but most FM radios transmit in the VHF + UHF ranges

-therefore, frequency multipliers are needed

-frequency multiplier: = amp. designed to select and amplify a harmonic of the input, e.g.: 16.200 MHz in, 48.600 MHz out

-frequency mult. usually a class C amplifier; strong harmonics

-T1 tuned to 16.200 MHz

-T2 in diagram is tuned to 48.6 MHz.

Second mult: x3 = 145.8 MHz

-efficiency falls with higher harmonics. 5th harmonic is the maximum used

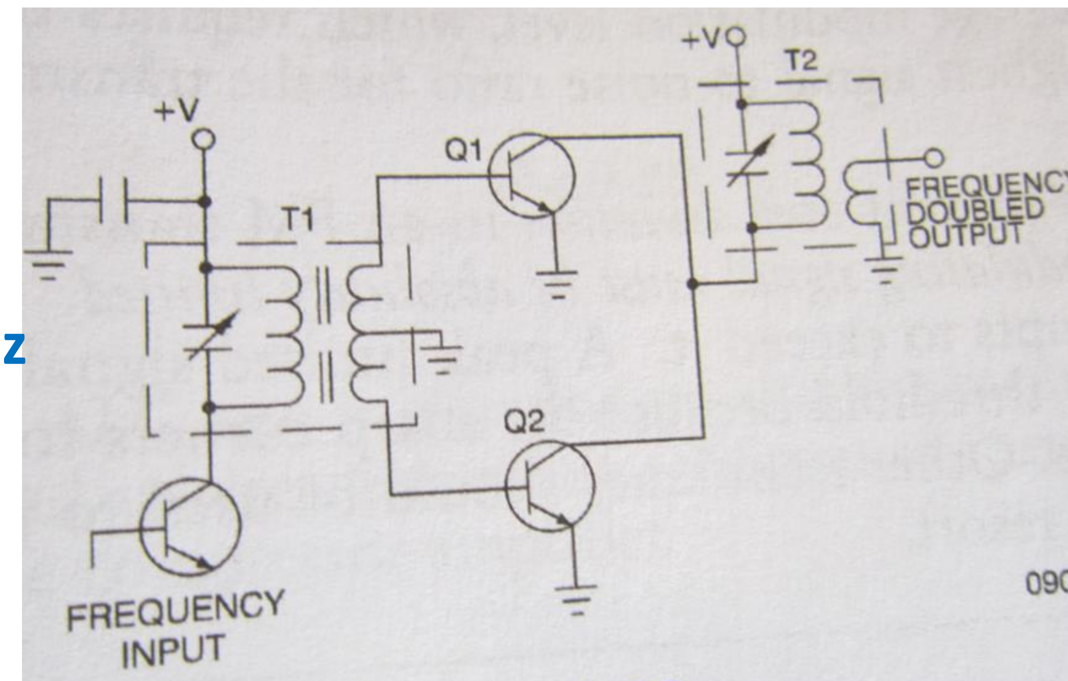


Fig 9-22

Signal Processing: limiting the modulating signal in various ways to produce an acceptable transmitted signal at all times.

Peak limiting (clipping) : prevents over deviation (FM) and over driving amps (AM + SSB)

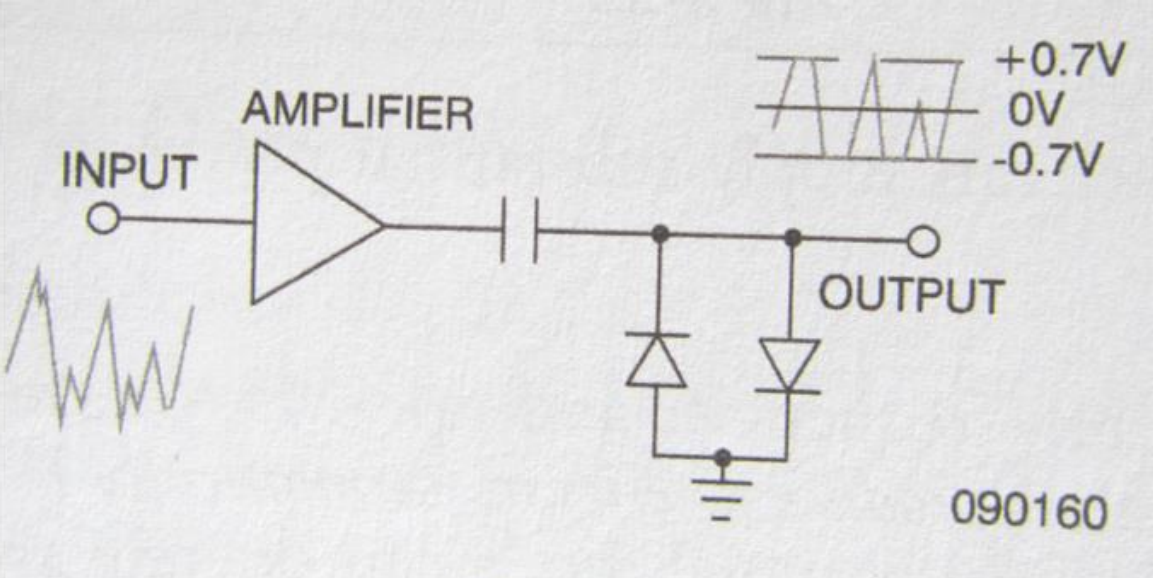


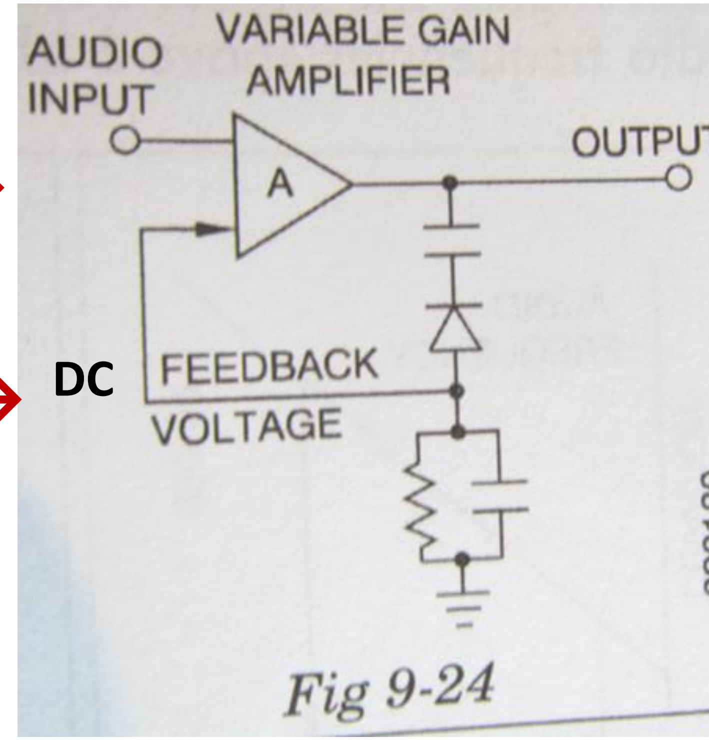
Fig 9-23

Compression: maintains a strong modulating signal by amplifying weak parts of the signal more than the strong parts

: can be done either at audio or RF stages

Compression requires a variable-gain amp. →

Negative feedback voltage increases with increasing input voltage →



Audio compression

RF compression, also called automatic level control (ALC) is required for SSB TX

ALC maintains peak SSB output at near constant level, near max output of TX

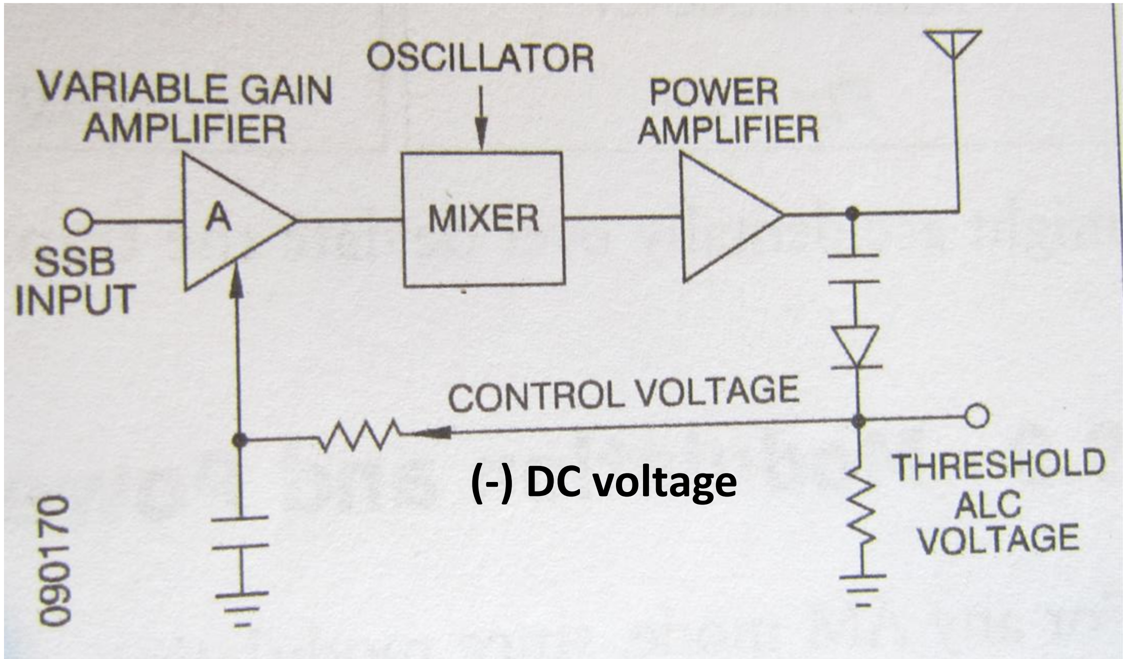


Fig 9-25

ALC is a negative feedback loop in TX

-ALC loop can include a high power linear amp. via a cable from the transceiver controlling the linear amp's gain.

Modulation audio band limiting

-to restrict high frequencies going to modulator
-restricts signal bandwidth
-prevents illegal distortion sidebands
-customized response for your voice and microphone

Uses low pass filtering:

1.- Active filter, using amplifier with shaped response
2. -RLC network to limit high frequency response
3. -DSP software for virtually any audio response curve

Speech frequency shaping

-speech has less energy in its highs than its lows, while noise has similar energy levels at all frequencies

-to improve the signal's S/N ratio, signal shaping is used in FM TX

Audio shaping for FM

Result: noise is reduced, S/N improved, especially in weak received FM signals

Like Dolby magnetic tape system

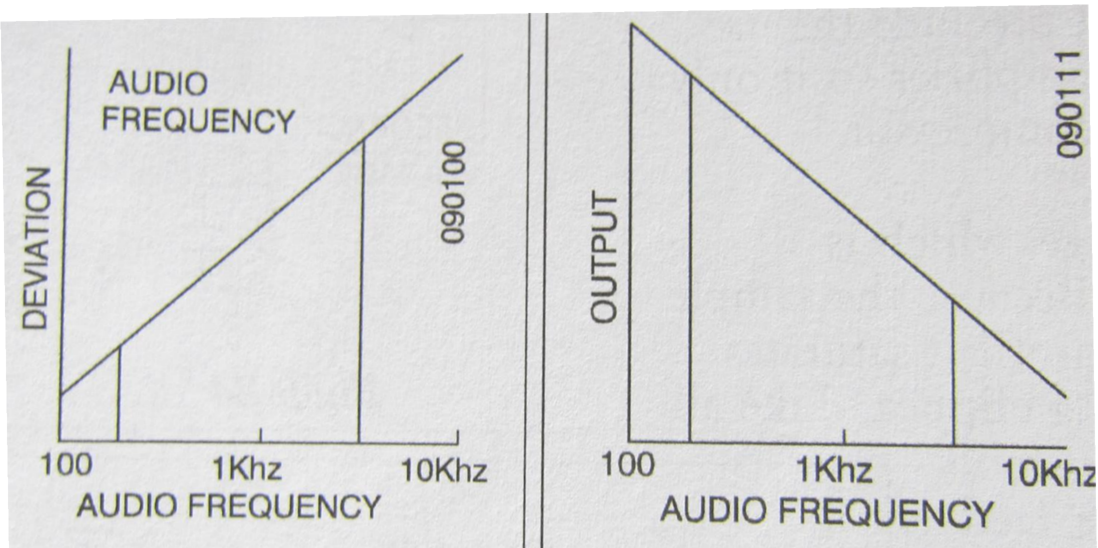


Fig 9-26 Fig 9-27

Pre-emphasis (in TX) De-emphasis (in RX)

Transmitter Spurious Noise: unwanted emissions by modern amateur transmitters

"Modern receivers are excellent; modern transmitters are worse than those of 20 years ago.".... Rob Sherwood NC0B (QST Nov. 2019)

1. CW keying sidebands (key clicks)
2. Odd-order inter-modulation (splatter) from distorted sidebands
3. Broadband synthesizer noise (DDS) –not present in older crystal -controlled oscillators
4. Phase noise from PLL frequency synthesizers
5. AM noise- may dominate phase noise; not measured by ARRL lab.

Composite noise: real mixture of above noises: what your RX hears

Cleanest amateur transmitter ever tested: Collins 32S-3 (1963)

End Of Transmitters!