Advanced Course: Ch. 4 Amplifiers

de VE1FA, 2019

Objectives

-define audio + radio frequency signal amplification
-how small signals are amplified
-linearity
-classes of amps, and where they are used
-active devices used in amplifiers:
tubes + transistors/integrated circuits

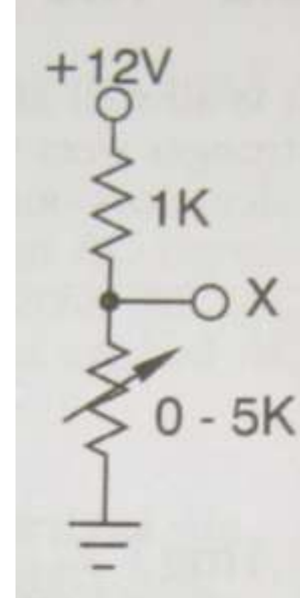

Fig 4-1

Amplifier- a circuit containing a DC power-consuming **active device** which **increases** the voltage (E), current (I), or power (W) of a DC or AC audio or RF signal.

-one of the most important functional units in electronics

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Active Devices

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<u>Active device</u>: a power-consuming device that <u>amplifies</u> or <u>modulates</u> a flow of electrons

<u>Transistors</u>

a. Bipolar: NPN and PNP

b. Field effect: JFET and MOSFET

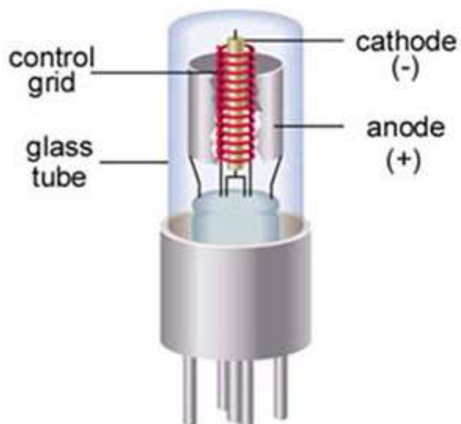
c. Integrated circuits = integrated transistor/diode circuits

3. <u>Vacuum tubes</u>, or <u>valves</u>

a. Triodes

b. Tetrodes

c. Pentodes



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Transistor (NPN, Si) amplifier: calculating currents

I = E/R

Collector I = E/RL = 5.0/1000 = 5.0mA

Base I = E/RB = 9.3/93000 = 0.1mA (DC bias)

Emitter I = IC + IB = 5.1 mA

hFE = beta (β) = IC/IB = 5.0 mA/0.1 mA = 50

X (base) to ground PN junction drop: 0.7 VDC

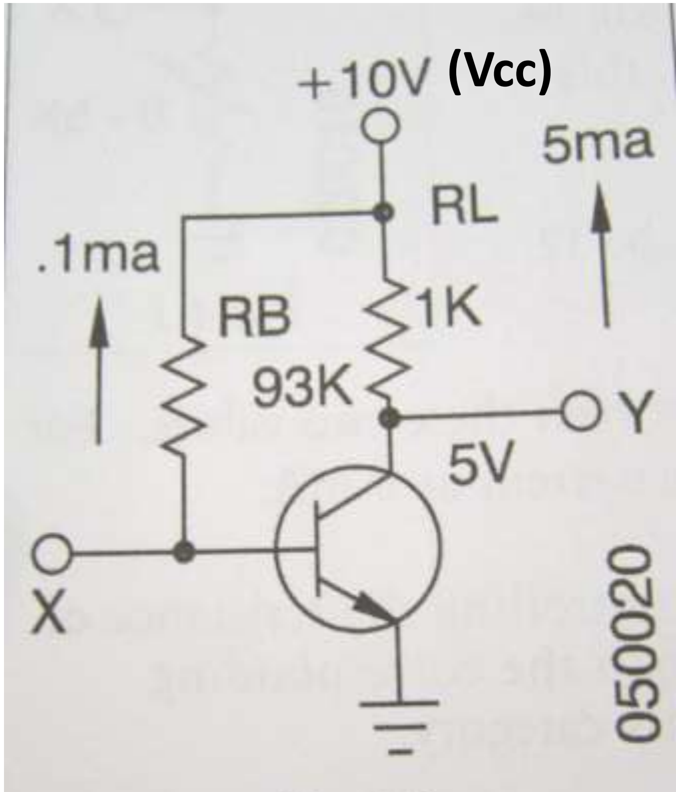

Fig 4-2

-input signal inserted between X and ground

-output (amplified) signal appears between Y and ground

This is a common emitter amplifier

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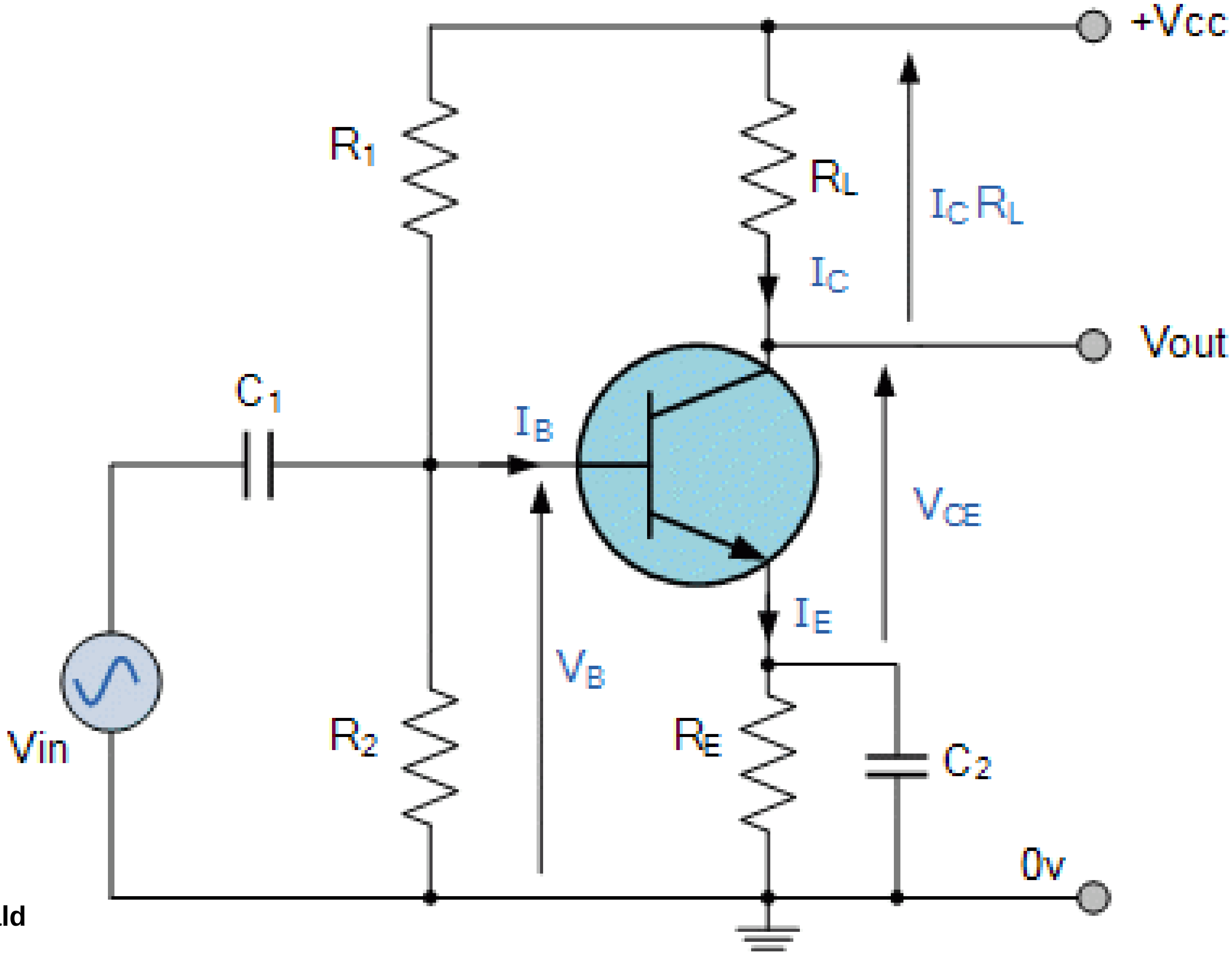
What does each component do?

What do the abbreviations stand for?



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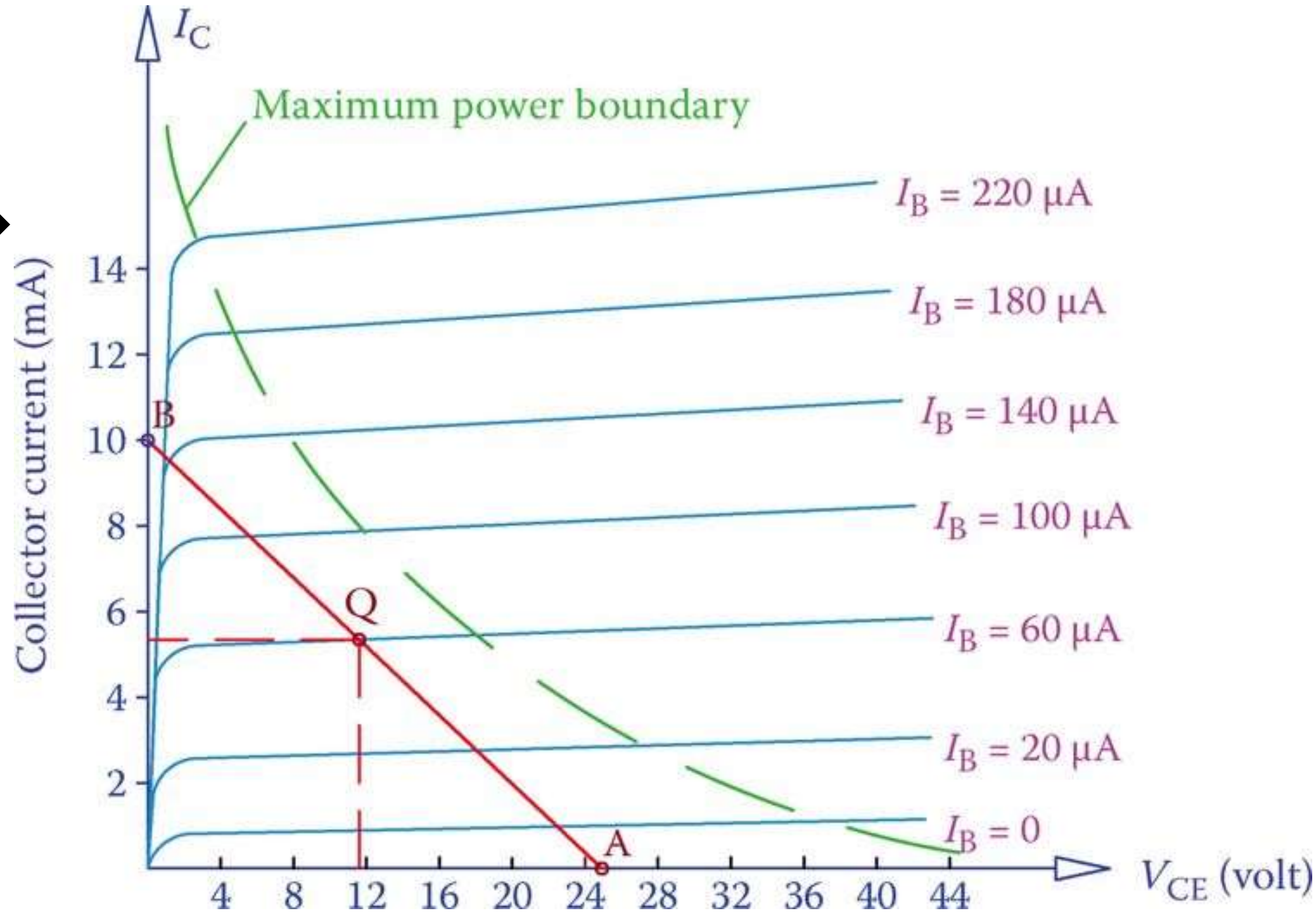
Transistor behavior must be understood to design an amp

Family of "characteristic curves"→

e.g.: 2N2222



IC nearly independent of VCE,
IC nearly totally dependent on IB

Q: good operating or bias point for "Class A" linear amp

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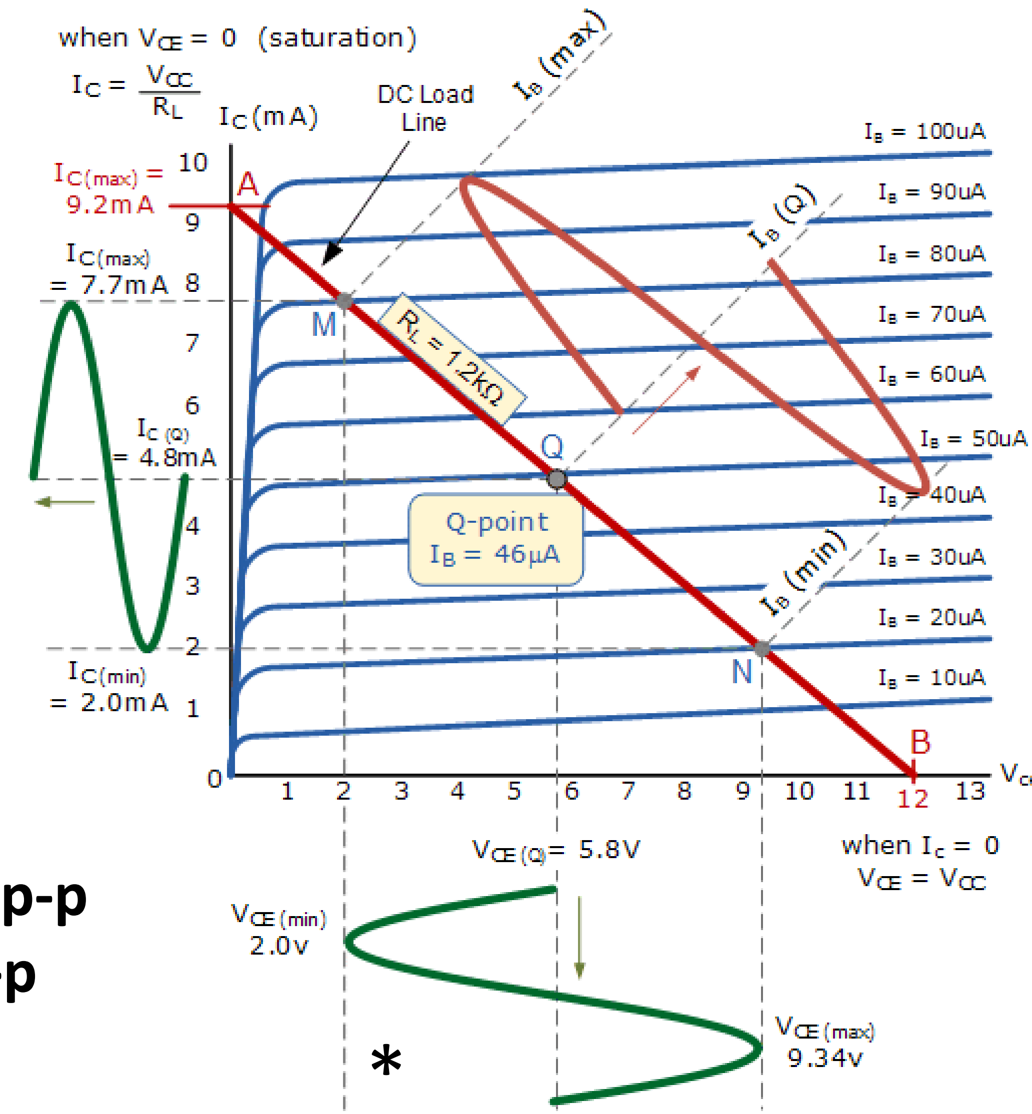
Characteristic curve of a particular transistor type showing "class A amplification", also called the "linear transfer characteristic"

*Output signal can be in current (IC) or voltage (VCE)

*

A → B = DC load line



Input sig: 60 uA p-p

Output sig: 2000-7700 uA p-p
or 2.00-9.34 V p-p

If RL = 1.2 kΩ

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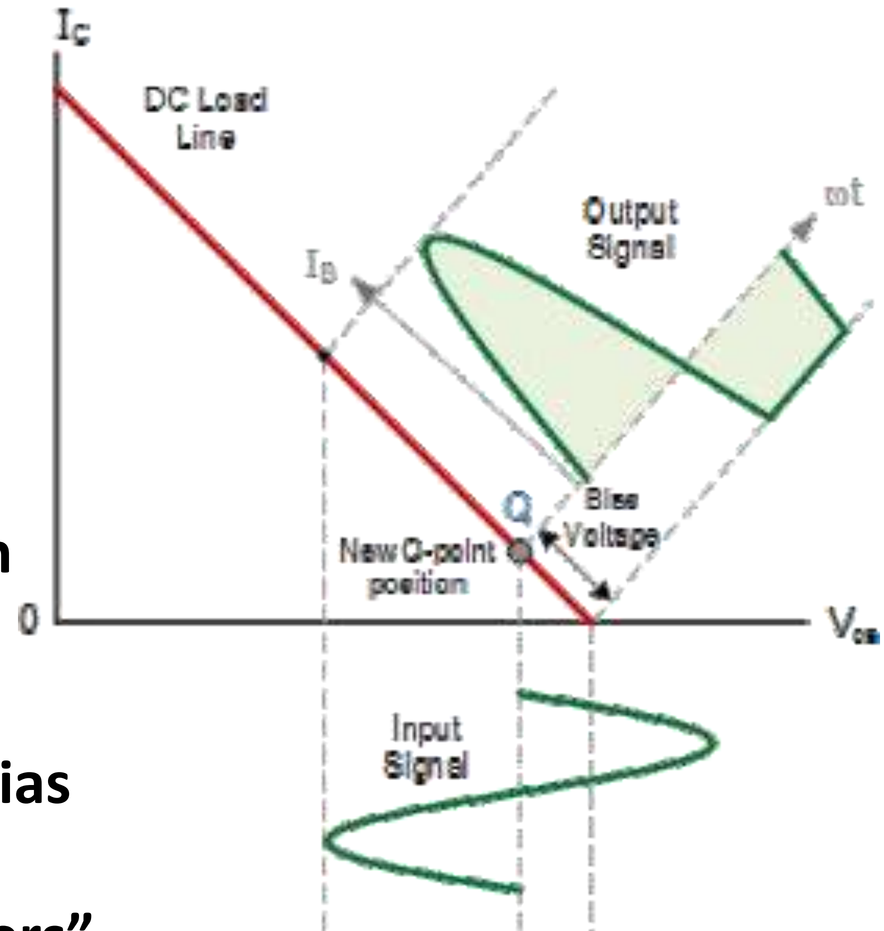
Class AB bias on push-pull amplifier (showing one of two transistors)

Bias poises transistor ABOVE the cutoff point, where gain is linear with input signal



-dead zone (producing crossover distortion) is avoided

-moving bias to middle of DC load line would give Class A operation

-moving bias down to IC = 0 (the cutoff point) would produce Class B bias

-SSB (transceivers and "linear amplifiers" are biased AB

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One electrode is always common to both input and output circuits in an amplifier.

This applies to FET, bipolar transistors and tubes.

Common Element	Emitter	Collector	Base
Input Element	Base	Base	Emitter
Output Element	Collector	Emitter	Collector
Voltage Gain	High (200 - 1000)	Low (< 1)	Medium (25 - 50)
Current Gain	High (25 - 300)	High (25 - 300)	Low (< 1)
Input Impedance	Medium	Very High	Low
Output Impedance	Medium	Low/Very Low	High
Phase Reversal	Yes	No	No
Power	High	Low	Medium

Fig 4-5

Usual configuration

Emitter/Cathode/ Source follower

Grounded base Grounded grid

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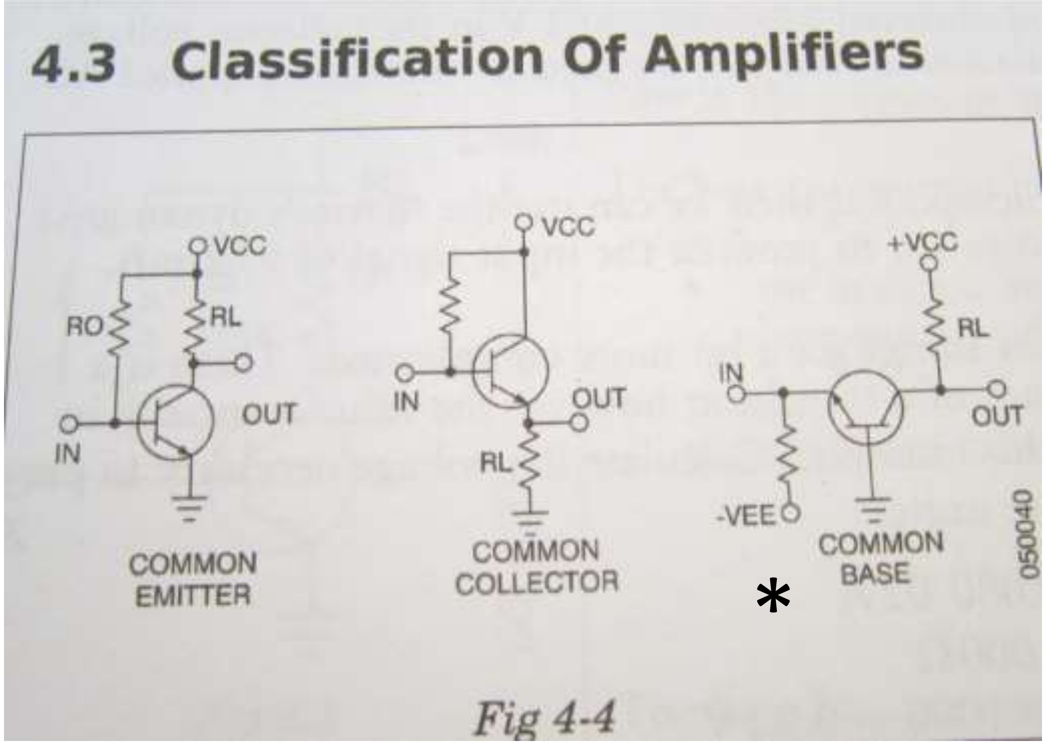
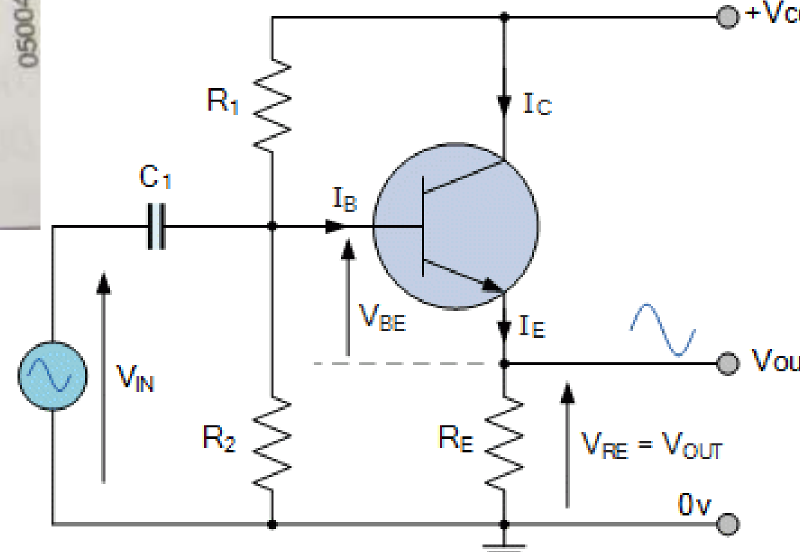


* Usually ground



Common collector/emitter follower

-High Z to low Z converter

-V gain = 1 or less

-I and P gains: often quite high

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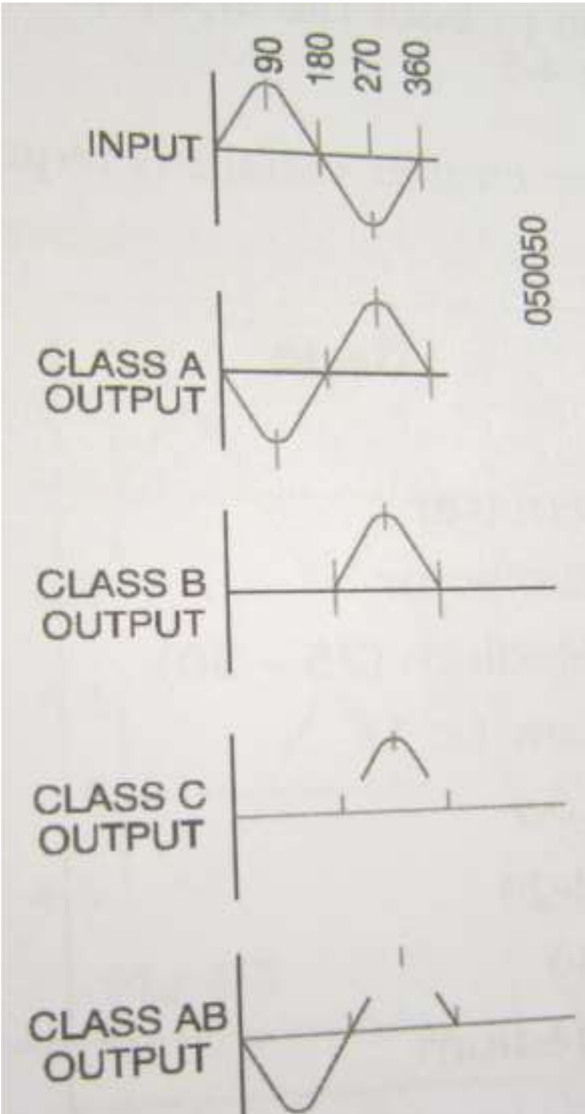
Where you set the <u>static bias</u> on a tube or transistor determines the amp's CLASS of OPERATION



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Very important for amplifier's:

- -efficiency
- -distortion
- -harmonic content

	A	AB	B	C
Current Angle	360°	> 180° but < 360°	180°	< 180°
Distortion	Low	Medium	High	Extreme
Efficiency	Low	Better than A; worse than B	Moderate	High
Use	Audio	Audio Power*	Audio Power/RF	RF Power

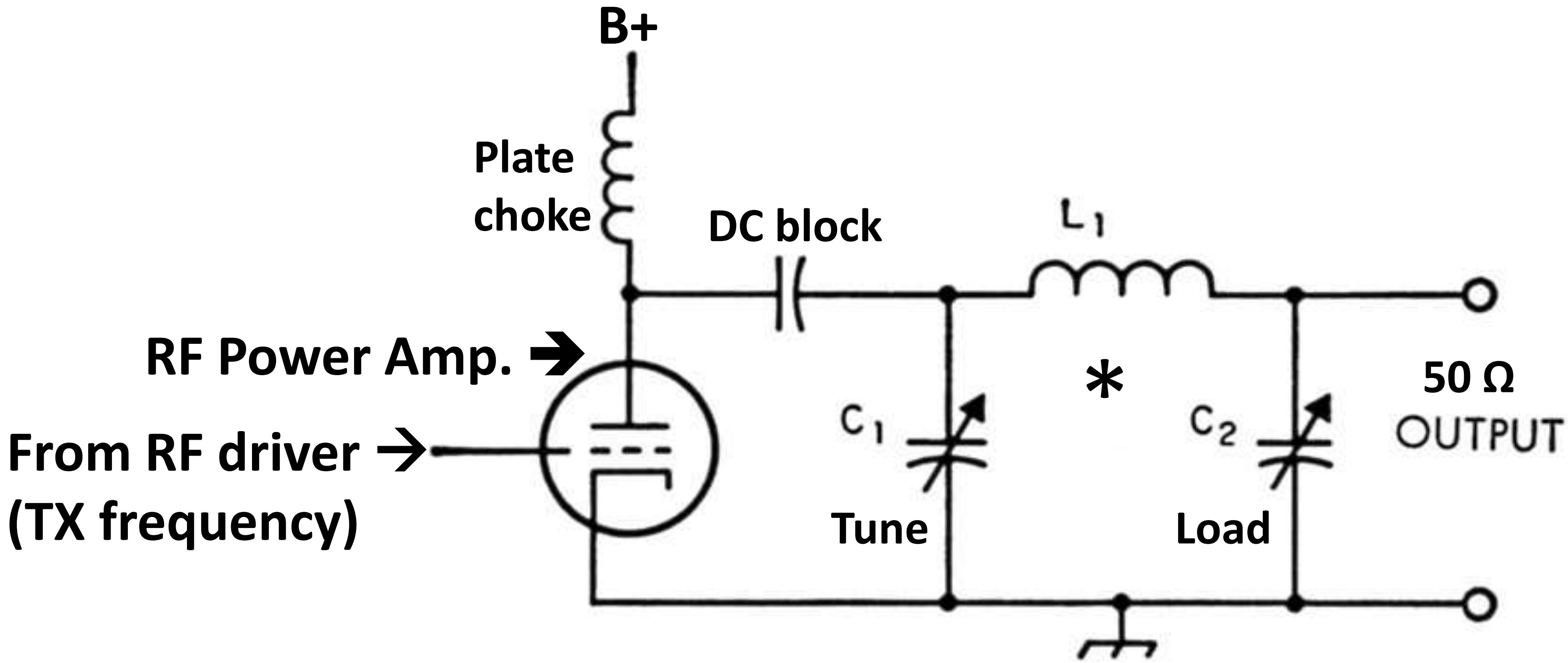
Fig 4-7

Class D + E & F, G, H

*** <u>Wrong!</u> Class AB almost always used for SSB**

Above is outdated:
Now : classes D, E, F, G, H of operation

Why bias class C can give a fairly clean RF output



* C1 + L1 + C2 = flywheel + filter = "Pi" output or "tank" circuit

AM, FM, and CW usually biased class C for high efficiency

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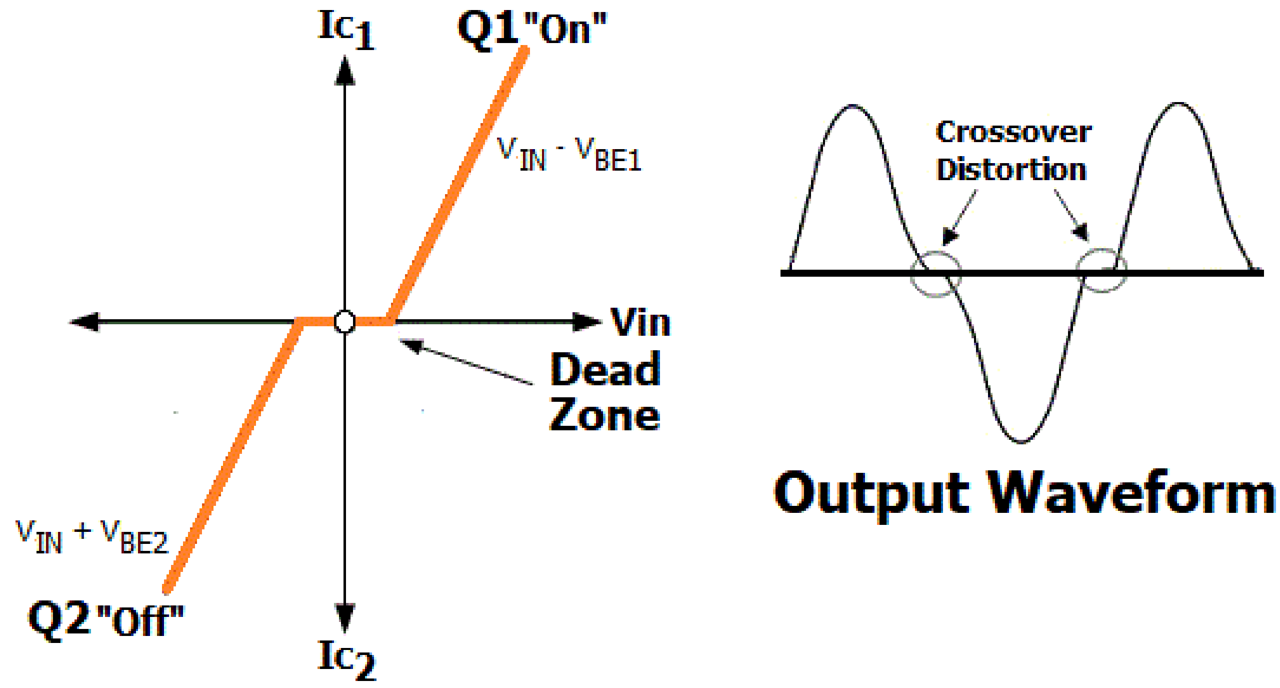
Class B push-pull amplifier

-usually has crossover distortion, due to non-linear response of tubes/transistors near cutoff



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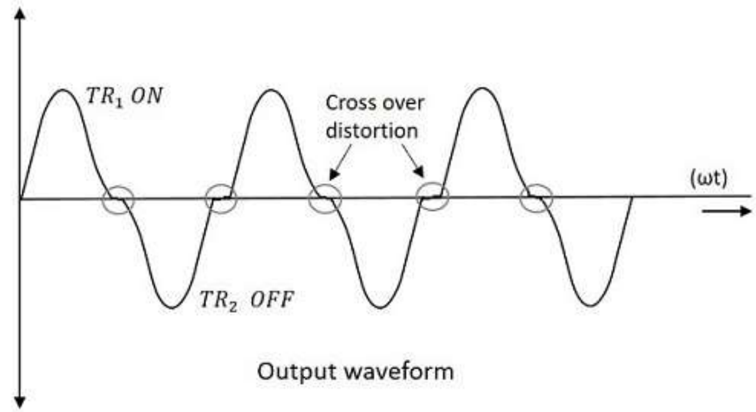
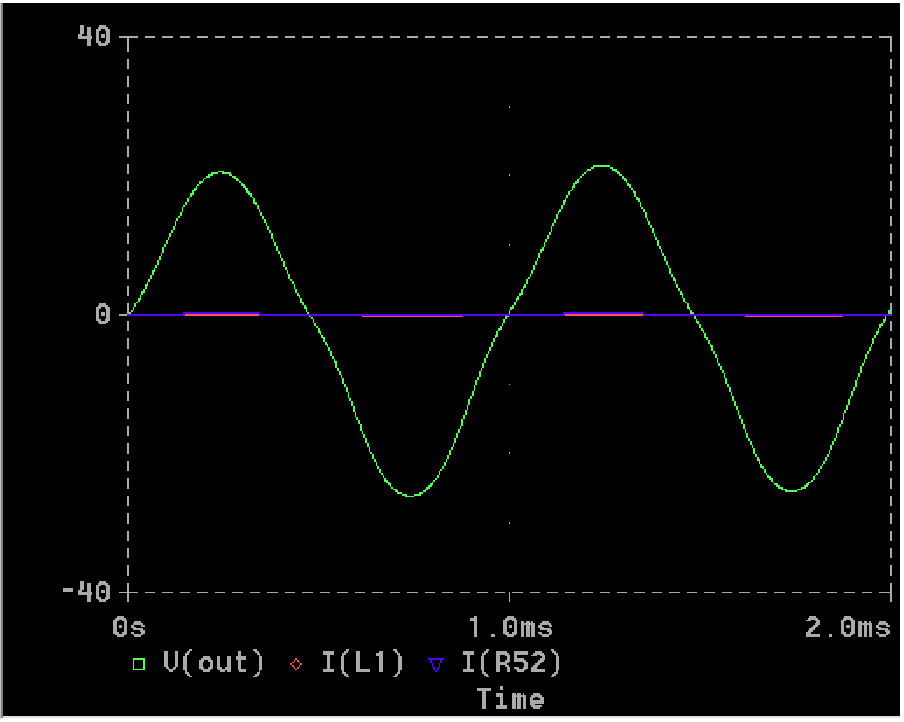
Linear amp: needs = or > 180° amp conduction

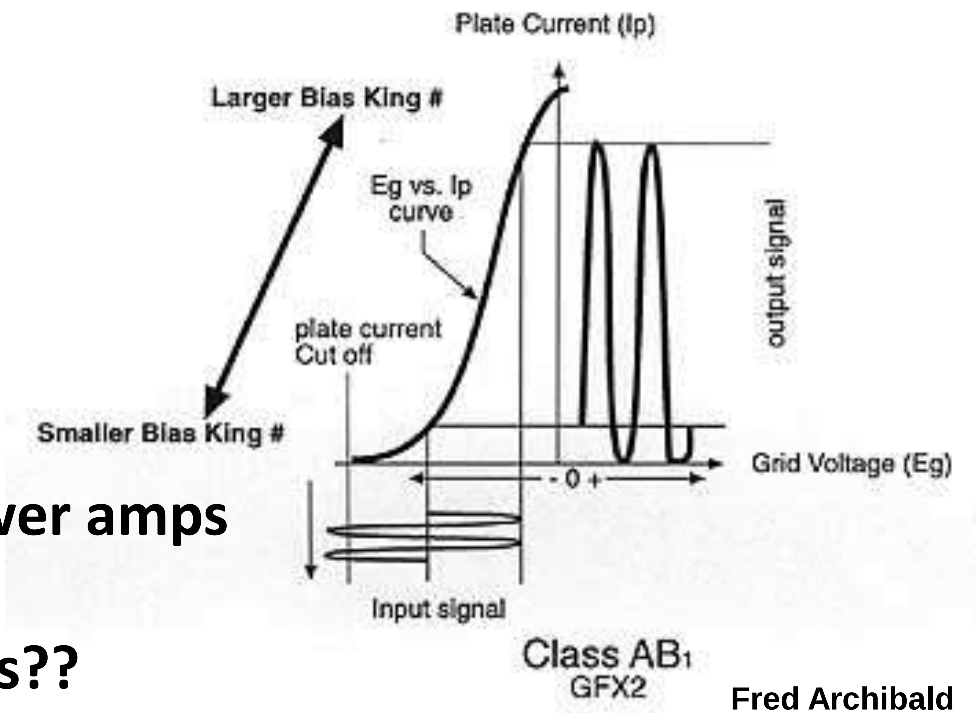
Class B biasing



Mild crossover distortion (below)



Class AB1 biasing →



Used in audio and RF linear power amps

Why not also in low-power amps??

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Newer modulation classes

Class D: -non-linear switching amp
-fast switching power MOSFETS
-up to 90% efficient

Class E + F: -power supply PWM (pulse width modulation)
-highly efficient (Nautel)
- RF applications

Class G + H: "Rail switching" class AB amps
-highly efficient

Purposes of RE, CIN, COUT

RE emitter resistor:

- -makes bias more negative
- -reduces chance of thermal runaway
- -reduces gain of transistor, increases fidelity (degeneration)
- -RE usually 10-15% of RL value

CIN + COUT

- -isolates DC operating power to just this stage
- -passes AF and/or RF signals, depending on capacitor values

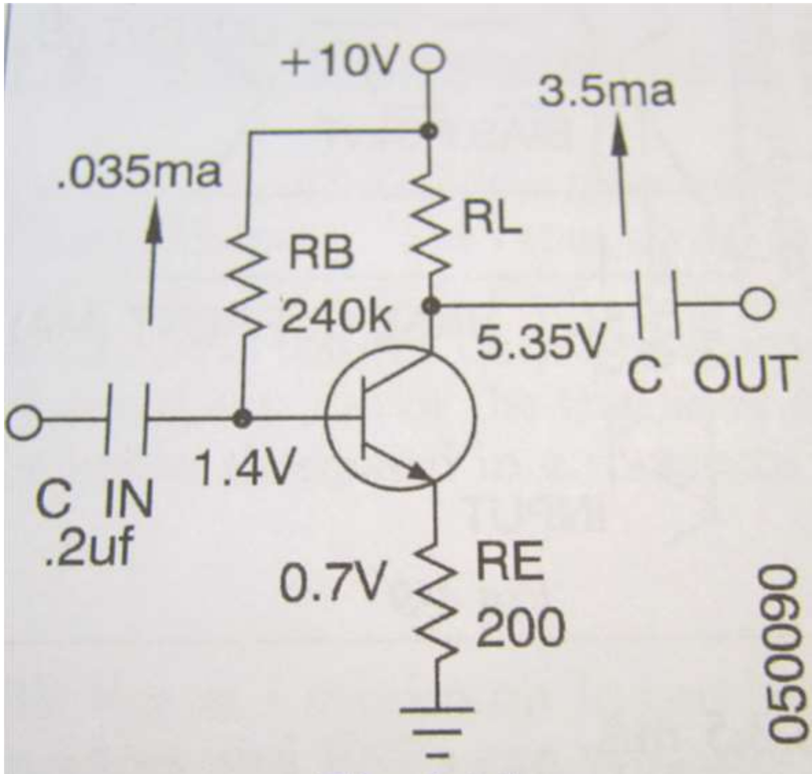

Fig 4-11

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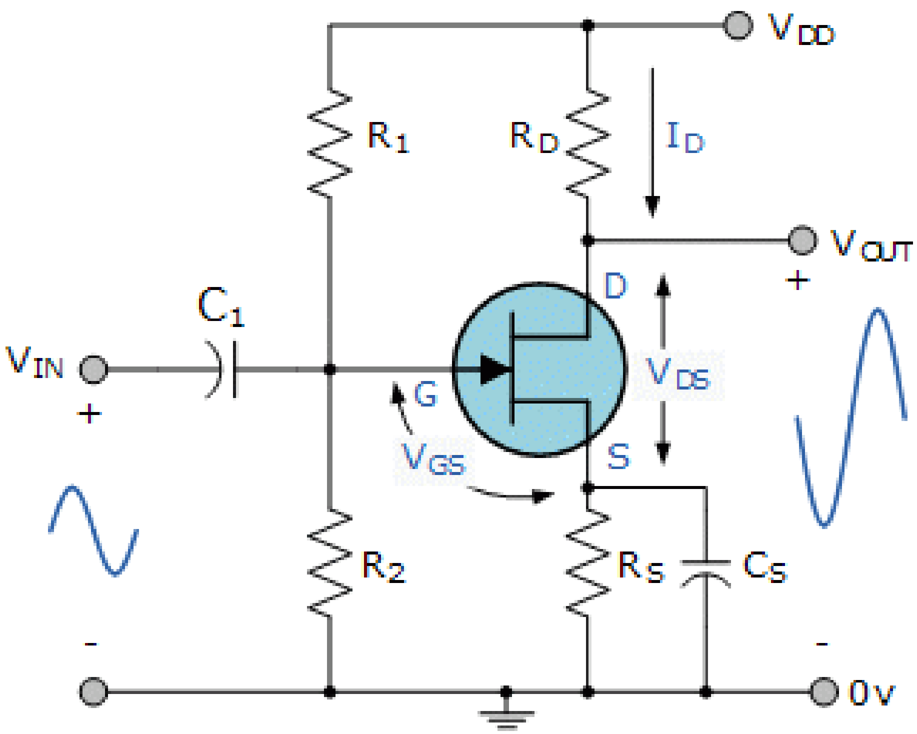
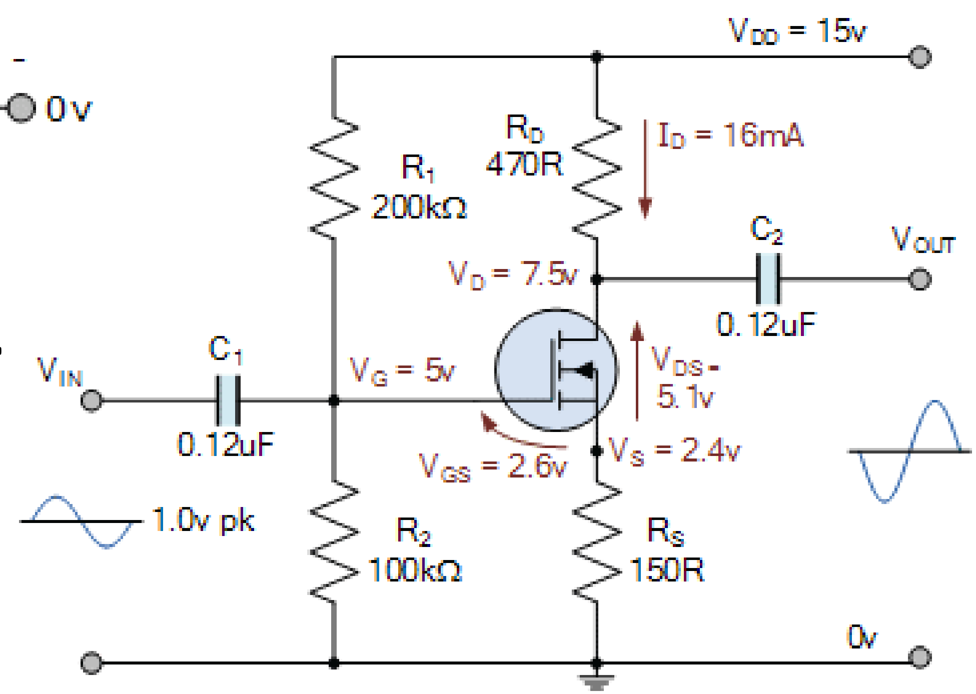
What does each component do?



JFET small signal amplifier



MOSFET small signal amplifier

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Basic tube (triode) small signal amplifier

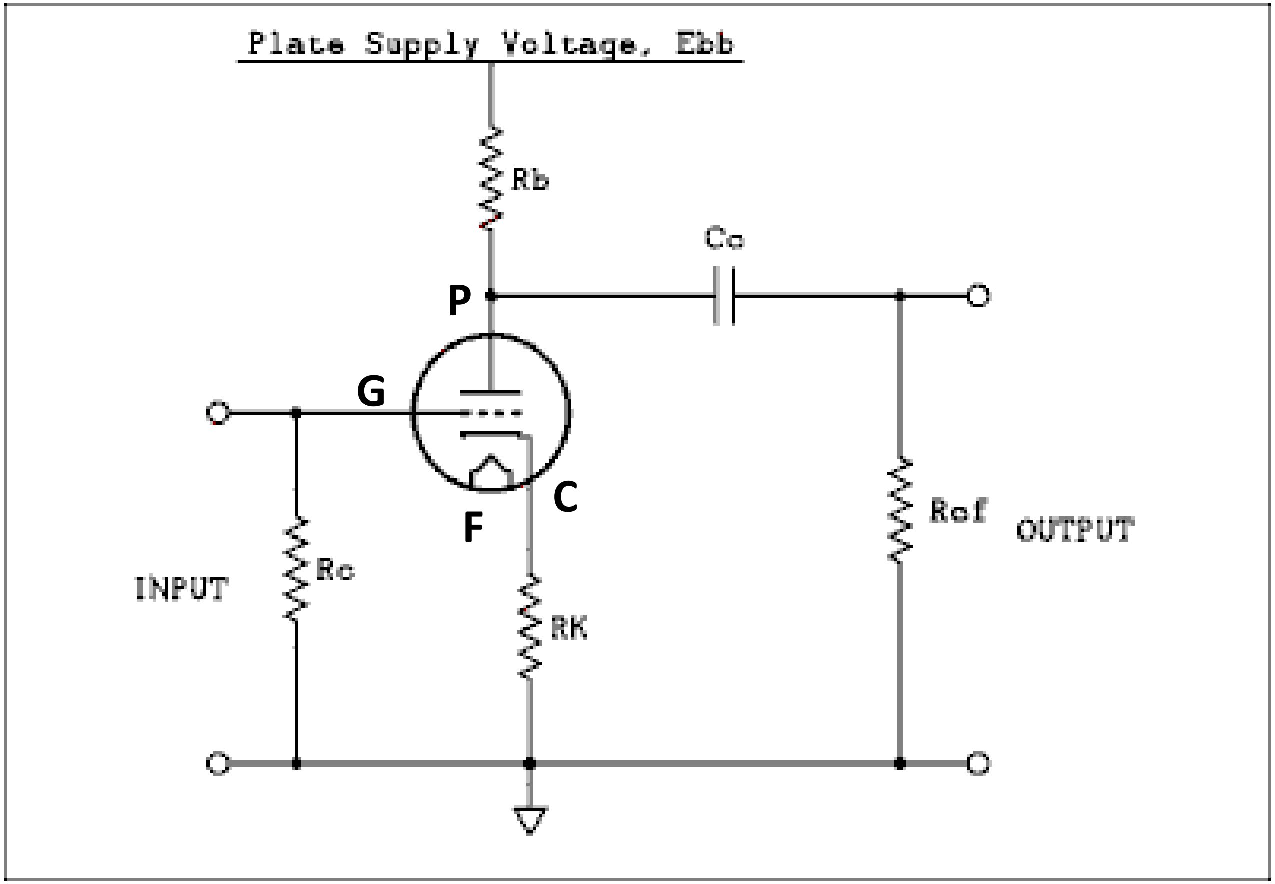
Rb - plate load

Rc – grid reference to ground

RK- cathode resistor

Rcf. –output load

Co – DC blocking output capacitor



Common emitter amplifier

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Transistor as a switch (on/off device)

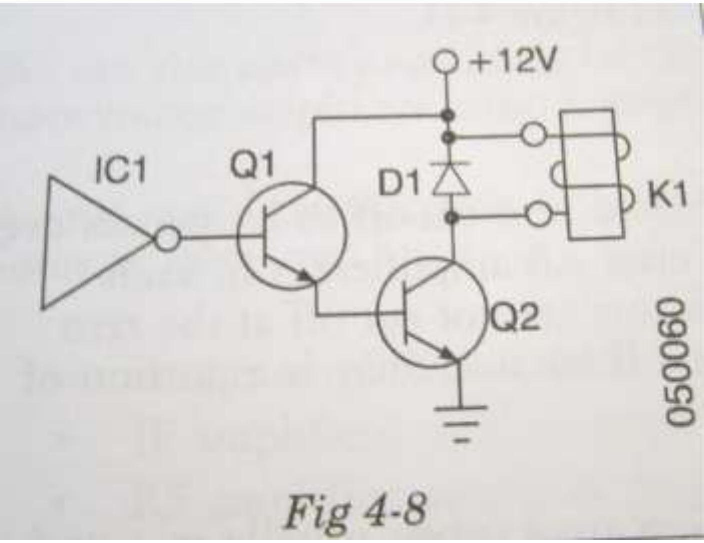
-max (saturation) or zero amplification/current flow

PD = VCE x IC

Alternative/adjunct to a mechanical relay

"Darlington pair", often in one case

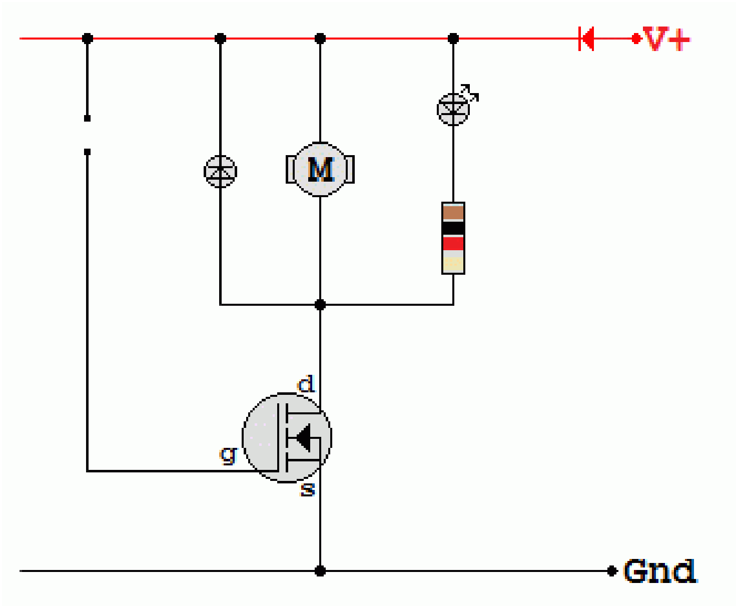
Activating Q1+Q2 grounds/activates relay K1



High current transistor can replace relay

Very low power can switch high power

Power MOSFETs have near 0 resistance when "on" →



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Class B biasing (one method)

Driver stage →

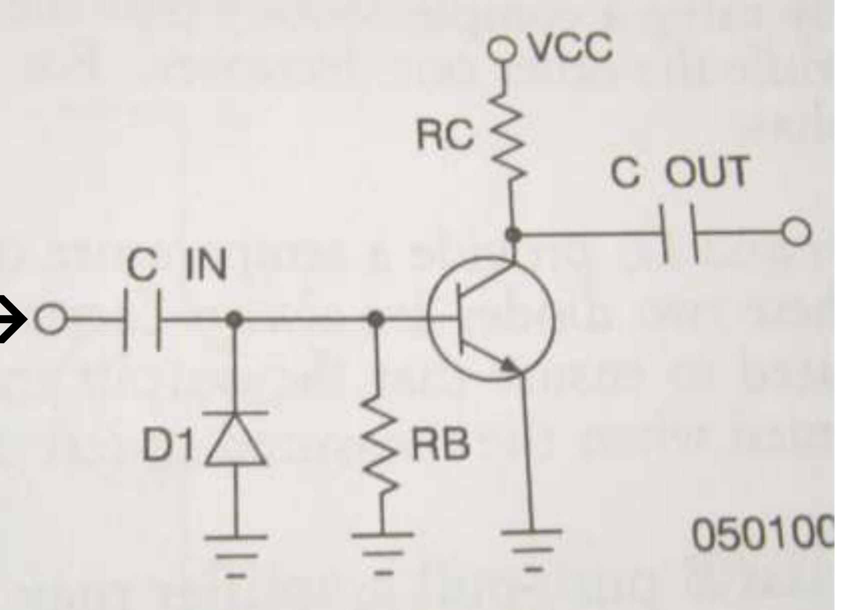

Fig 4-12

D1 is oriented <u>opposite</u> to the EB junction diode

This produces symmetrical load to driver stage
(if both diodes are Si or Ge,
and have similar properties)

RB sets base I at <u>cutoff</u>

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The push-pull amp: when the final tubes/transistors are operated out of phase

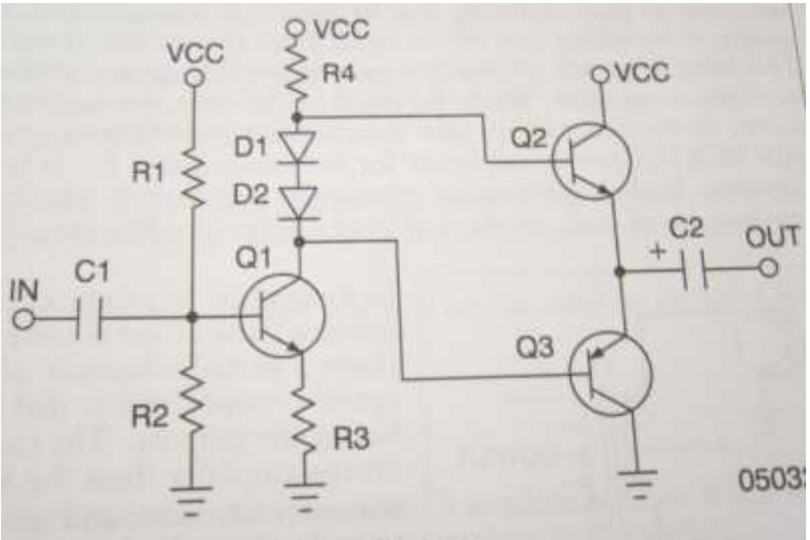
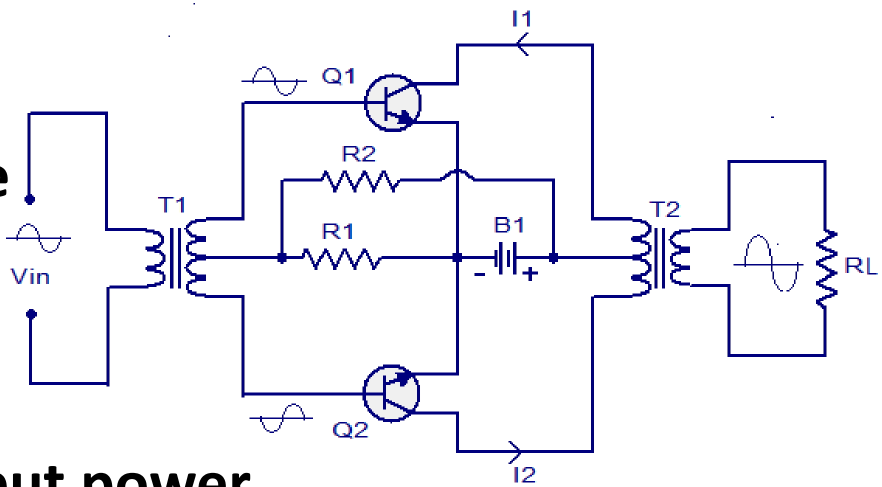


Fig 4-13

-"totem-pole" style push-pull (PNP + NPN complimentary pair)

-in complimentary pair, device characteristics match, but polarity is opposite



Transformer-type push pull amp

-common transceiver RF output stage

-common hi-fi audio output stage

- B1 provides correct Vcc (usually power supply, not battery)

-two devices (Q1 + Q2) share the output power

-bias: R1 + R2

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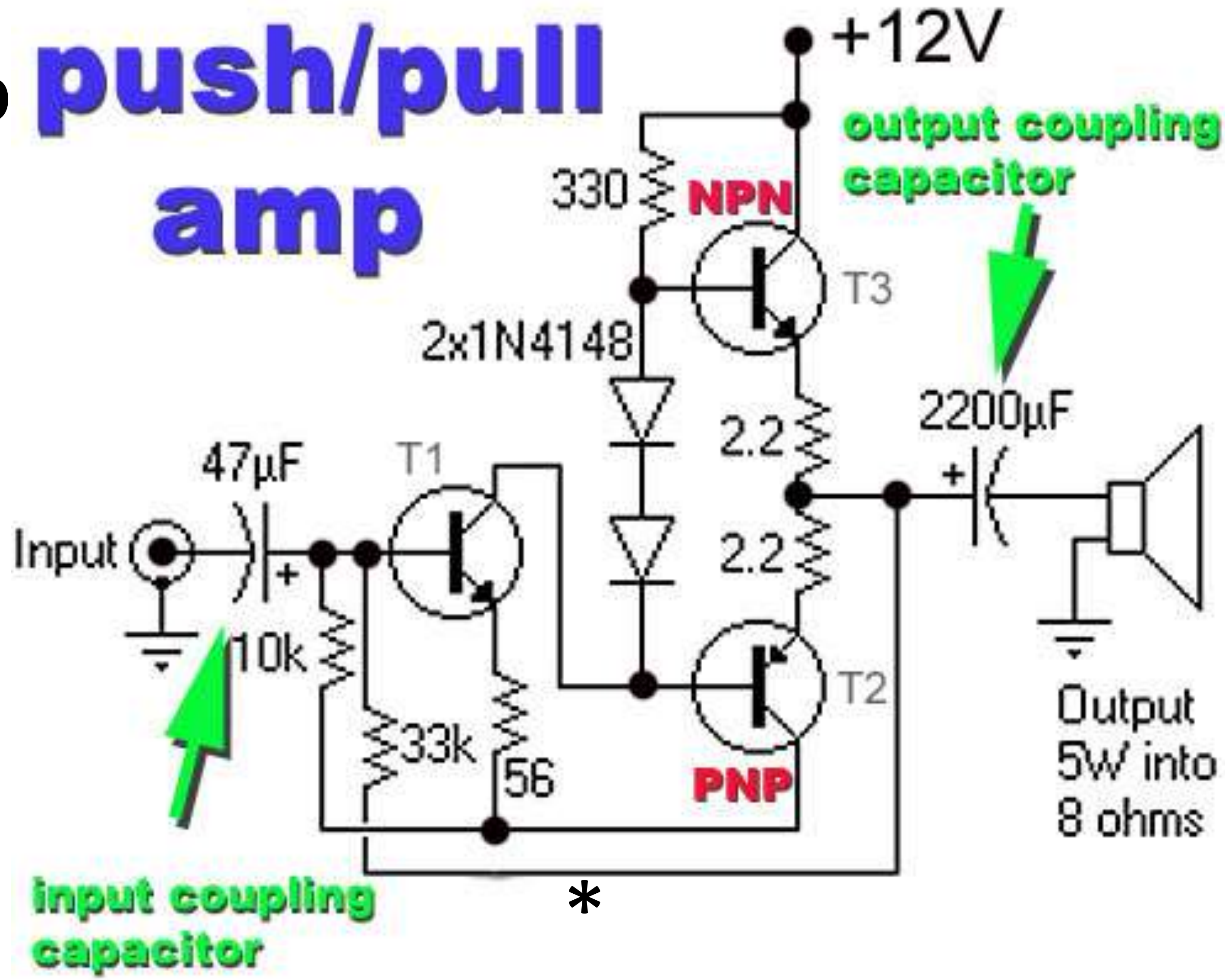
5W audio push/pull amp



*Note negative feedback!

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Quasi-complimentary push-pull circuit

Similar to totem pole push-pull circuit, but power from matched NPN transistors

-extra stage = higher power out, if power transistors used
-C3: large value allows strong bass notes

-C2 isolates DC on Q1 from rest of amp

-C4+R9: negative feedback loop
- 180° out-of-phase signal re-inserted at Q1.

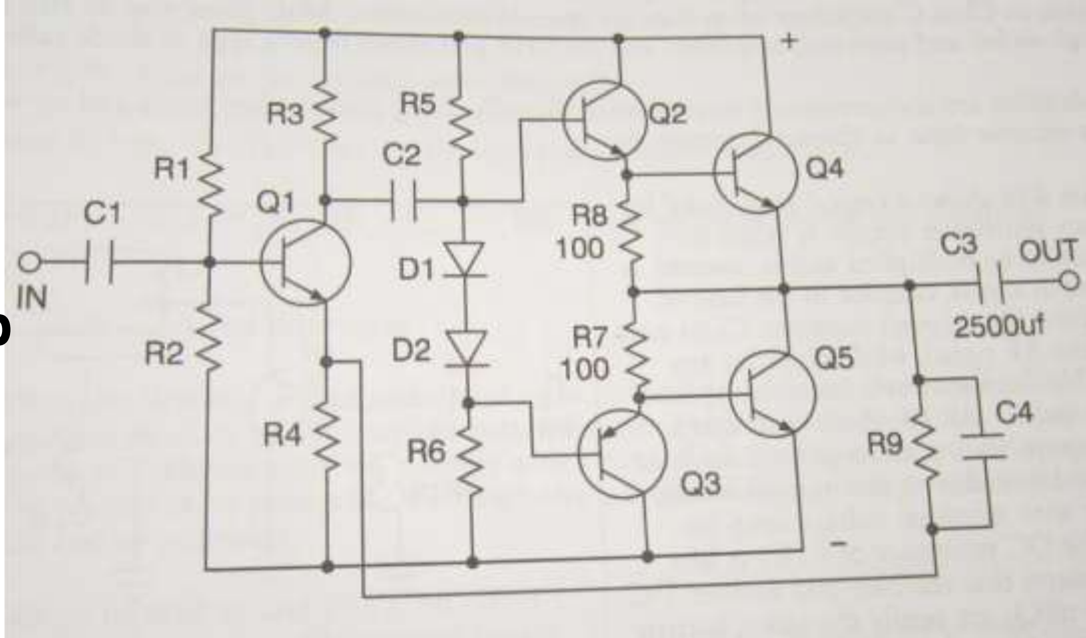

Fig 4-15

Negative feedback: -reduces gain
-reduces distortion and noise
-increases stability and linearity

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RF frequency multiplier amplifier

Can select a multiple of f1 and amplify it

-uses class C bias to produce high distortion of f1

-resonant circuit L1+C2 is tuned to a desired multiple of f1

-eg: if f1=1.000 MHz, then output could be 2, 3, 4, 5, 6....etc. MHz

- the higher the harmonic (multiple), the less output is obtained at nf1

-L1+C2 is load of Q1

- C3 references output to ground

-C1, C4 isolate DC in multiplier.

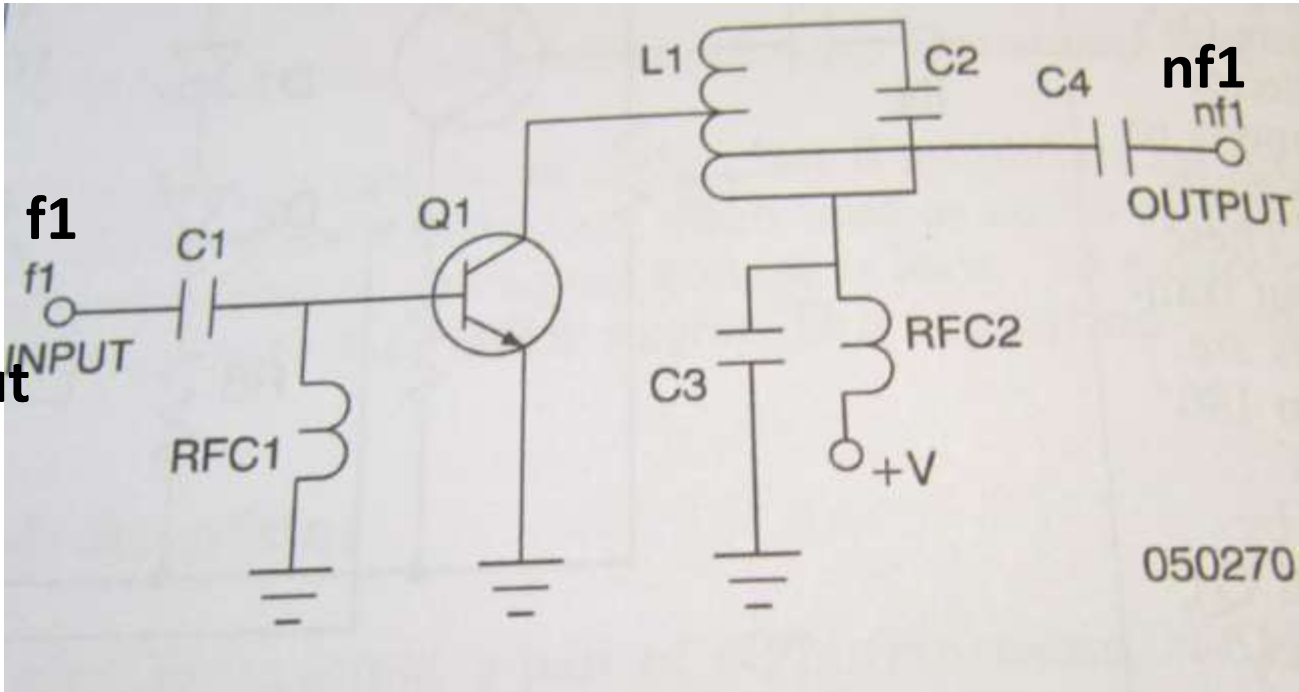

Fig 4-16

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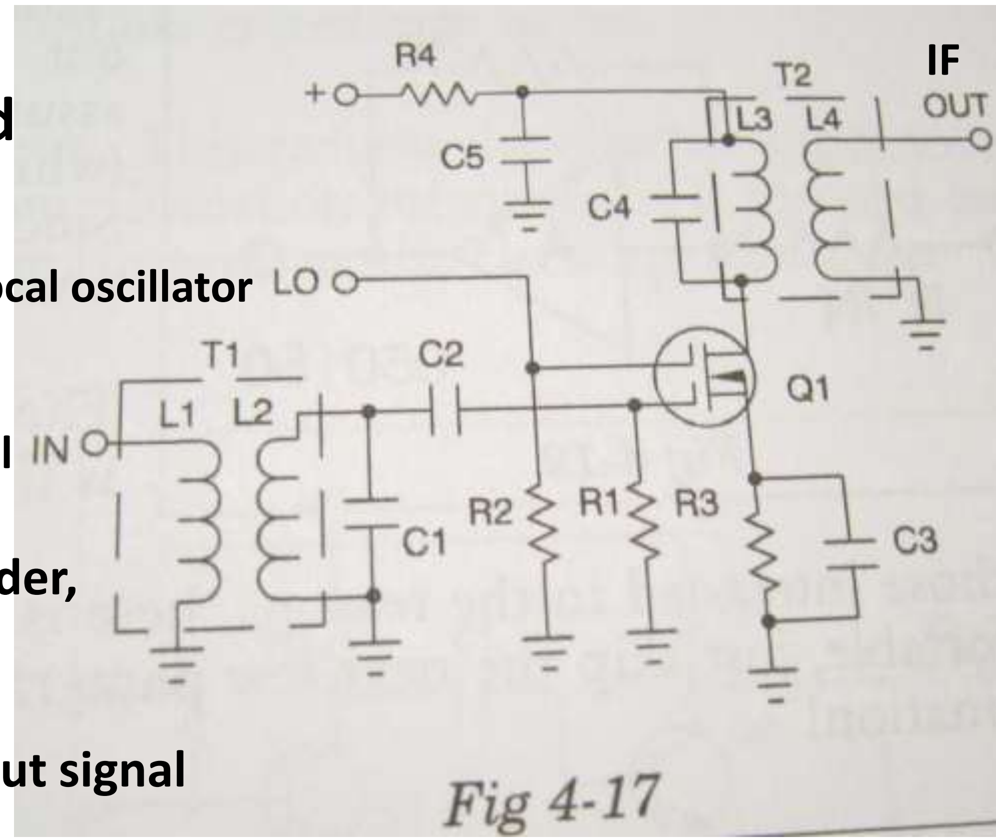
RF mixers

-RF mixer + local oscillator = “converter”

-non-linear circuit allowing 2 or more frequencies to mix and form products (sums and differences)

-key in all direct conversion and superhet RXs

-diode = basic mixer



“Unbalanced Mixer”

Sums + differences produced: first order, second, third, higher order

Unbal. Mix: puts out both LO and input signal

Balanced Mix. : puts out either LO or Input signal

Double Bal. Mix.: puts out neither LO or Input signal

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Single ended (unbalanced) vacuum tube mixer

Mixer products

fs= received signal

fo = local oscillator input

-many products, most unwanted (spurious)

-inputs still strong in output (no cancellation due to 180° phase shift)

-high order products are much weaker

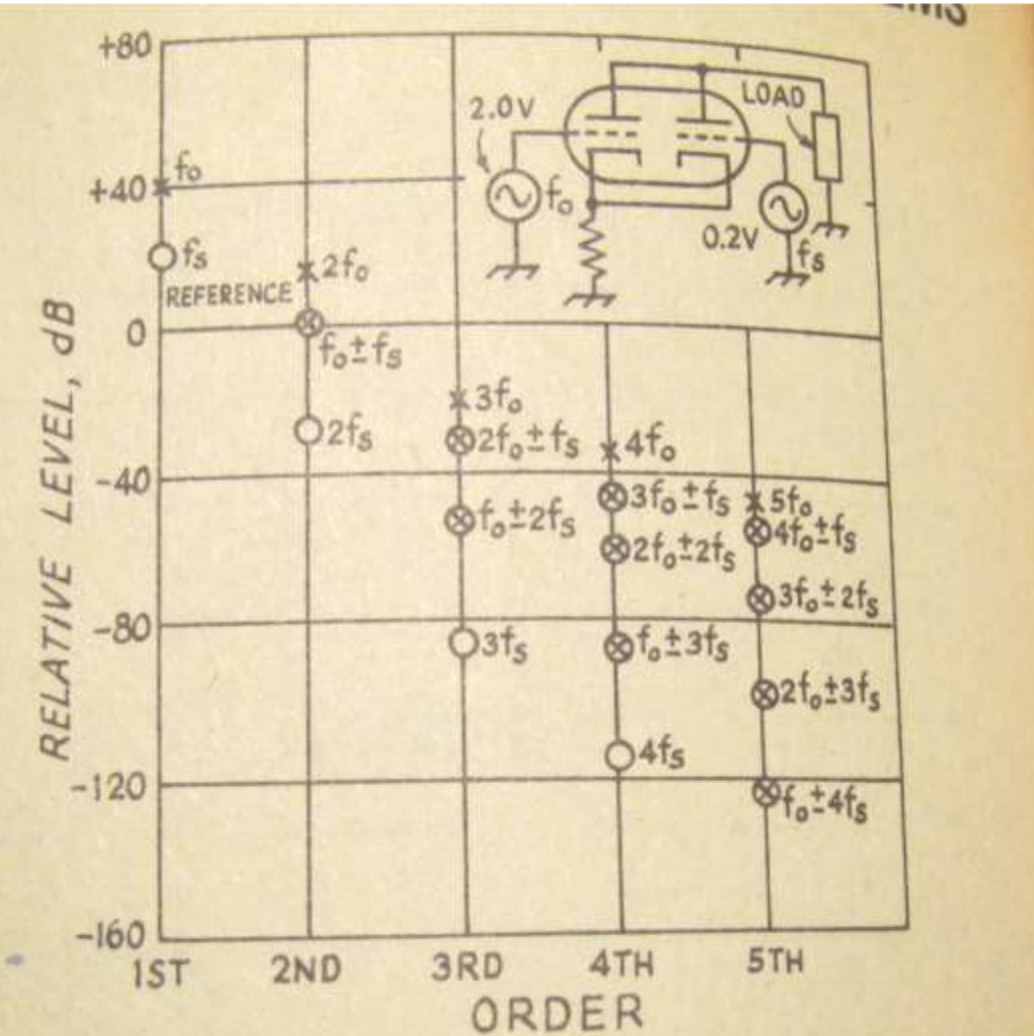

Fig. 8-14 — Chart showing the relative levels of spurious signals generated by a 12AU7A mixer.

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Single-ended (unbalanced) tube mixer

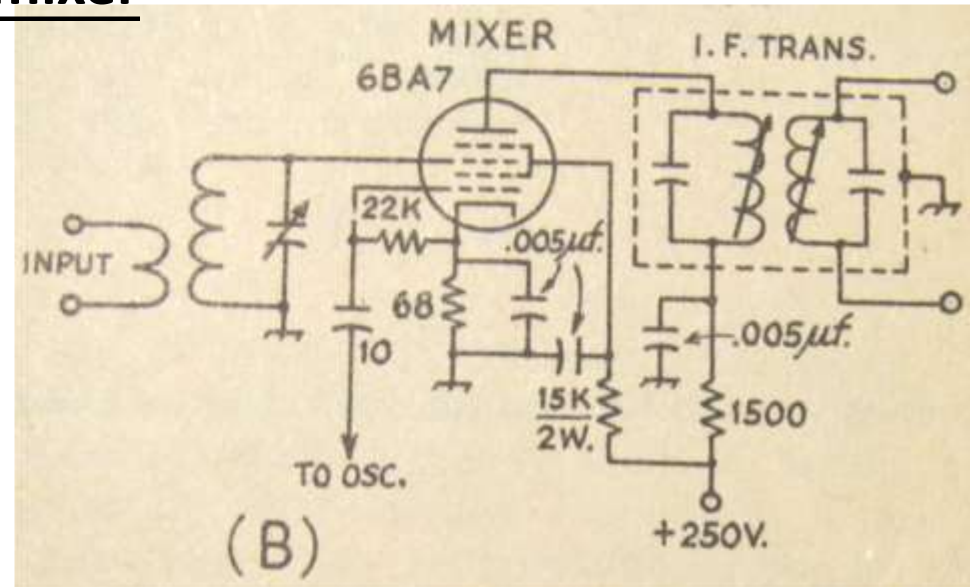
-good mixer gain

-LO and signal are lightly loaded and not coupled to each other

-unbalanced

-poor dynamic range

-gainmultigrid tube = high noise



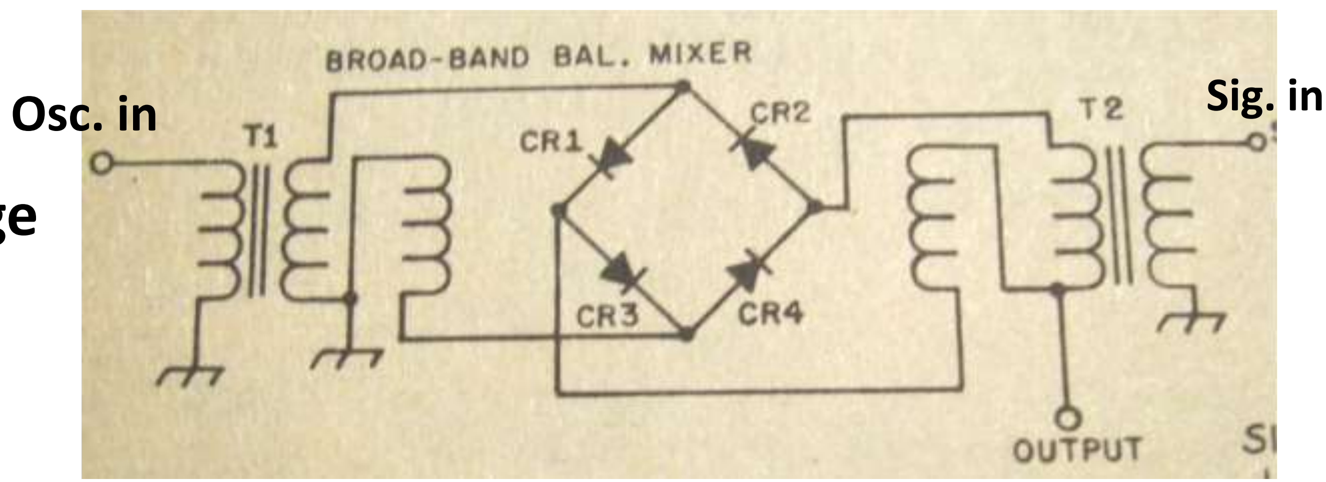
Diode ring mixer

-quiet (low noise)

-good dynamic range

-double balanced

-negative gain



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Modern HF high performance RX mixer circuit (Kenwood TS-590SG, 2014)

Double-balanced "quad" mixer

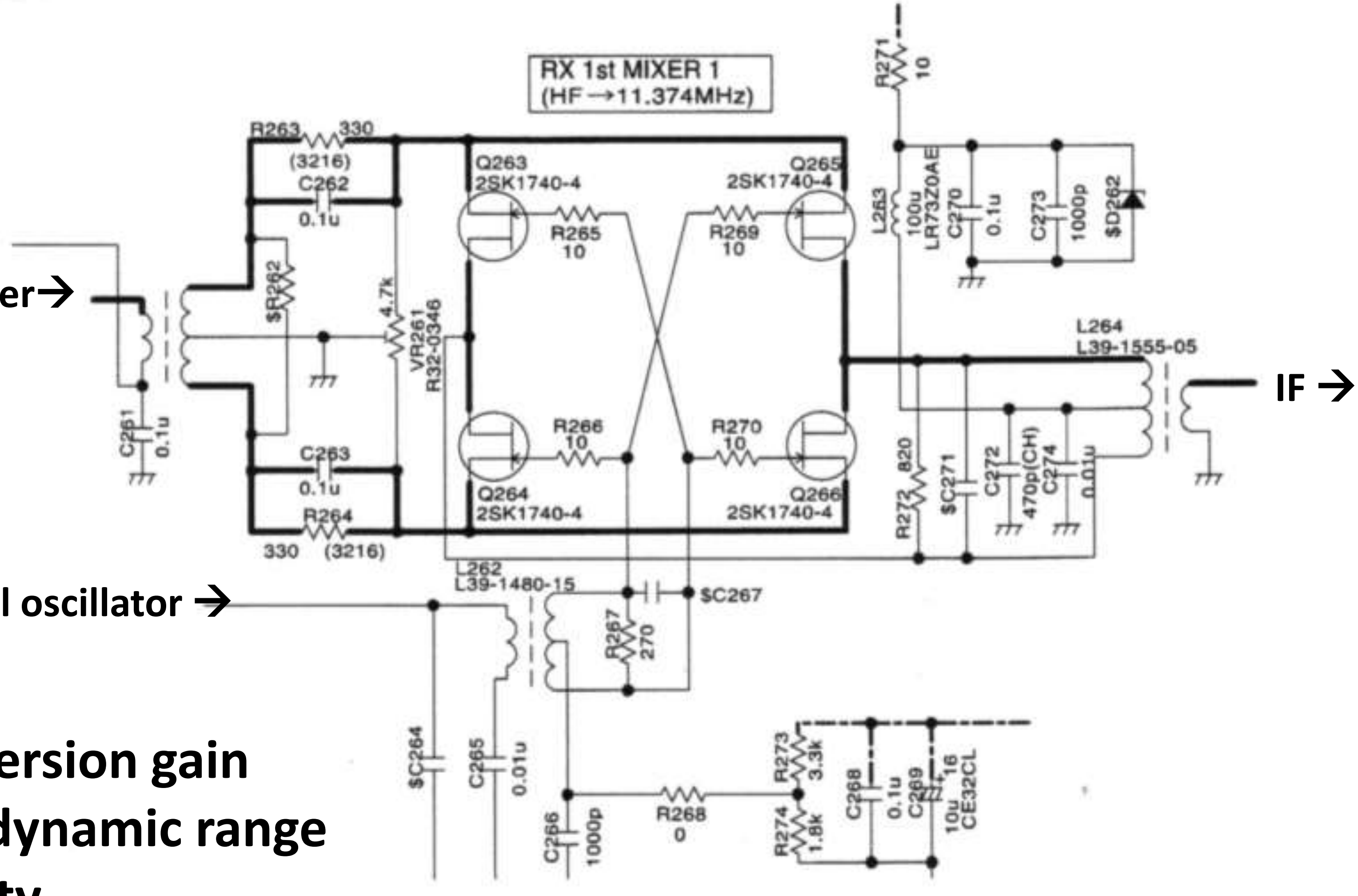

Figure 1-3 Receiver Mixer Circuit

- -low noise
- - good conversion gain
- -very wide dynamic range
- -high stability

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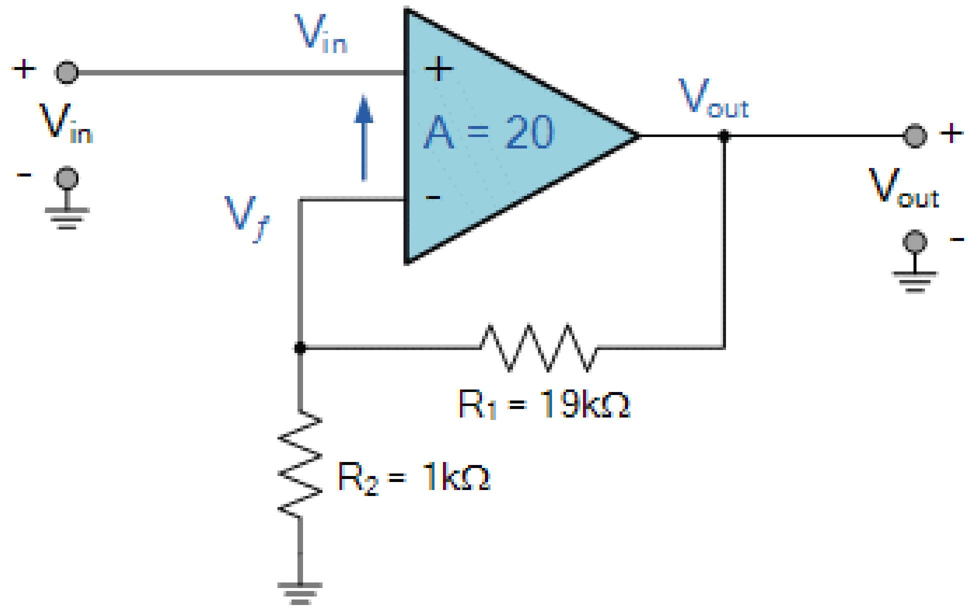
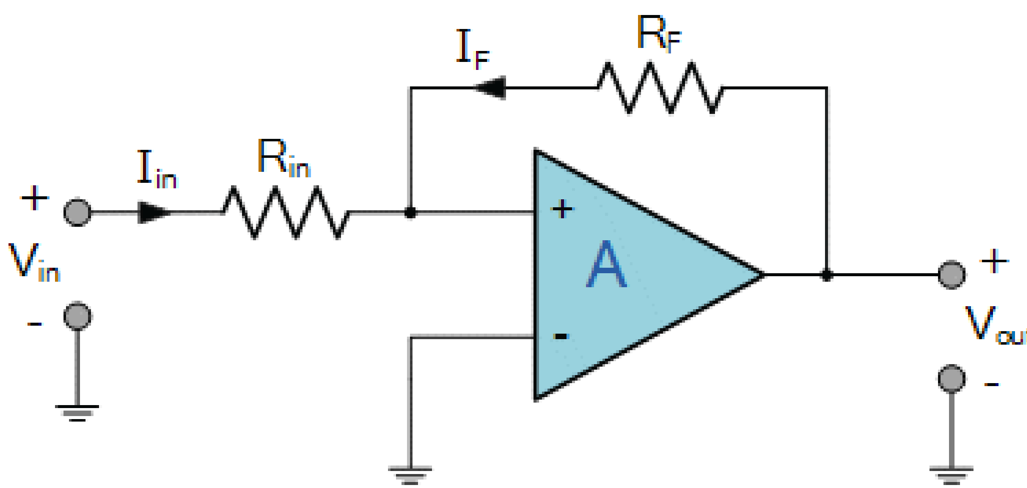
<u>Feedback</u>: returning part of the output power of an amplifier to its input

<u>Negative</u> feedback
- -less gain + distortion
- -increased stability
- -less thermal drift



<u>Positive</u> feedback
- -increased gain
- -increased noise + distortion
- -oscillator!



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Feedback

Effective (closed loop) gain (ACL) = AOL – feedback (F)

AOL = open loop gain

ACL = AOL/1+(AOLx F)

F = RIN/RIN + RF

ACL = RF/RIN

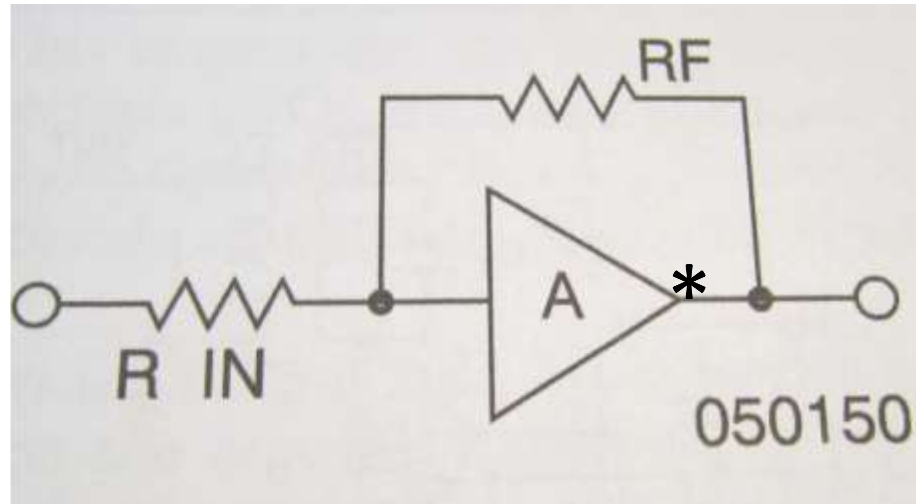

Fig 4-19

* Output is 180° out of phase with input

Amplifier Gain: can be expressed in I, V, P, or dB

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Negative feedback over 2 stages

Feedback factor: F = R2/R2 + R7

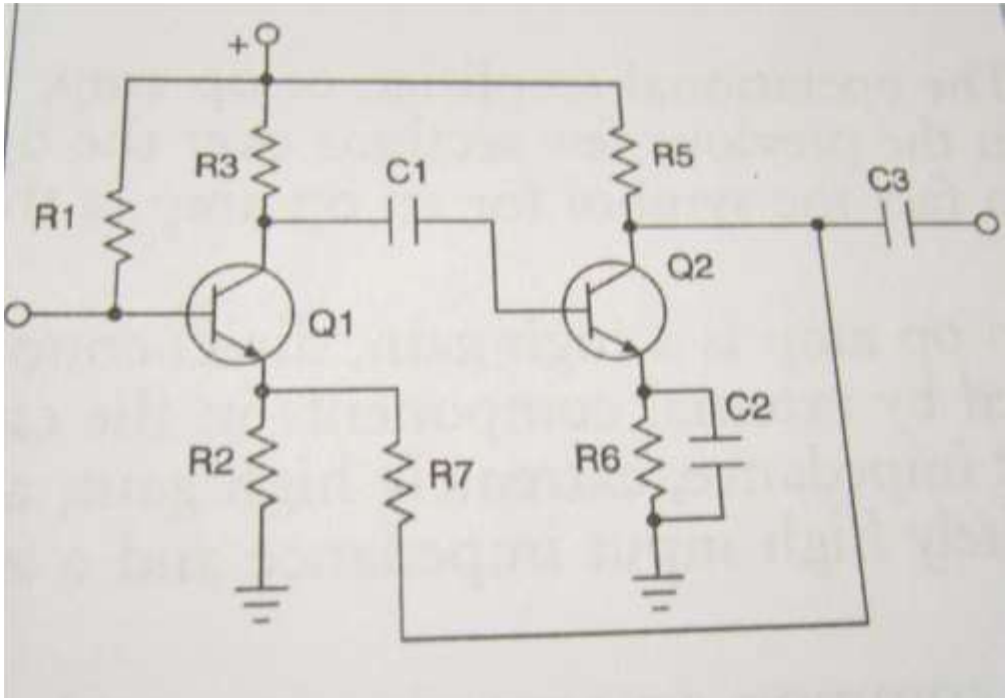

Fig 4-20

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The "op-amp" analog integrated circuit

Output may swing either side of 0 if + and – DC supplies are used

Non-inverting (+) input: output is in phase with input

Inverting (-) input: output is 180° out-of-phase with the input

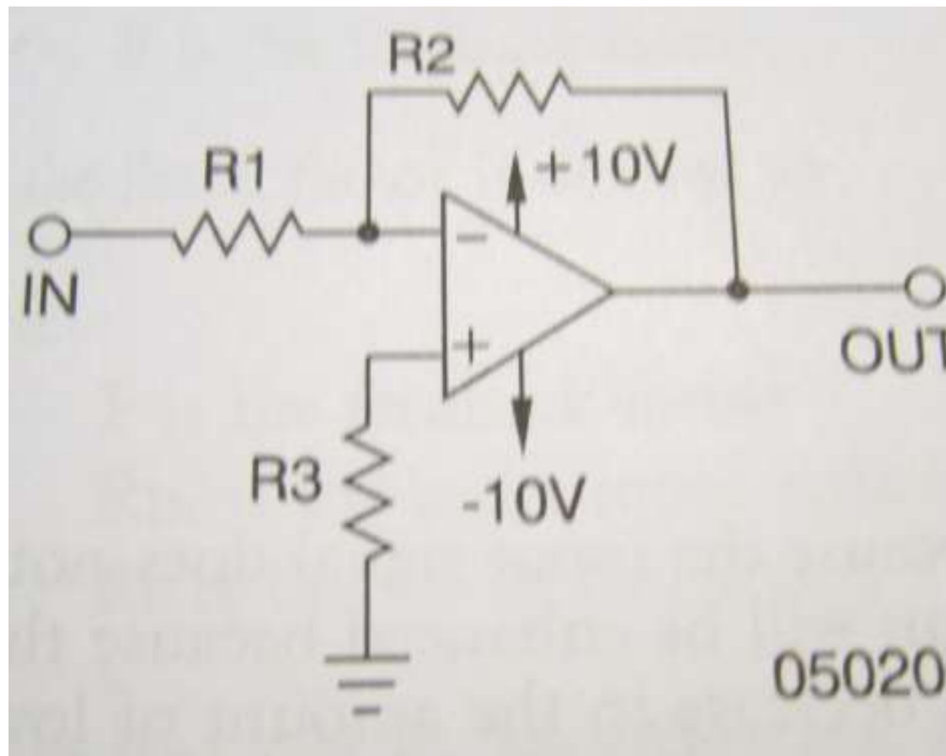

Fig 4-21

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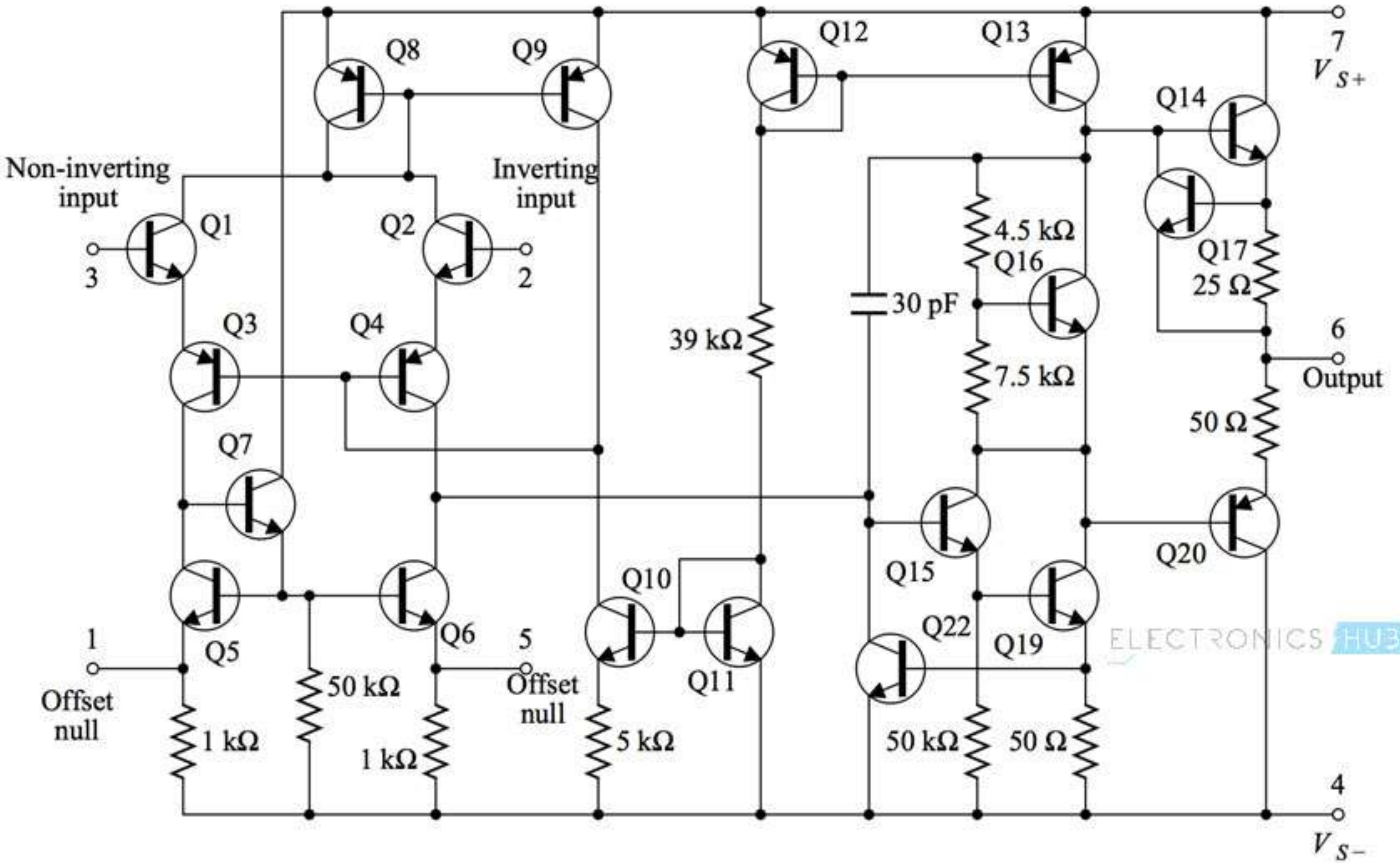
LM741 Linear Monolithic DC to 1.5 MHz integrated circuit (IC) operational amplifier, or "Op Amp"



22 NPN transistors, 11 resistors, 1 capacitor

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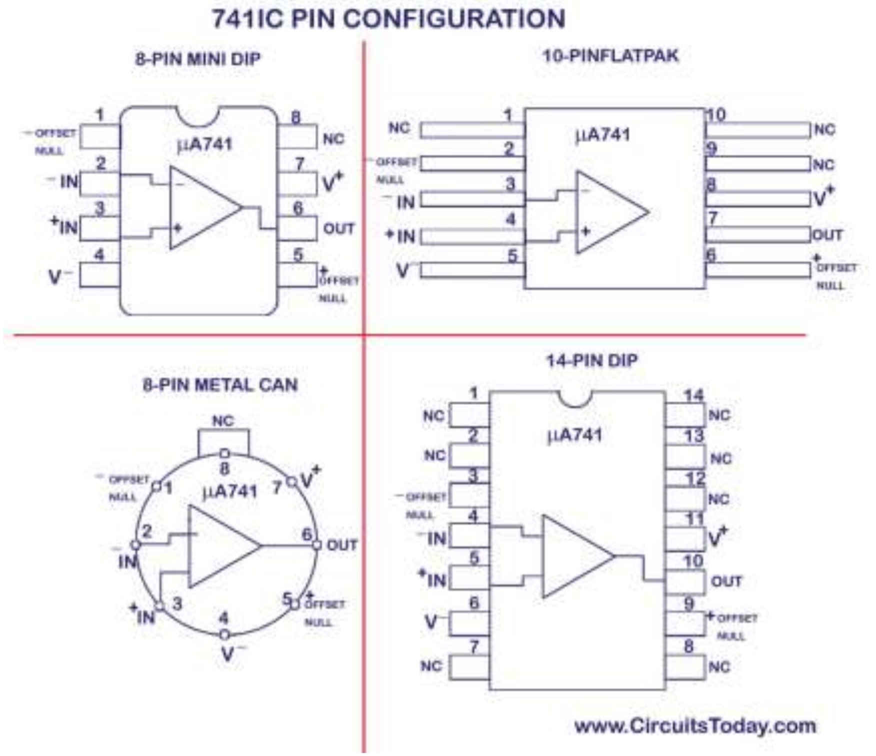
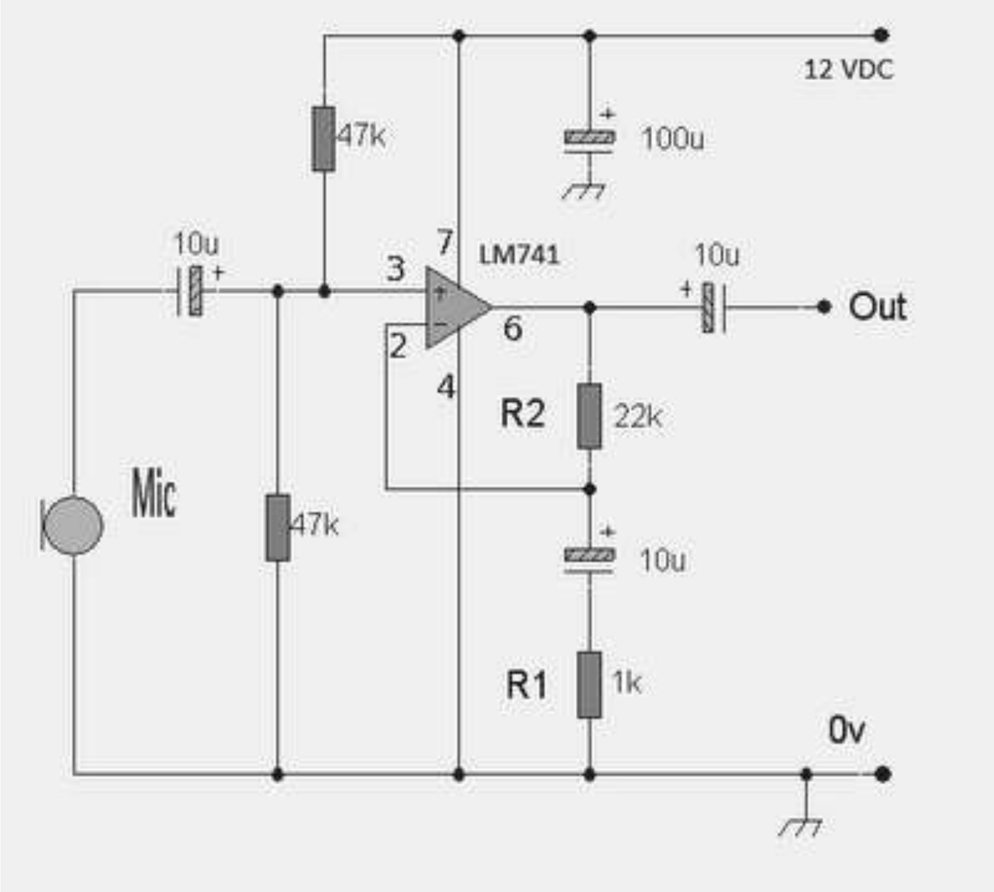
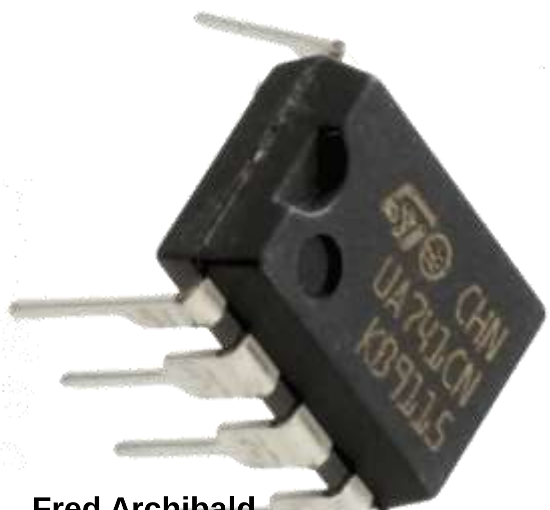
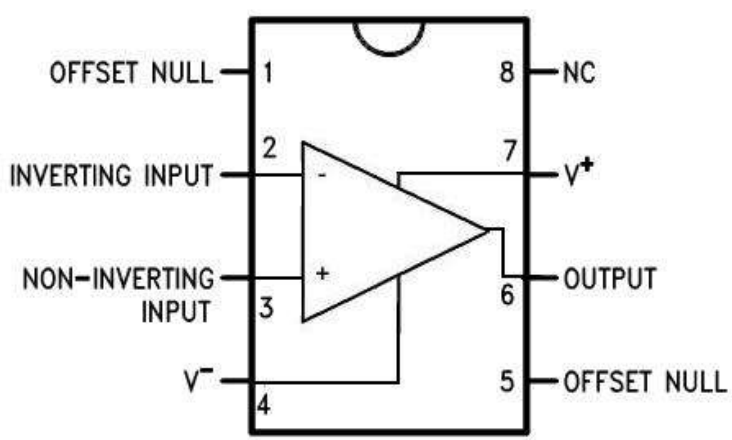






LM741 Pinout Diagram



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Operational Amplifiers (analog integrated circuits)

- **-older designs only good (low noise) to about 20 kHz and have slower slew rates**
- **-typical "open loop power gain" = 200,000-400,000**
- **-gain often reduced by (-) feedback to 1, 5, 10, or 50**

Frequency-independent negative feedback

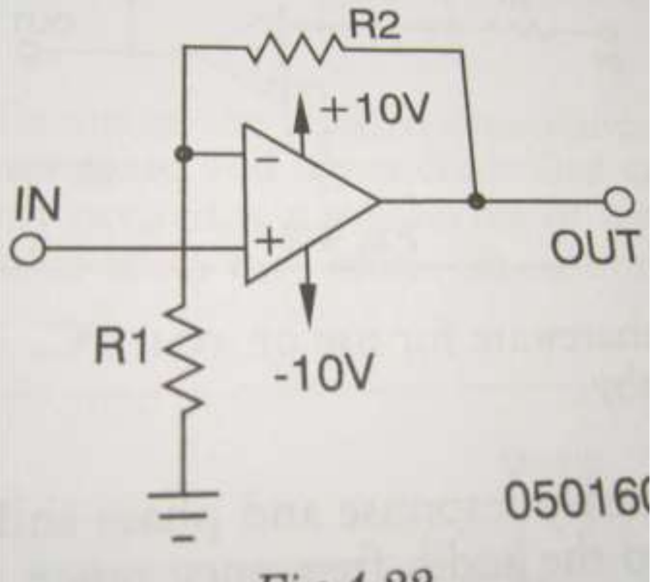

Fig 4-22

Frequency-dependent negative feedback

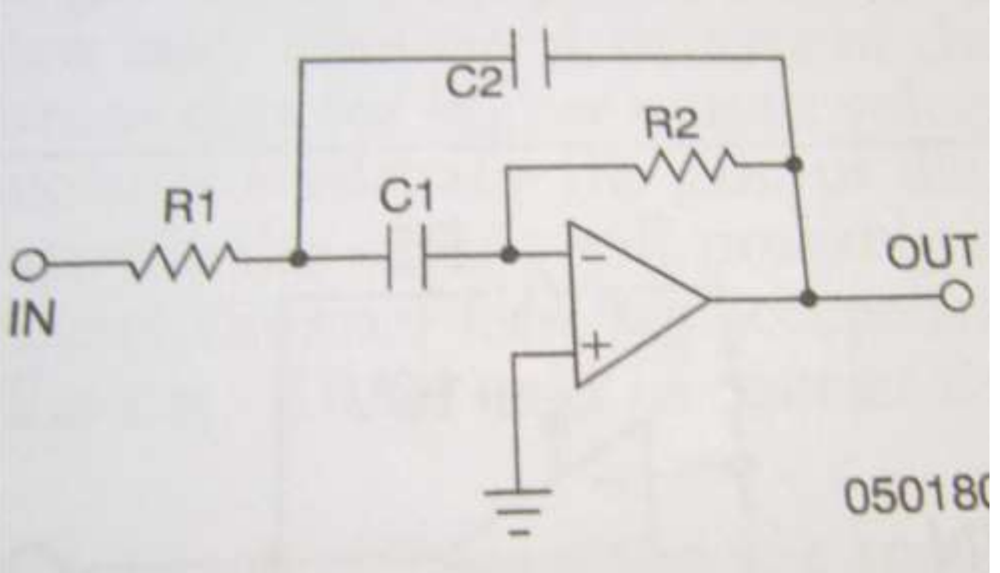

Fig 4-24

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Calculating GNI (non-inverting voltage gain)

GNI = R2/R1 +1

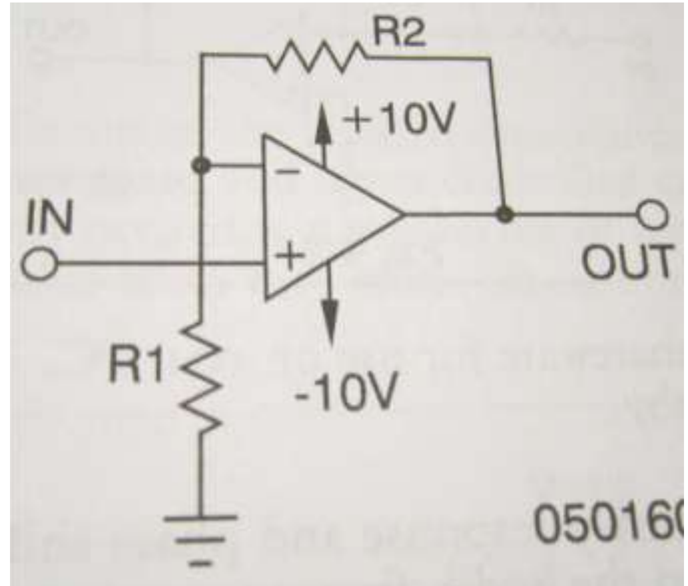

Fig 4-22

GNI = 1 (unity)

Analogous to cathode, source, or emitter follower

-converts high Z to lower Z

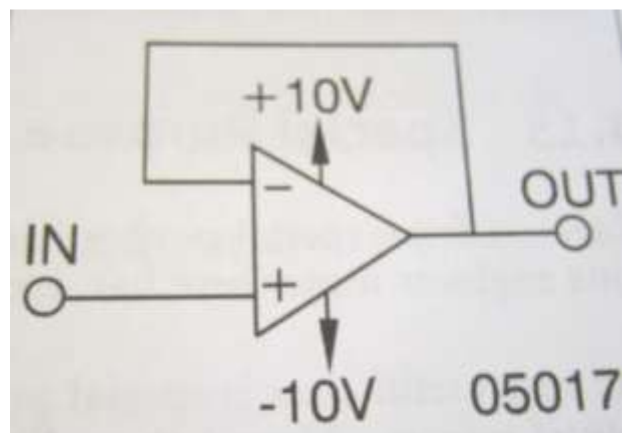

Fig 4-23

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VE1FA

Frequency-multiplying RF JFET amplifier (with neutralization)

JFET internal capacitance causes roll-off, tendency to oscillate

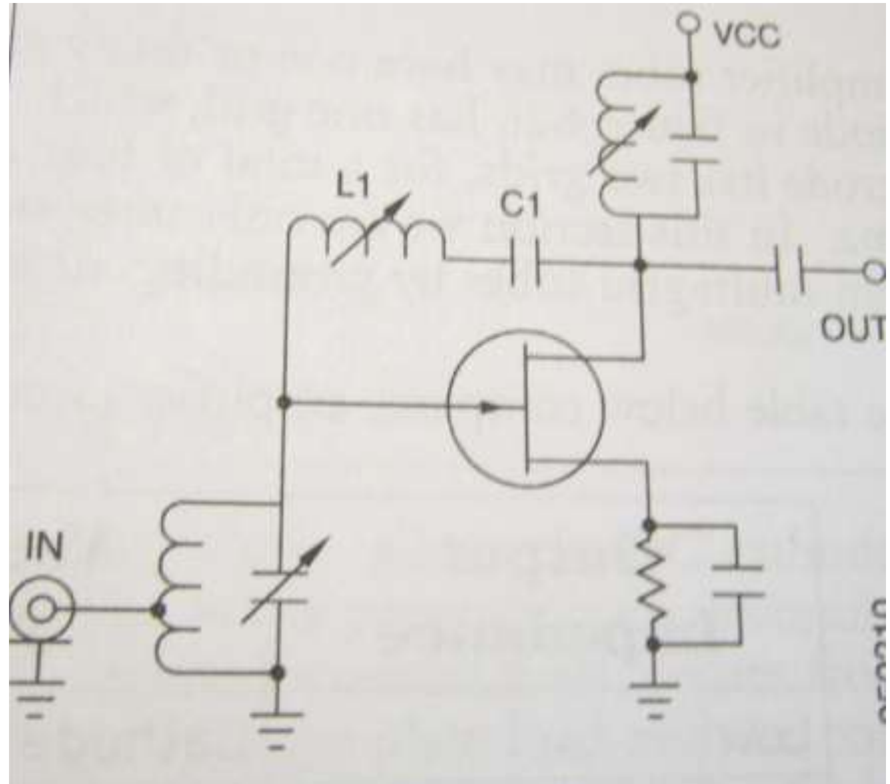

Fig 4-25

<u>Oscillation</u>: a problem in many amplifiers

L1+C1 are a <u>neutralizing</u> circuit
- negative feedback at a certain frequency

Neutralization needed mostly when input + output circuits are tuned to the same frequency

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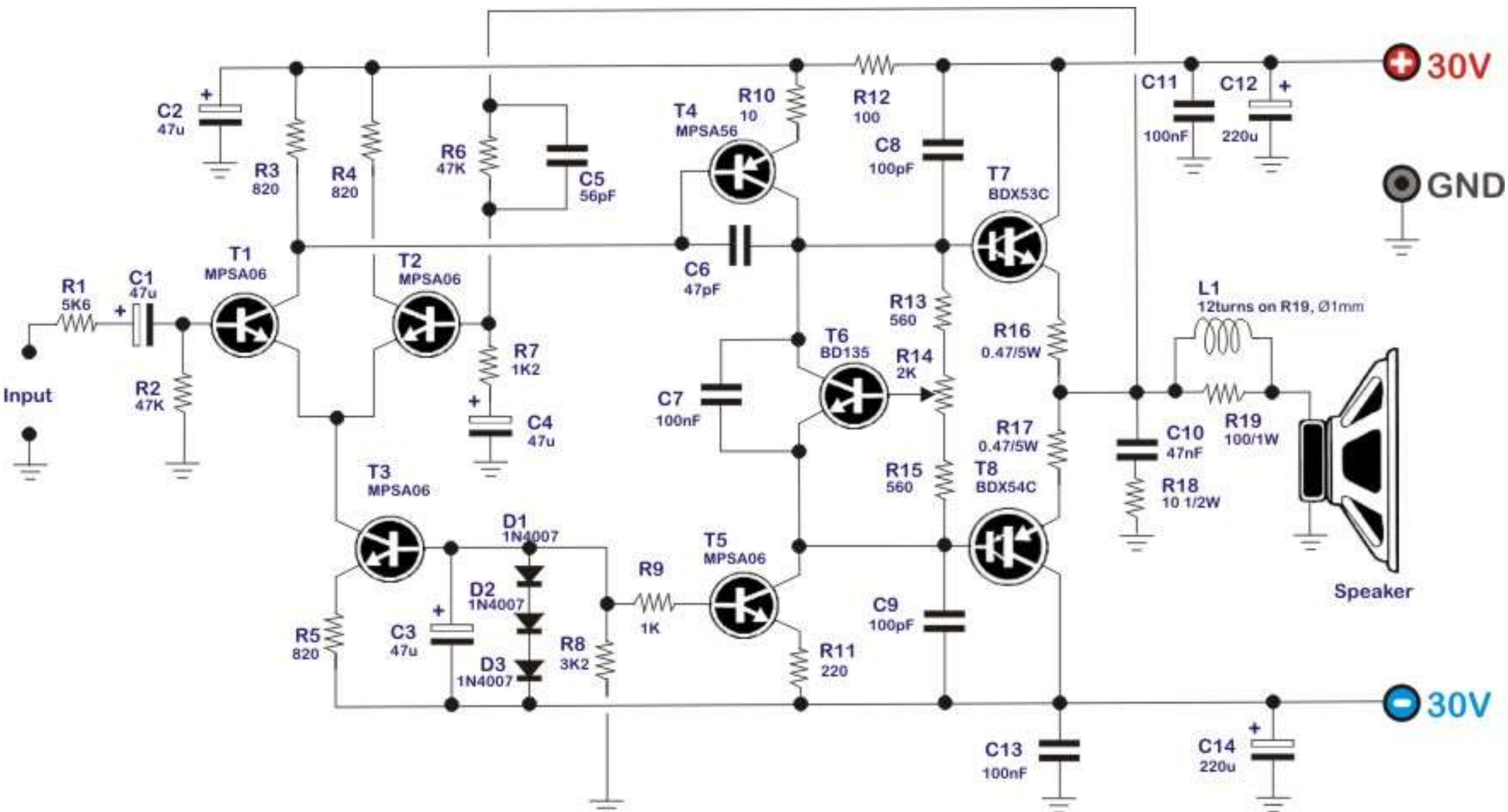
35W High Fidelity Audio Amplifier



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Another 30 W Audio Amp: What’s Different?

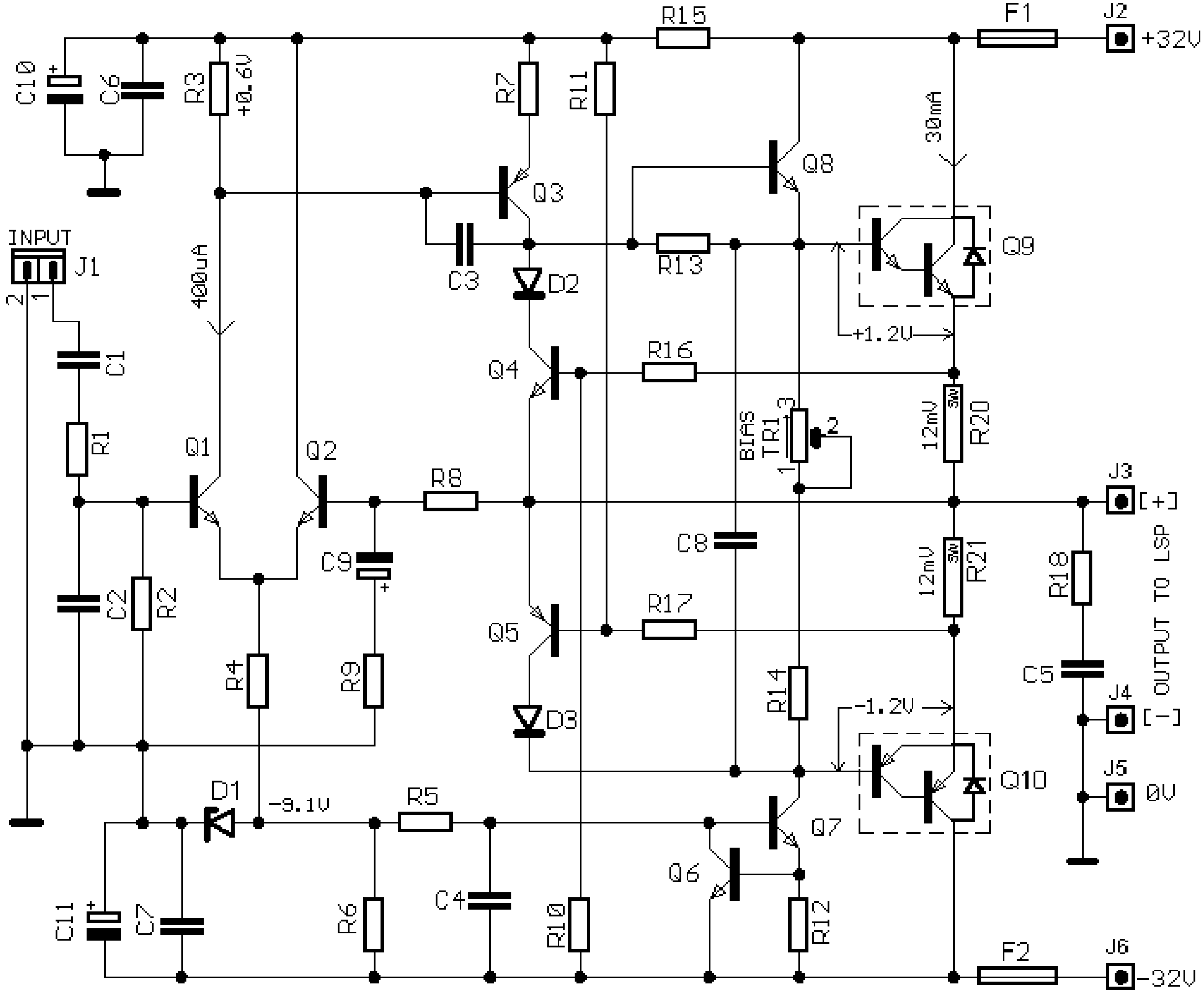

Fig.1--POWER AMPLFIER 30W

Sam 8/02

Fred Archibald
VE1FA

-2 X 36 W stereo (2-channel) audio amplifier

-runs on +13.8 VDC

<u>Note:</u>

-double-sided PCB

- uses both through-hole and SMT

-heat-sinks needed

-SMT vs. through-hole components

-<u>big</u> reduction in cost and parts count with ICs

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VE1FA

Modern “grounded grid” HF linear amplifier output tube

Input is from transmitter/exciter

Will amplify 60-70 W to 700-800 W

Examples: 3CX800A7, 4 x 811A, 3-500Z

C1-L1-C2 tuned + Z-match input

C6-L2-C7-L3 tuned output circuit

EP is about 3400 VDC, IP about 500 mA

An appropriate resistor from the cathode to B- will allow effective self bias. Bias is usually AB1.

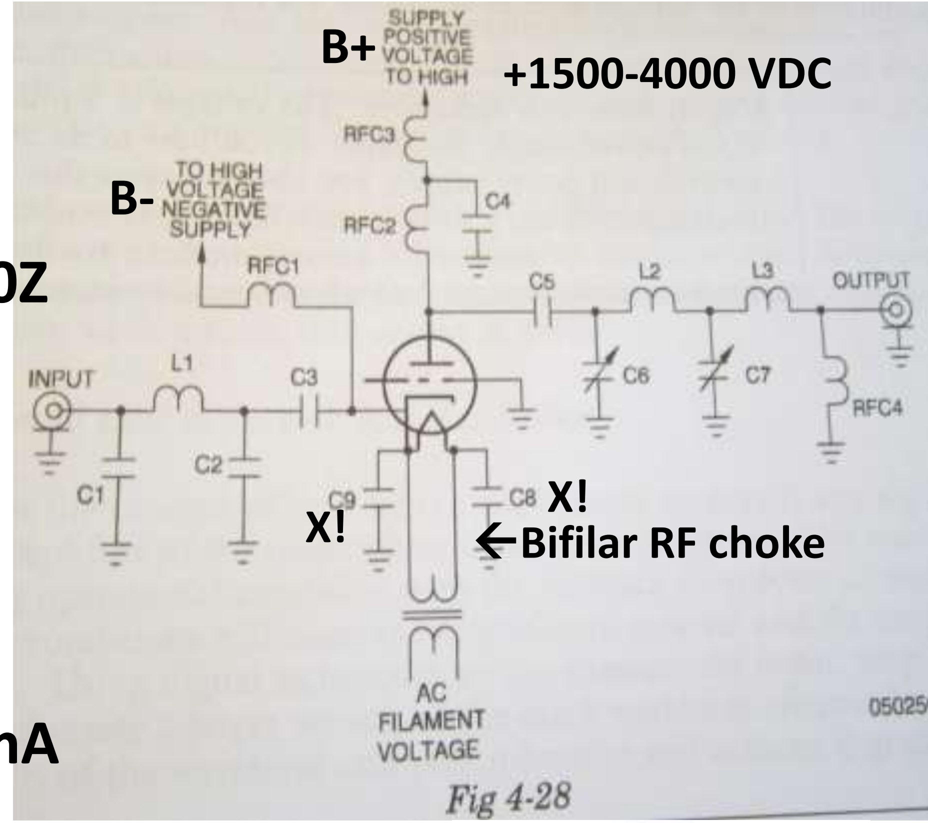

Fig 4-28

Modern ceramic triode tube →

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Comparing 2 popular linear amplifiers

Elecraft KPA-500 (MOSFETs)
500W PEP, SSB + CW
No-tune, lots of
Automation + protection
$2700 CAD   26 lbs, 50V Vcc

Ameritron AL-80B (3-500Z tube)

1kW PEP SSB, 800W CW
Manual, $2000 CAD
48 lbs
3200 VDC

3-500Z
Triode tube

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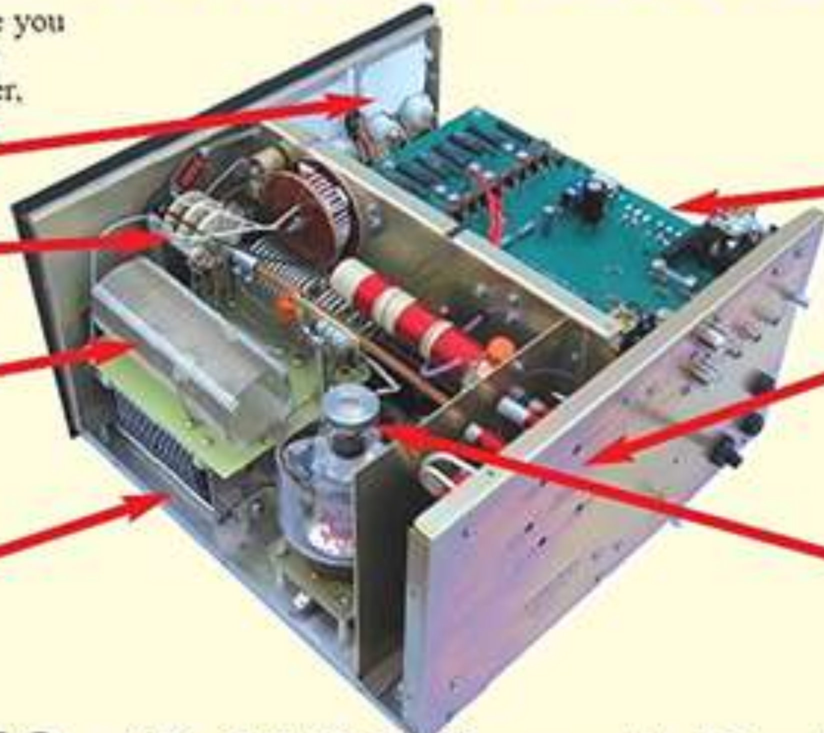
An inside look at AMERITRON'S *AL-80B*

Dual illuminated cross-needle meters give you four separate indicators that monitor your operating conditions -- PEP forward power, PEP reflected power, SWR, Grid Current, Plate Current, Plate Voltage and ALC.

Heavy Duty Bandswitch.

Tank coils spaced away from chassis for optimum "Q".

Pi-Network gives smooth tuning and full band coverage, even on 160 and 80 Meters.



Heavy duty power supply: 26 lb. high silicone steel transformer and computer grade capacitors.

Rear panel adjustable input Pi-Network.

Genuine *classic* 3-500 Tube.

AMERITRON'S *AL-80B* Kilowatt Desktop Linear

SPECIFICATIONS:
Frequency Coverage: 1.8, 3.5,7, 14, 21 MHz and WARC bands. Export/User modified models include 10/12 Meters.
Input Circuit: Adjustable Pi-Network, VSWR 1.3:1 or less at resonance.
Output Circuit: Pi-L/Pi-Network.
Input Bandwidth: 20% for 2:1 VSWR or better.
Drive Requirement: 85 Watts for 800 Watt CW output. 10 dB gain.
Shipping Weight: Amplifier, 54 lbs.; tube, 3 lb.
Operating Weight: 48 pounds.
Efficiency: CW/SSB better than 66%.
Dimensions: $15\frac{1}{4}$Dx14Wx$8\frac{1}{2}$H inches.

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END of Amplifiers!