Transistor PA Bias Circuits

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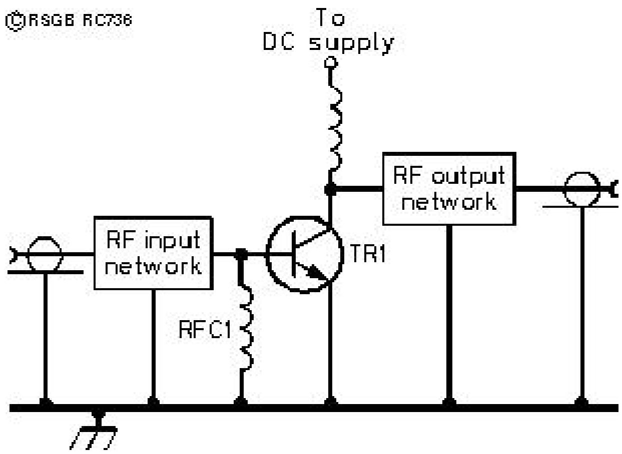
Why Use Bias?

Why do we need a base bias supply at all? The answer is that the base-emitter junction of a bipolar transistor has a turn-on voltage of about 0.65V, below which very little current flows. This is not a problem for FM operation, where the drive level is constant, and always enough to 'turn on' the PA transistor. FM-only PAs usually have an RF choke to provide a DC return path directly from the base to ground (**Fig 1** below).



This circuit has no bias - only RFC1 from base to ground. An amplifier using this circuit is not linear - never use it for SSB!

This is sometimes called 'Class C' operation. But for SSB modulation, the delayed turn-on at low drive levels is disastrous: it means that all the low-level parts of the modulation are severely distorted and the amplifier only delivers RF power in bursts on speech peaks. This is why you must **never** use an FM-only power amplifier on SSB - the splatter is horrendous!

For linear operation, it is **essential** to use a fixed DC bias to make sure that the transistor is already 'turned on' before any RF drive arrives (so-called 'Class AB'). Typically, if the transistor is drawing about 100mA in 'standing current' with no RF drive, distortion will be quite low, provided that the bias supply can also cope with the higher demands of peak modulation. (There's nothing magical about 100mA, by the way; it's just a good figure to aim for in many cases.)

The standing collector current in the RF power transistor depends on the current flowing from the bias supply into the base, and on the beta of the transistor (ratio of collector current to base current). For a typical RF power transistor with a beta of 50, a standing collector current of 100mA needs a base current of 2mA. However, beta is not a very well-controlled value, so the next transistor might need only 2mA; or maybe 7mA. That's one reason why the bias supply **must** be adjustable. Another reason is that a very small change in base voltage can make a very big difference to the collector current.

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Common Design Mistakes

When you drive the transistor with RF, the collector current rises to several amperes. At maximum drive the base current can be as high as hundreds of milliamps, which the bias supply must provide.

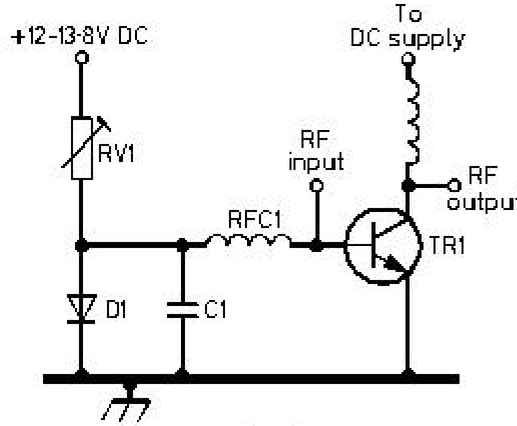
Most bias circuits fail to do this!

It is very important that the bias supply maintains a fairly constant output voltage, even at maximum current demand; if it fails to do that, the RF drive will bias the transistor back towards Class C, causing heavy splatter on speech peaks.

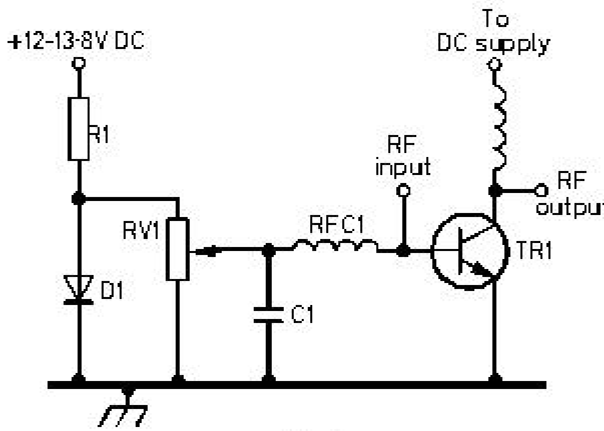
Another difficulty is that the base-emitter voltage of a transistor decreases as the transistor heats up. If the bias supply voltage remains constant, the transistor will draw more base current - and hence more collector current - when it's hot than when it's cool. More collector current means more power dissipation, which means more heat, which means more base current, which means more collector current... which can very quickly mean "goodbye transistor" due to thermal runaway. The solutions to this problem are a large, effective heatsink and a base bias supply whose output voltage **decreases** with temperature so that the PA collector current remains fairly constant.

Bad circuits

Here are two variants of a very common circuit - which generally works **very badly**.



(a)



(b)

The voltage drop across the forward-biased diode D1 is approximately the same as the voltage drop across the transistor's base-emitter junction, and by adjusting RV1 to send the correct current through D1, the collector current in TR1 can be set to the desired value.

If D1 is in thermal contact with TR1, the voltage across D1 will drop as TR1 and D1 heat up together, maintaining a constant and temperature-stabilized current through TR1.

Well, that's what's *supposed* to happen...

There are many problems with this simple circuit. The main one is that in order to maintain a constant voltage across D1, the permanent standing current through D1 must be several times higher than the maximum base current drawn by TR1 at the peak of RF drive. This requires an enormous standing current through RV1 and D1 - one ampere or even more. Most designers fail to provide this. Some commercial circuits even use a low-current signal diode such as a lN914 for D1! Bias regulation totally fails when peaks of RF drive create a heavy demand for base current, so this circuit is a real splatter-generator.

The next section describes a much better circuit.

Two-Transistor Bias Circuit

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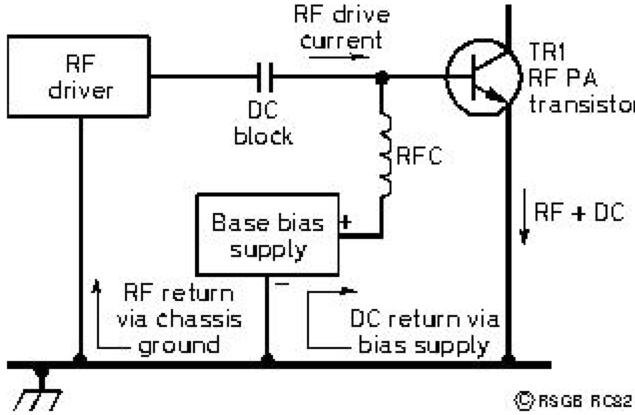


In this circuit, RF drive turns on TR1 and makes it draw both base and collector current. The RF return path is via TR1 emitter and chassis ground - but the DC return path is through the bias bias supply. This means that the bias supply must be capable of delivering the full DC base current at maximum RF drive.

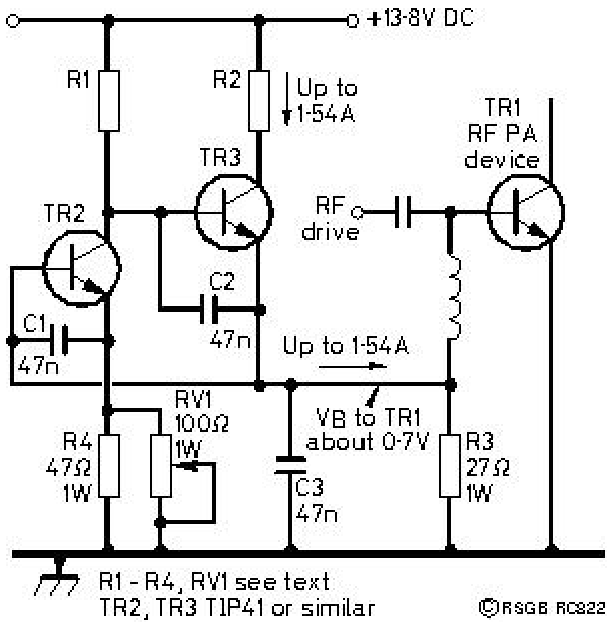
To provide an adjustable, precisely-regulated bias voltage to the base of the PA transistor. This voltage must remain constant in spite of the very large variations in base current caused by the RF drive.

Note the difference between the RF and DC current paths in the circuit above: it is the RF drive waveform that turns-on the transistor and makes it draw both base current and collector current, but the DC return path for the base current is through the base bias supply. This means that the bias supply must be capable of delivering **the full-drive base current**, and not just the small current required to bias the transistor to its idling current of about l00mA.

Another requirement for the base bias supply is a small negative temperature coefficient to help avoid thermal runaway caused by the decrease in base-emitter voltage drop of TR1 with increasing temperature.

The Bias Circuit

Here is the classic two-transistor bias circuit (RF components not shown):



How It Works

To understand how this or any other voltage regulator circuit works, there’s a standard technique to apply: imagine that the output voltage falls for some reason (e.g., because more current is drawn by the load) and work out what happens to compensate for it.

If the output voltage Vb falls for some reason, then TR2 will draw less current. That will reduce the voltage drop across R1, making the voltage rise at the connection between the collector of TR2 and the base of TR3. TR3 is an emitter-follower which delivers the output voltage with a high current capability. As its base voltage rises, so too will its emitter voltage, compensating for the fall in output voltage that we imagined at the start of this paragraph. If the output voltage were to try and rise for some reason, it’s equally easy to work out that TR3 would deliver less current and thus make the voltage tend to fall back to its original value.

Similar reasoning explains the negative temperature coefficient of this circuit. TR2 is the temperature-sensing transistor bolted to the heatsink close to the RF power transistor TR1. An increase in temperature will cause a decrease in the base-emitter voltage drop of TR2, and a corresponding increase in the collector current drawn. This will increase the voltage drop across R1 and lower the base voltage of TR3, whose emitter-follower action will lower the output voltage. Thus the response to the temperature increase is a reduction in bias voltage supplied to TR1.

Design Procedure

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As you read this, refer to the circuit above.

1. Estimate currents and voltages

How much collector current will TR1 draw at full RF output? Say you're designing for a 100W PA powered from 13.8V, which will be reduced to about 13.0V by the time it reaches the TR1 collector. Assuming an efficiency of 50% - it's best to err on the low side when making this estimate - the peak DC input will be (100W divided by 50%) = 200W, which at 13.0V represents 15.4A. Assuming that the current gain of TR1 falls as low as 10 at maximum collector current, that's 1.54A of base current to be supplied to TR1 through TR3.

Now let's look at the voltages. The base voltage of TR1 must be about the standard silicon Vbe value of +0.7V. This is also the emitter voltage of TR3, and the base of TR3 must therefore be another Vbe higher than its emitter, i.e. about +1.4V. R2 limits the amount of base current this circuit can deliver when TR3 is turned fully on. Allowing about 1.0V from emitter to collector of TR3 in this condition, the collector voltage would be 1.7V and the voltage drop across R2 would be (13.8 - 1.7) = 12.1V.

2. Select R2

The estimated peak base current of 1.54A must flow through R2, so its resistance must be 7.86 ohms and its wattage 18.63W. For practical purposes, choose a lower-resistance component with a higher wattage, i.e. a 6.8-ohm 20W resistor. At this point it's useful to note that unlike any of the 'passive' shunt regulators, which draw large currents all the time, this circuit draws very little standby current from the DC supply: R2 and TR3 only handle significant current at high levels of RF drive to TR1.

3. Semiconductors

TR3 gets its base current through R1, with relatively little going through TR2. At this point we have to decide what device to use for TR3, and TR2 can be the same. A good selection would be something like the TIP41A (cost about £0.50/$1). This has a flat TO-220 package suitable for tucking under the PC board as the temperature sensor TR2 (see next section) and also a 6A/65W rating which with heat-sinking will be ample to handle the power in the TR3 position. The TIP41A has a typical current gain of 50, so when the collector current is 1.54A the base current must be (1.54A divided by 50)A = 30mA. This current flows through R1 across a potential difference of (13.8 - 1.4)V, so the value of R1 required is 413 ohms - we'll call that 390 ohms as the next lower standard value. The power dissipated in R1 is less than 0.5W -work it out.

4. Other components

R3 is chosen so that TR3 is always passing a minimum of, say, 25mA to keep the system stable at low currents. That's (0.7V divided by 25mA) which is 27 ohms to the nearest standard value. You might imagine that this could be a low-wattage component, but if the bias supply fails (e.g. R2 goes open-circuit) the amplifier will revert to Class C and all the RF-driven base current to TR1 will go through R3, and if R3 then burns out you'll lose the expensive RF power transistor. For the sake of a few extra coppers, make R3 a 1W resistor.

The final two resistors in this circuit are RV1 which will set the required bias current through TR1, and R4 which is a safety resistor in case RV1 fails open-circuit. Initially, make RV1 a 100-ohm 1W trimpot, and R4 a 47-ohm 1W fixed resistor.

Garnish with 47nF capacitors to prevent the circuit being upset by stray RF, and it's ready to test.

Construction and Testing

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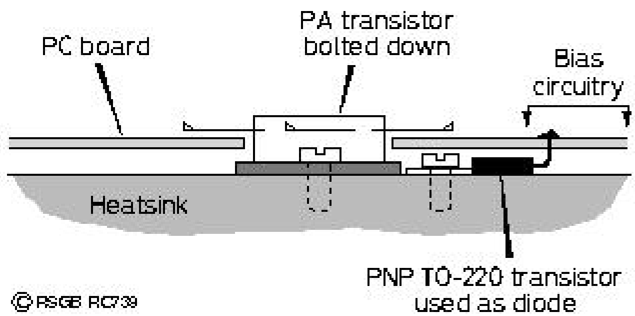
Construction



TR2 acts as a temperature sensor, so the best place to track temperature variations is to bolt TR2 to the heatsink, very close to the flange of the PA transistor TR1.

TR2 is not grounded, so don't forget to use insulating hardware!

Testing

DO NOT test the bias circuit using TR1 as a guinea-pig! Big RF power transistors are too expensive to risk mistakes!

Initially, just check it without any load except R3, and confirm that RV1 will adjust the output voltage through the necessary 0.6-0.75V region. Hook up an NPN audio power transistor in place of TR1 and confirm that you can set the collector current to 100mA. Play a hot-air blower on the back of the heatsink where it will heat up TR2 by conduction, but won't affect your temporary test transistor, and confirm that the standing current in TR1 falls as TR2 heats up. Now you can feel reasonably confident to connect the real TR1.

Further checks

When the amplifier is working correctly, you can adjust a few component values to provide even greater long-term reliability.

R2 needs to be low enough to supply the maximum possible base current at full RF output, with something in reserve, but a much lower value would unnecessarily endanger the PA device under fault conditions. Check the voltage drops across R2 and TR3 under full-drive conditions, and review the value of R2.

RV1: If the slider of RV1 loses contact, the bias output could jump to a dangerously high value. You can do two things to reduce this risk. First, spend a little money on a new, good-quality cermet trimpot. For even greater reliability, after initial testing you could replace the 47-ohm resistor R4 with a lower preferred value that allows RV1 to be set close to its maximum resistance (while still leaving enough room for adjustment).

I hope this has given you the information and the confidence you need to design and use this highly effective active bias circuit. Calculating the component values has required nothing more than Ohm's law. You only have to remember what you already know - and then use it!

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