Brass Tacks

An in-depth look at a radio-related topic



Amplifiers



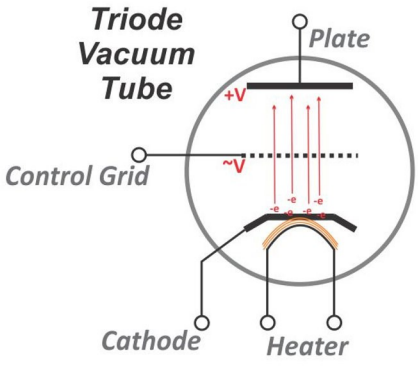
When you look at an innocently appearing antenna, it typically doesn't seem like it's doing much. Indeed, an antenna is merely a piece of conductive material reaching its fingers in the sky in an effort to snag some passing electromagnetic signals. And if the antenna is constructed appropriately, it can "catch" those signals quite well. But if you were to measure the strength of the signals picked up by the antenna, you might find that they're very weak. It's like feeling the slight breeze from a pair of fluttering butterfly wings from across the room.

To bring the received signal up to a meaningful (manageable) level requires increasing its strength without compromising its integrity. This process is known as ***amplification***, and it's achieved by a component, circuit, or device known as an ***amplifier*** (or ***amp*** for short). The title of this article might more aptly be named after the process, because the focus is more on the effect than a piece of hardware.

The vacuum tube amplifier

In 1907, Lee de Forest invented the electronic amplifier when he noticed that he could linearly modify a large current exiting a vacuum tube by a smaller current entering the tube. This feat alone transformed the world of electronics and gave birth to the broadcast radio industry. It also spelled the end to spark-gap transmitters by creating a safer, more efficient, and less-expensive means of generating a CW (continuous wave) signal.

A ***vacuum tube*** is nothing more than a small, evacuated glass bottle with some conductors inside it, connected to the outside by ***electrodes***. Let's imagine such a glass bottle with five electrodes protruding from it, like in the diagram to the right. Two of the electrodes are connected internally to two ends of a ***heater*** filament, to heat up a piece of metal we call the ***cathode***., which is connected to a third electrode. A fourth electrode is connected to another piece of metal we call the anode, or ***plate***. Edmond Becquerel discovered that heating the cathode metal with the heater like this will cause the cathode to emit (throw off) electrons in all directions.



Later, John Ambrose Fleming discovered that when he connected a voltage source across the cathode and the plate while the cathode was heated, the electrons that flew off the cathode were attracted to the plate, allowing electrons to flow from the cathode to the plate and completing a circuit. When Lee de Forest placed a small metal wire ***grid*** (screen) in the glass bottle and connected it to a fifth electrode, he discovered that he could apply a small controllable voltage to the screen, which repelled some of the electrons. This grid allowed him to *control* the flow of electrons from the cathode to the plate.

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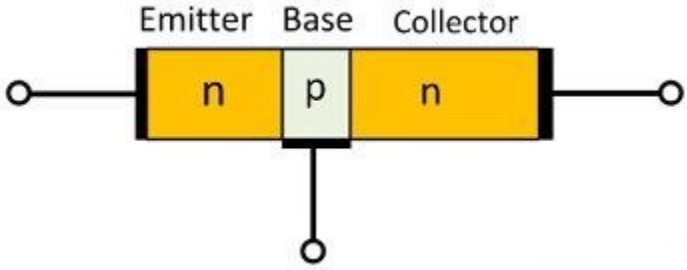


If we had such a glass bottle with five electrodes placed as described, we could introduce a variable voltage to the grid, which would result in a much larger but proportional variable current between the plate and the cathode. If we then used a microphone to create that small variable voltage on the grid, and connected the plate to a speaker, suddenly our voice into the microphone could be heard with a much greater loudness at the speaker. This increase of volume loudness is known as *amplification*, and is a basic description of how to use a vacuum tube *triode* (three electrodes, the cathode, grid, and plate) to create an amplifier.

While a number of high-powered amplifiers, such as those found in broadcast stations and military installations, are still developed and manufactured using vacuum tubes, today's amateur radio (RF) and guitar (AF) amps are built largely using solid-state devices.

The solid-state amplifier

In the mid-20th Century, researchers discovered that if they added a poisonous impurity to non-conducting silicon, the material can act as a conductor under certain circumstances. When they placed a voltage source across this material, it remained an insulator, but when they applied a small controllable voltage to a spot on the side of the material while the voltage source was applied to it, the material began conducting current. In fact, the current that flowed between the voltage source connections was proportional to the voltage applied to the side, once again introducing amplification, but not by a vacuum tube.



This three-electrode, solid-state device is known as a ***transistor***, which has replaced the vacuum tube in most amplifier applications, due to its energy efficiency, smaller size, and lower cost. The transistor is said to be ***solid-state*** because it contains only solid components, unlike a vacuum tube, which is evacuated except for the gaseous cloud of electrons that provide the conduction mechanism. And because a transistor is made from a material that conducts electric current conditionally, it's called a ***semiconductor***.

Semiconductor amplifiers can be made very small, very powerful, possess high noise immunity, high transfer speed, are inexpensive, and are easily manufactured. These and other advantages place the solid-state amplifier in nearly every electronic device on the planet. And the variety of amplifiers available to the designer and the experimenter as a result, are a huge convenience that also promotes unprecedented creativity.

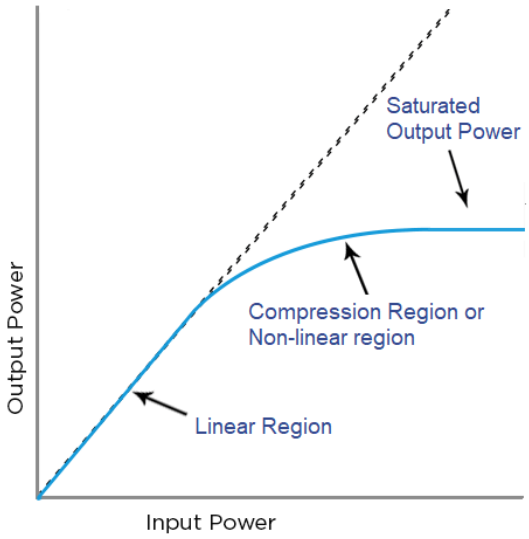
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Linearity, gain, compression, saturation

If the output power of an amplifier is a simple multiple of its input, the relationship can be graphed as a straight line. Because of this, we refer to such a device as a ***linear*** amplifier. The amount of output power compared with that of the input signal is a multiplier known as amplifier ***gain***, often abbreviated by the letter G (gain) or A (amplification), often expressed in dB or dBm (dB with respect to milliwatts).



It's not possible for an amplifier to be infinitely linear (dotted line); that is, a linear amplifier can amplify an input signal up to a specified maximum, beyond which the output signal can result in little to no amplification. The region (span of input power levels) in which the increase of input power results in a reduced (less than linear gain) increase in output is known as the ***non-linear region*** or the ***compression region***. The region in which an input increase results in no output increase is a condition known as ***saturation***.

These parameters can be important to understand when considering or designing an amplifier for a specific application. For example, if you need an amplifier circuit of 6 dB gain (in other words, A = 4) that must amplify a signal between 100 mW and 1500 mW, but a proposed circuit saturates at 5 W, then the circuit will likely introduce distortion or clipping when the input is driven too high (1.5 W × 4 = 6 W, which is greater than the maximum 5 W).

If a signal is driven in the compression region, not only is the amplification no longer linear, but it can generate non-linear products. Undesirable harmonics, intermodulation, noise, and other spurious signals can result from the non-linear relationship between the input and output of the amplifier. And because the gain relationship is no longer purely linear, the graph of this effect appears to compress the line, and we refer to it as ***gain compression***.

In an audio amplifier, gain compression can result in distortion, a hum, or even an undesirable improvement in timbre or tone quality. (How can an improvement be undesirable? I suppose like a flower can be a "weed" in your watermelon garden.) If a gain-compressed signal is sent from a transmitter through an antenna, recipients might report that you sound a little like Donald Duck, or like you have a bad cold.

In many cases, neither you nor your contact might notice anything resulting at all from gain compression, but instead, your signal might be heard on a different band altogether, like the Police band. Not good. To avoid this sad situation, 1) understand the spread of the linear region in your amplifier and 2) do your best to remain within that region by not increasing the input power level beyond the point where the signal begins to exhibit non-linearity.

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The power amplifier

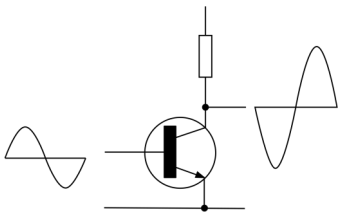
Some amplifiers are designed to output a high amount of power; that is, they possess the ability to present a greater voltage and allow for a higher current draw than is typical with smaller component amplifiers. These find applications in broadcast stations, military communication facilities, servo motors, and yes, ham radios. A ***power amplifier*** (PA) is typically the final stage in a series of signal-handling circuits, and so is often simply referred to as the *final power amplifier*, or ***final*** for short. So, when you hear that somebody has *blown his finals*, you now know that a final power amplifier, especially its power transistor, in his rig has met its demise.

Because of the amount of energy that must be conveyed through a power amplifier, particular attention is paid to its ***efficiency***, since power losses are exaggerated at higher power levels, as evidenced by the heat felt near them during operation. But not all power amplifiers are created equally, and some are designed to fill particular needs, in spite of their inefficiencies or other seeming drawbacks.

In general, power amplifiers can be categorized by the component they're intended to drive (feed power into) and the frequency range of their operations. The audio power amplifier is designed to drive a loudspeaker, the RF (radio frequency) power amplifier is designed to drive an antenna, and a PWM (pulse-width modulation) power amplifier is designed to drive servo motors.

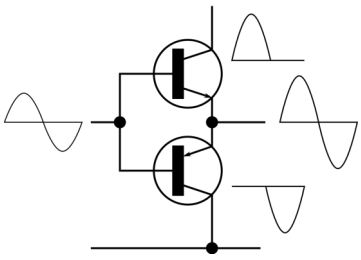
Power amplifiers of all three categories are divided into letter designations that define their modes or ***classifications***, each with its own set of advantages, disadvantages, and purposes. Some of them are characterized by the percentage of each cycle that's used for the amplification function, often noted by an angle (portion of the 360˚ cycle), but let's simply list them by percentage of the cycle. Here's a summary of the most common power amplifier classes:

Class A



- Characteristic: linear, uses 100% of the cycle
- Efficiency: 25%
- Advantages: simpler, less expensive, better high frequency performance, highest audio fidelity
- Disadvantages: lots of wasted power
- Applications: audio amplifiers, op amps

Class B



- Characteristic: linear, uses 50% of the cycle, push-pull architecture (to remove even-order harmonics)
- Efficiency: 60% to 78.5%
- Advantages: high efficiency
- Disadvantages: crossover distortion, significant harmonic distortion
- Applications: small, inexpensive, or toy electronics

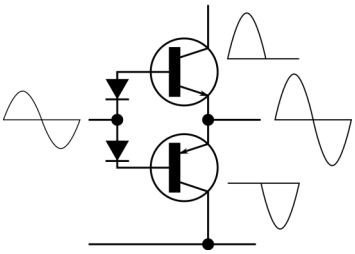
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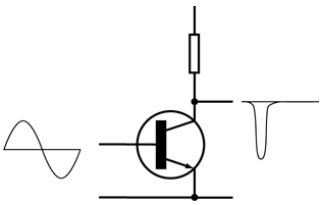
Class AB

- Characteristic: linear, uses more than 50% of the cycle, push-pull architecture (to remove even-order harmonics)
- Efficiency: greater than 60%
- Advantages: crossover distortion nearly eliminated, good compromise between Class A and Class B amplifiers
- Disadvantages: sacrifices some efficiency over linearity
- Applications: audio amplifiers, amateur radio transceivers and stand-alone amplifiers



Class C

- Characteristic: nonlinear, uses less than 33% of the cycle, distortion can result when used for a single sideband signal
- Efficiency: 60% to 70%
- Disadvantage: poorest linearity of all amplifier classes, heavy distortion, not fit for audio amplification
- Applications: HF sine wave oscillators



Class D

- Characteristic: nonlinear, uses PWM switching technology to achieve the highest efficiency, 100 dB dynamic range, smallest footprint
- Efficiency: greater than 80%, sometimes reaching nearly 100%
- Advantages: efficient switching amplifier, more efficient than linear amplifiers because they are at saturation or cutoff for most of the cycle
- Applications: control motors, servos

Other classes

Other power amplifier classes, such as E, F, G, H, I, S, and T exist, but are merely variations of ones already mentioned, and differ largely by signal type and efficiency.

The RF power amplifier

Because the presumed readership of this discussion likely has a deep interest in radio, here are a few last thoughts about the RF power amplifier. First, an amplifier is called *push-pull* because it contains two transistors, one of which is active during the first cycle half, to pull the current from the output (load), and the other is active during the second half, to push the current to the output. Advantages of a push-pull amplifier over other types include high efficiency, higher power output, cancellation of even-order harmonics, and generation of less distortion for the same power.

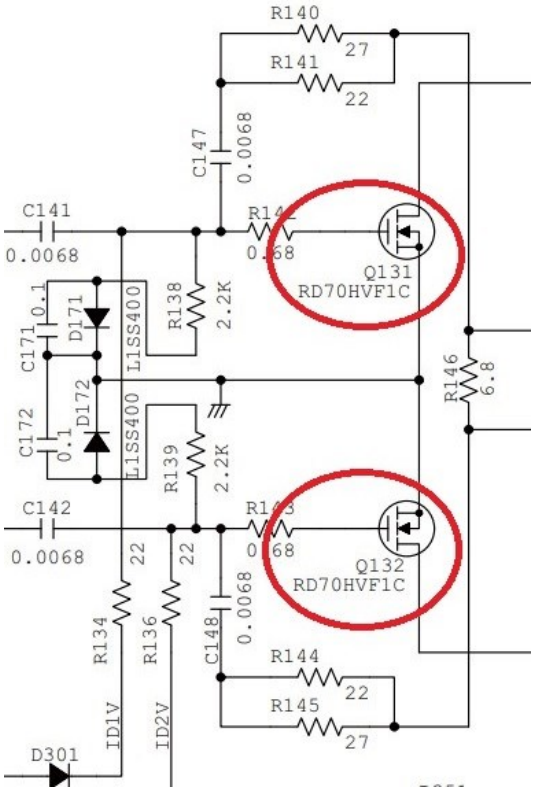
Second, many of today's radio finals are outfitted with MOSFETs (metal-oxide-semiconductor field-effect transistors). The Icom IC-7300, for example, uses a pair of Mitsubishi RD70HVF1C

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N-channel MOSFETs in a type of Class AB push-pull configuration, as shown in this schematic snippet:



PA section of the Icom IC-7300



Power transistor of the Icom IC-7300

The differential amplifier

The op amp (operational amplifier) is an off-the-shelf, pre-designed circuit amplifier whose functions and properties are configurable by adding components between its inputs and output. An op amp can be wired to produce a variety of waveforms, including triangular, sawtooth, square, and sinusoid. It can also be used to produce a variety of functions, such as filtering, oscillation, and yes, amplification.

An op amp is a special case of a ***differential amplifier***, in that its input is a pair of signals, whose output is determined by the difference between the input voltages, multiplied by the amplifier gain. In many differential signal applications, the input signals are reverse polarity (inverted) from each other, resulting in an amplified difference of twice the input signal amplitude. This feature gives the signal added resistance to noise, including that from common-mode, allowing for improvements in signal and impedance integrity over larger distances.

A variety of differential amplifiers are available for other two-wire applications, such as twisted

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pair phone, USB, ethernet, standard serial (RS-422), SATA, PCI Express, InfiniBand, DisplayPort, microstrip, DDR SDRAM, and HDMI. As you can see, most high-speed serial digital transmission lines terminate in a differential amplifier designed to boost their signals.

The stand-alone amplifier

A radio amateur tends to envision an *amplifier* as a unit that's attached to an amateur radio transceiver to boost its power. Although we've focused on the amplification process and the circuitry that provides the function, this article would be incomplete without including a section dedicated to ***stand-alone*** amplifiers. Our purpose isn't to help you operate, care for, or troubleshoot your amplifier, but simply to understand a little about it.

For the purposes of amateur radio, a stand-alone amplifier tends to be a linear type that covers 160 meters through 10 meters, or even 6 meters. The unit might require 240 VAC to power it, if it's designed to deliver more than, say, 1000 watts. An amplifier might require an external power supply, or include a built-in supply, which can make the unit quite heavy. Most can work with any modern amateur radio HF transceiver.

Stand-alone amateur radio linear amplifiers are available to purchase in a variety of choices, such as tube vs. solid-state, maximum output power, and whether they have an internal power supply. Their features might include automatic operation, a front panel control (even color) display, and a built-in autotuner. Distributors can advertise a variety of parameters as selling points, such as dual-power (both 120 VAC *and* 240 VAC), harmonic emissions suppression, external (CAT or serial port) control, low intermodulation distortion, and internal (thermal, fold-back) protection circuitry.

Here are a few samples of stand-alone amateur radio HF amplifiers, to give you some idea of available products and their features, along with their prices, as of the date of this article:

ACOM 1200S

Price: $4275

- Output: 1200 watts
- Type: solid-state
- Bands: 160 meters to 6 meters
- Tuner: built-in autotuner
- Weight: 32 lbs
- Powered by: 240 VAC



Ameritron AL-80B

Price: $2300

- Output: 1000 watts
- Type: tube
- Bands: 160 meters to 15 meters
- Tuner: none
- Weight: 48 lbs
- Powered by: 120 VAC



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FlexRadio Power Genius XL Price: $6000

- Output: 1500 watts
- Type: solid-state
- Bands: 160 meters to 6 meters
- Tuner: built-in autotuner
- Weight: 38 lbs
- Powered by: 240 VAC



Palstar LA-1K Price: $3700

- Output: 1000 watts
- Type: solid-state
- Bands: 160 meters to 6 meters
- Tuner: none
- Weight: 27 lbs
- Powered by: 240 VAC



SPE Expert 1.5K-FA Price: $5600

- Output: 1500 watts
- Type: solid-state
- Bands: 160 meters to 6 meters
- Tuner: built-in autotuner
- Weight: 21 lbs
- Powered by: 240 VAC



ACOM 500S Price: $3400

- Output: 500 watts
- Type: solid-state
- Bands: 160 meters to 6 meters
- Weight: 18 lbs
- Powered by: 240 VAC



RM Italy MLA100 Price: $760

- Output: 100 watts
- Type: solid-state
- Bands: 160 meters to 6 meters
- Weight: 3 lbs
- Powered by: 13.8 VDC



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When considering whether to purchase a stand-alone amplifier unit, you should ask yourself whether you really *need* one, or whether a *better antenna* can serve you more. Many who have purchased a stand-alone amplifier claim 1) they believe they could be heard much better, as evidenced by numbers of good reports during contesting, 2) their locations (due to obstructions) demands more power than barefoot stations can provide, and 3) in an emergency, their signals could let them be of service to a lot more locations around the globe.

Finally

Due to the myriad applications, the field of electronic amplifiers is huge, so I had to limit our discussion to their very basic definitions, functions, and purposes. Important topics not covered include feedback, dynamic range, noise, stability, self-oscillation, slew rate, delay, thermal runaway, and third-order intercept.

For stand-alone amplifier units, I didn't cover care or usage, which are large topics in themselves. The interface between an appliance amplifier and a transceiver can be difficult to configure, but later models have become much more intuitive and user-friendly. As solid-state electronics become more robust and available, more stand-alone units are moving away from tube designs. The need for tube warmups, plate current monitoring, and load adjustments are becoming a thing of the past.



Summary

Invented in 1907, the electronic amplifier is a circuit or device that can increase the power level of a signal. The vacuum tube was the first device used for electronic amplification circuitry, and it works by controlling a relatively high output current proportional to a smaller input current. Most of today's amateur and other applications employ solid-state amplifiers, which use transistors to perform the amplification function. Power amplifiers are specially classed because of their function as device drivers, among which the RF PA is particularly applicable to many amateur radio finals. A stand-alone amplifier is a device that can be acquired separately to provide power amplification for existing transceivers.

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