Understanding Power Amplifiers

Thursday October 6, 2022
Gordon Gibby
Alachua County ARES® / NFARC
TECH NITE PRESENTATIONS

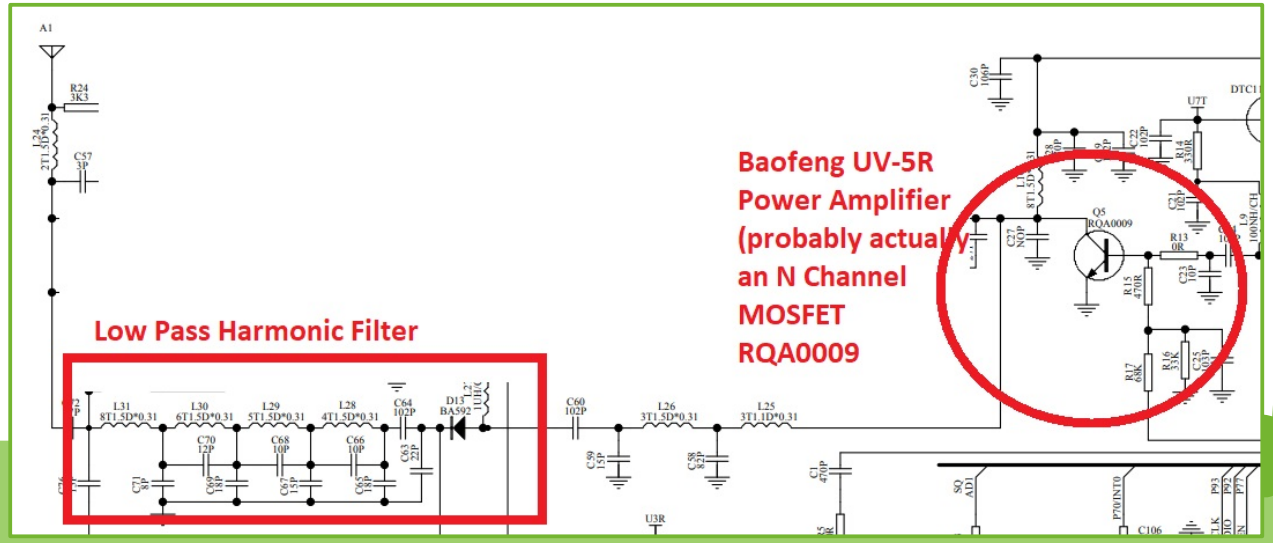
- You can go a long way without understanding these subtle differences.
- But you can avoid problems and understand expensive systems a lot better….if you do understand these points.
- All of this is fair game for General / Extra Class License tests

The final amplifier is DIFFERENT

- Generally, the signal levels at the early stages are tiny – received signals may be -100dBm and signals in the early stages of a transmitter may be tiny fractions of a milliwatt (like negative 20 dBm)
- The power amplifier may produce 1 watt (30 dBm) or as much as 100 watts (50 dBm) – or even 1000 watts (60 dBm).
- If a low level amplifier is only 10% efficient, it may waste only a milliwatt
- If a power amplifier is even 50% efficient, it may waste 1-100-400 WATTS – this is hugely more important to batteries or power supplies

Dual 3-500Z Power Amplifier for HF

- The power amplifier is often ALL about EFFICIENCY
- While not significantly distorting the signal.
- FCC has requirements for distortion, typically 43dB weaker (that’s a LOT weaker) than the main signal.



Baofeng power amplifier N-Channel MOSFET

RENESAS

Datasheet

RQA0009SXAQS

Silicon N-Channel MOS FET

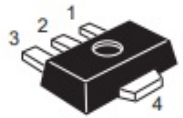
R07DS0493EJ0200
(Previous: REJ03G1566-0100)
Rev.2.00
Jun 28, 2011

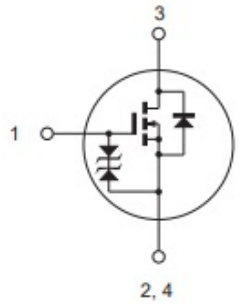
Features

- High Output Power, High Gain, High Efficiency
  Pout = +37.8 dBm, Linear Gain = 18 dB, PAE = 65%
  (V_{DS} = 6 V, f = 520 MHz)
- Compact package capable of surface mounting
- Electrostatic Discharge Immunity Test
  (IEC Standard, 61000-4-2, Level4)

Outline

RENESAS Package code: PLZZ0004CA-A
(Package Name : UPAK)





1. Gate
2. Source
3. Drain
4. Source

- Some ham radio signals have widely varying amplitude
  - Single side band
  - Pactor, ARDOP, PSK31, some portions of VARA
- Some ham radio signals always have the same amplitude
  - Frequency Modulation
  - Frequency Shift modulation (a version of FM)

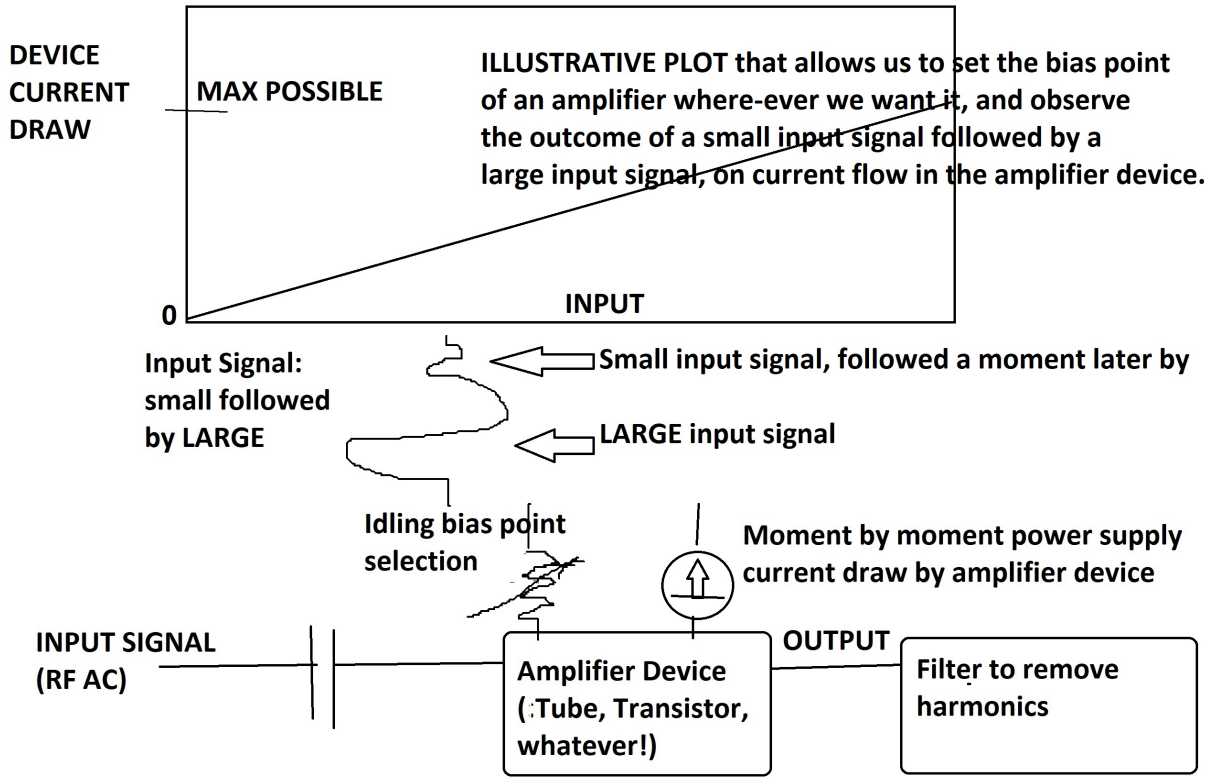
- Amplifiers are often MOST EFFICIENT when operated at FULL POWER.
- Operating the amplifier at lower power typically is lower efficiency.
- Amplifiers can be designed to optimize efficiency at full power level at the expense of linearity at lower levels

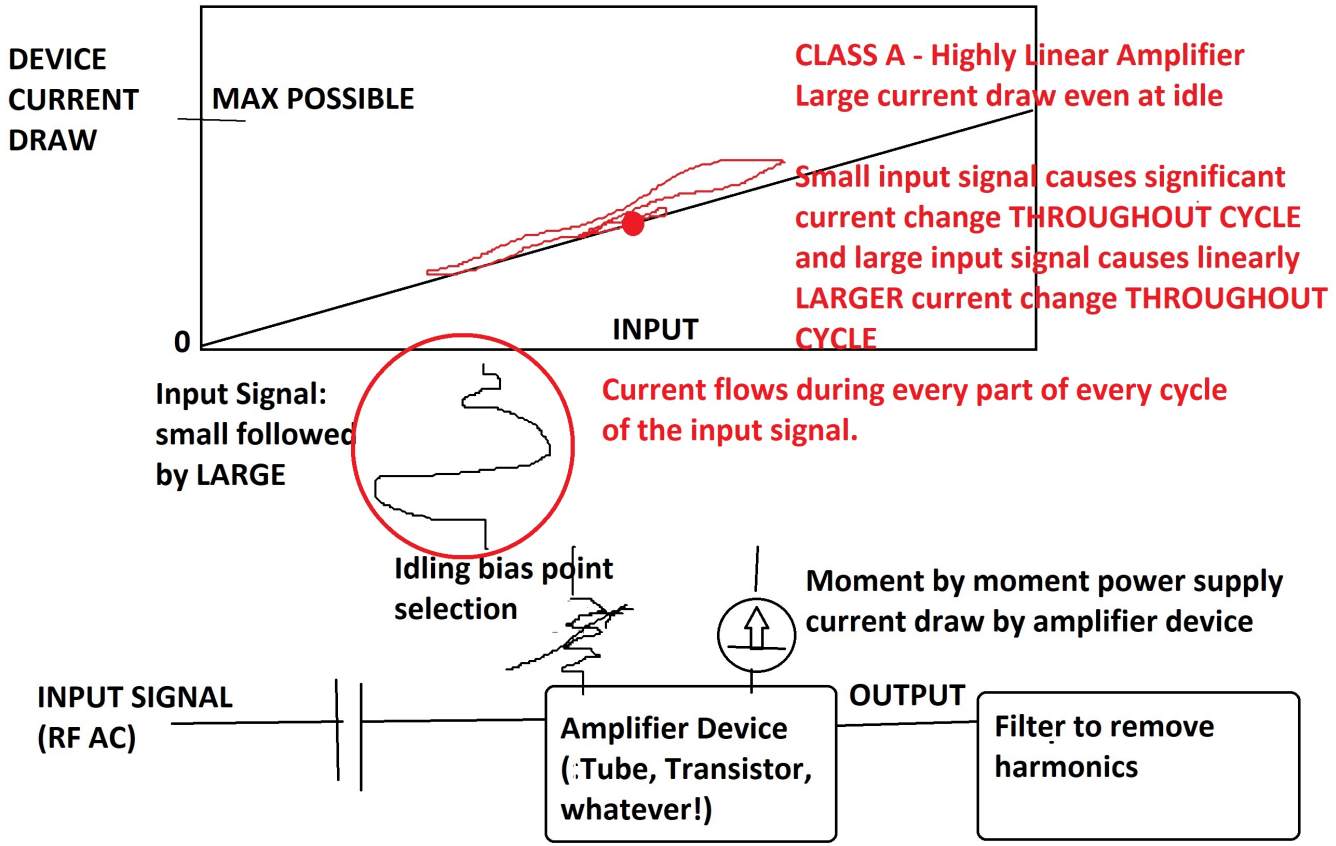
Is an amplifier linear?

- If an 10X amplifier (10dB gain) is perfectly linear, it amplifies both whispers (soft signals) and screams (loud signals) both by exactly 10X
- If an amplifier doesn’t amplify soft signals – it isn’t linear.
- FM amplifiers NEVER SEE SOFT SIGNALS. Their input signal is either THERE, or NOT there.
- FM Amplifiers do not need to be linear.

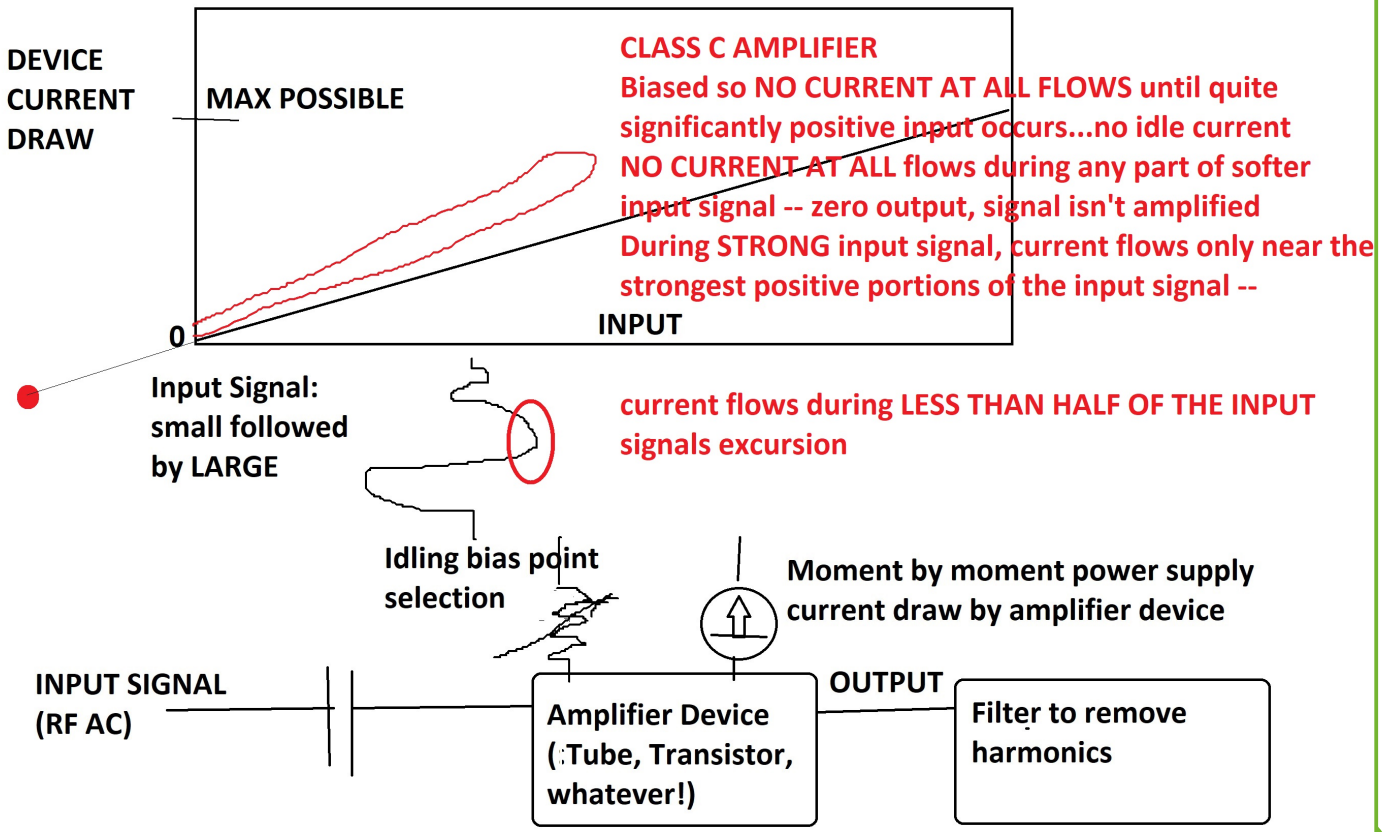
Operating Point

- The operating point of an amplifier is selected by the designer
- The operating point gives the current passed by the final device, and the voltage across it, with NO SIGNAL incoming.
- The operating point of a Class A amplifier (the most linear there is, used for low level audio amplification of stereo amplifiers) is such that a lot of current is ALWAYS being used
  - Small signals cause the current to go slightly up, and slightly down on an incoming AC signal
  - Large signals cause the current to go UP and DOWN, but never to full current and never all the way to zero current.


DEVICE CURRENT DRAW
MAX POSSIBLE
ILLUSTRATIVE PLOT that allows us to set the bias point of an amplifier where-ever we want it, and observe the outcome of a small input signal followed by a large input signal, on current flow in the amplifier device.
0
INPUT
Input Signal: small followed by LARGE
Small input signal, followed a moment later by
LARGE input signal
Idling bias point selection
Moment by moment power supply current draw by amplifier device
INPUT SIGNAL (RF AC)
Amplifier Device (:Tube, Transistor, whatever!)
OUTPUT
Filter to remove harmonics

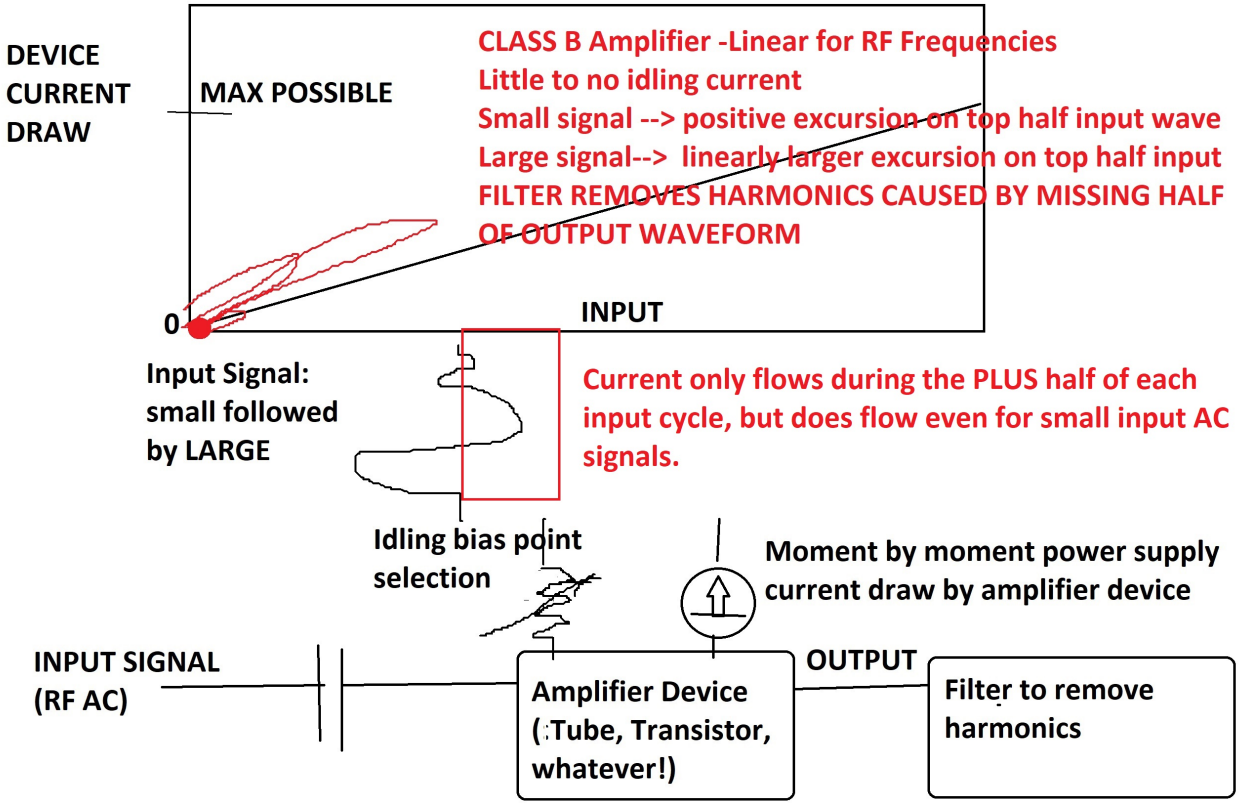

DEVICE CURRENT DRAW
MAX POSSIBLE
0
INPUT
CLASS A - Highly Linear Amplifier
Large current draw even at idle
Small input signal causes significant current change THROUGHOUT CYCLE and large input signal causes linearly LARGER current change THROUGHOUT CYCLE
Input Signal: small followed by LARGE
Current flows during every part of every cycle of the input signal.
Idling bias point selection
Moment by moment power supply current draw by amplifier device
INPUT SIGNAL (RF AC)
Amplifier Device (Tube, Transistor, whatever!)
OUTPUT
Filter to remove harmonics

- The operating point of a Class C amplifier (non linear) is such that at baseline there isn’t any current (or almost none) being conducted by the device. SO NO POWER WASTED.
- Small input signals do not even get the amplifier to conduct. They aren’t amplified; they are ignored and likely blocked
- LARGE input signals cause the amplifier to conduct heavily for only a PORTION of the input signal (the highest parts of the positive incoming wave for example) and briefly product a burst of RF current.

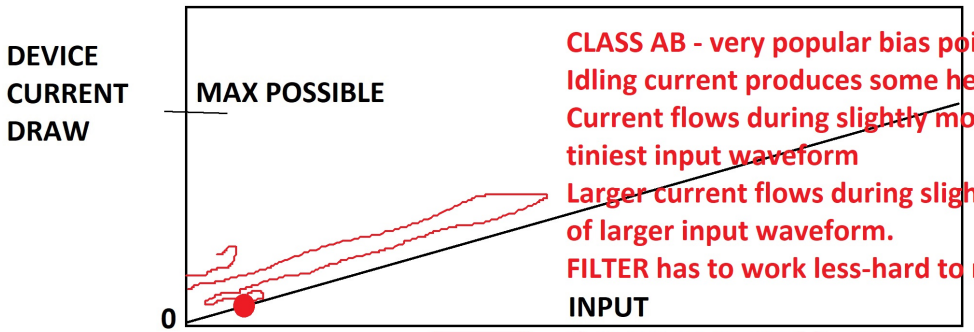

DEVICE CURRENT DRAW
MAX POSSIBLE
0
INPUT
CLASS C AMPLIFIER
Biased so NO CURRENT AT ALL FLOWS until quite significantly positive input occurs...no idle current
NO CURRENT AT ALL flows during any part of softer input signal -- zero output, signal isn't amplified
During STRONG input signal, current flows only near the strongest positive portions of the input signal --
Input Signal: small followed by LARGE
current flows during LESS THAN HALF OF THE INPUT signals excursion
Idling bias point selection
Moment by moment power supply current draw by amplifier device
INPUT SIGNAL (RF AC)
Amplifier Device (:Tube, Transistor, whatever!)
OUTPUT
Filter to remove harmonics

- These BURSTS of conduction may be only 25% of the total period of the incoming waveform (“90 degrees” out of 360).
- This causes very significant production of harmonics.
- These harmonics MUST be filtered out by a well-designed low pass filter or the amplifier will not meet FCC requirements.
- Class C amplifiers work FINE for FM and CW. Baofeng transceivers will have Class C power amplifiers….and sometimes inadequate low pass filters

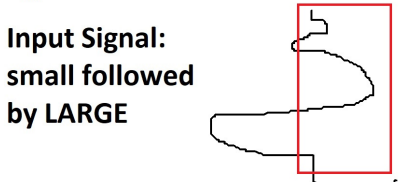
- The LEAST you can conduct and still be considered LINEAR is that you MUST conduct on HALF of a tiny input signal.
- That means you will conduct on 50% (“180 degrees”) of ANY input signal.
- That means for practical purposes, your device is biased so that it is always on the verge of beginning to conduct.
- This is called CLASS B.
- Often high quality amplifiers have two 180-degree amplifiers (“push-pull”) each doing half of the input signal, and combining in an output transformer. Very common in stereo amplifiers, but very rarely used in VACUUM TUBE ham radio at RF (easier for us to filter out harmonics than at audio

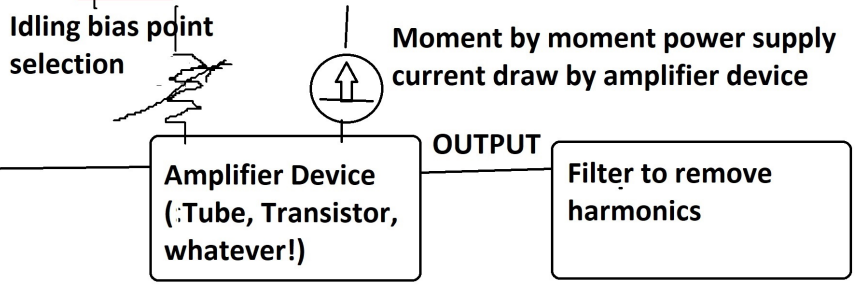

DEVICE CURRENT DRAW
MAX POSSIBLE
CLASS B Amplifier -Linear for RF Frequencies
Little to no idling current
Small signal --> positive excursion on top half input wave
Large signal--> linearly larger excursion on top half input
FILTER REMOVES HARMONICS CAUSED BY MISSING HALF OF OUTPUT WAVEFORM
0
INPUT
Input Signal: small followed by LARGE
Current only flows during the PLUS half of each input cycle, but does flow even for small input AC signals.
Idling bias point selection
Moment by moment power supply current draw by amplifier device
INPUT SIGNAL (RF AC)
Amplifier Device (:Tube, Transistor, whatever!)
OUTPUT
Filter to remove harmonics

- Class AB1 is very popular in higher powered amplifiers.
- Class AB1 amplifiers are always conducting A LITTLE BIT.
- So even a tiny input signal swings their current up a bit, down a bit. They amplify even the tiniest signals.
- But larger signals swing them to conducting a LOT on the positive input portion….and all the way to NON-CONDUCTING on the negative input portion. (That does cause harmonics)
- We say that they conduct maybe during 200 degrees of the input signal.
- These are a good compromise with efficiency of maybe 60%, linear, and appropriate filtering gets rid of the harmonics they make.



CLASS AB - very popular bias point for SSB amplifiers
Idling current produces some heat wastage.
Current flows during slightly more than half of even tiniest input waveform
Larger current flows during slightly more than half of larger input waveform.
FILTER has to work less-hard to remove the harmonics that are generated by not reproducing the entire input cycle.





Idle Operating Point applies to **both** Tube and Transistor Amplifiers

- Older Class C tube amplifiers had idling current of Zero
- Class C FM transistor amplifiers may have idling current at or near zero
- Both amplifiers don’t produce any significant heat when there is no input.
- Both amplifiers work FINE with a CW or FM input signal that is basically THERE, or NOT-THERE.
- Efficiency approx 70% – highly desirable at VHF/UHF where getting good efficiency is DIFFICULT.
- EXTENSIVE LOW PASS FILTERING REQUIRED (Baofengs are remiss)

Class AB Amplifiers

- Very popular amplifiers
- Tube type – Ameritron, Heathkit, etc etc etc 811A 572B 6146
- Transistor Type – Ameritron, MFJ, Acorn etc etc etc – very expensive MOSFETs and BJT (bipolar junction transistor)
- SETTING IDLING “Bias” CURRENT VERY IMPORTANT FOR BOTH.
- SB-200 amp runs maybe 70mA @ 2200V = 150 Watts idling
- ALL HAVE LOW PASS FILTERS TO CURB HARMONICS

Class B Amplifier

- Not really popular in ham radio most of the time –
- Tubes are LARGE and require a lot of circuitry to support, so most TUBE TYPE amplifiers used 1 or 2 Tubes in parallel, **in Class AB**, instead of 2 in push pull Class B (one handling top, the other bottom of input AC waveform
-

MOSFETs changed things

- MOSFETS are SMALLER, and have power limitations
- EASIER to have 2 or even 4 MOSFETS in a solid state amplifier
- Easy to use them in Class B push-pull. Combine with a ferrite TRANSFORMER to add their outputs.
- Ashhar Farhan: extensive push-pull output amps Class B or AB
- Ameritron ALS-606- FOUR mosfets operating in banks of push-pull

ALS-606 (EOC Amplifier)

PA Amplifier

Power amplification comes from a single 600-watt power amplifier module. The PA module (PAM-606) **uses four MFR-150 field effect transistors.** Bias each MRF-150 at an equal quiescent current within the range of 100 mA to 300 mA. It is important to bias each FET the same. IMD performance changes very little within this bias range. Transistor conduction angle is slightly over 180-degrees, **providing linear class-AB operation.** Normal dc drain operating voltage is approximately 50 volts. The linear supply is unregulated, and can run as high as 60 volts without harm, although it is much better to keep voltage below 56 volts. See the power supply manual.

Unlike the standard Motorola based modules, **the PAM-606 module uses two diametrically opposed push-pull pairs.** This shortens ground path distance while simultaneously reducing circuit board ground plane current levels. This greatly improves VHF performance. The dual diametrically opposed push-pull pairs drive balanced low impedance striplines. The balanced striplines parallel at a unique 1:9 broadband matching transformer.

FM / SSB VHF AMPLIFIER

RM ITALY VHF HT Amplifier LA-145

85W Output / 4W input $200

bias point select!!

Gotchas

- FM transmissions are always at full power = lots of battery drain
- SSB transmissions average only 35% full power (VOICE)
- FM much more popular VHF/UHF (more efficient amplifiers)
- SSB much more popular HF (less power consumption, more distance)
- SSB – DATA may resemble FM – because FSK techniques are always ON full power!! Resemble FM
- CW resembles FM and Class C amplifiers were common