Herbert S. Brier W9EGQ
385 Johnson Street
Gary IN 46402

PART I

TRANSISTOR RF POWER AMPLIFIERS

The following discussion of transistor rf power amplifiers assumes the reader knows his *alphas* and *betas* of transistor theory. He may also have had some experience with transistors in audio and small signal applications. The experience will have conditioned him to the importance of protecting transistors from excessive voltage and heat. But transistors perform so much differently as rf power amplifiers than they do in other applications that the previous experience is not essential to understand the discussion.

Figure 1 is the diagram of a typical transistor rf power amplifier. Transistors have largely replaced vacuum tubes in commercial and amateur VHF mobile transmitters at power levels up to 100 watts or so. Their compactness and high overall efficiency more than compensates for their high first cost. But, except in specialized applications, rf transistors quickly price themselves out of the market at power levels above a few watts in equipment operated from the commercial power lines.

As standard automobile and aircraft batteries deliver nominal voltages of 14 and 28 volts, it is hardly coincidental that most rf power transistors are designed to operate at these voltages. Incidentally, the 28 volt

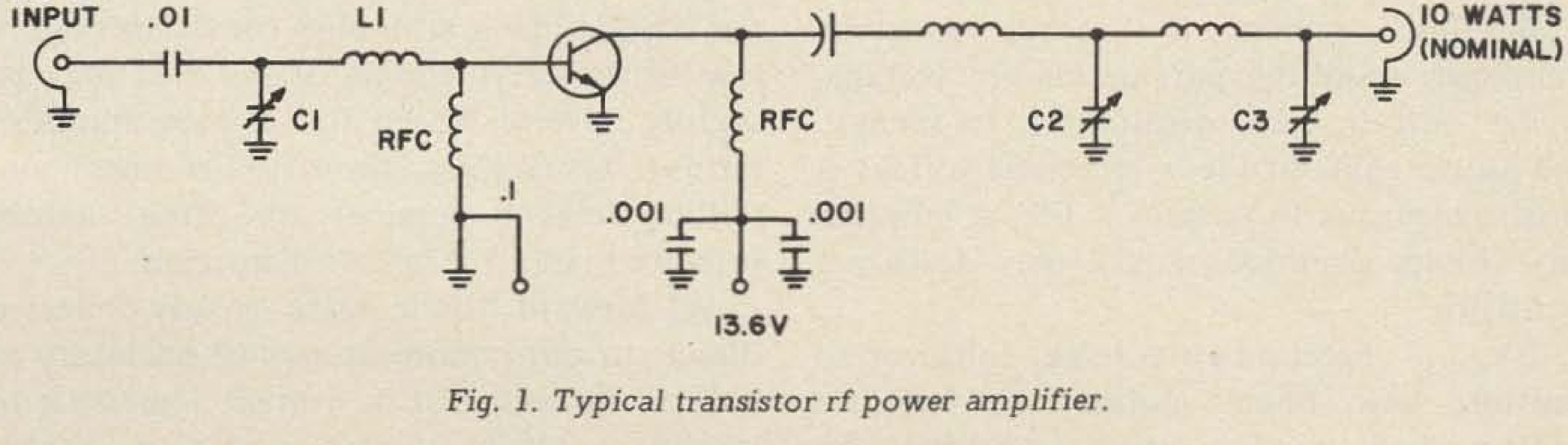

Fig. 1. Typical transistor rf power amplifier.

transistors are appreciably more efficent and cost less, watt per watt, than the 14 volt units.

Virtually all modern rf power transistors are silicon NPN's and are usually operated in the common emitter configuration. Early rf power transistors were easily destroyed by momentary overloads, transients, and stresses developed in tuneup operations. Newer units will not take unlimited abuse, but they are more rugged than the older ones; some of them will even survive being operated as rated voltages and rf drive into an open load circuit for at least a short time.

Operating Parameters

In quick review, the more important transistor operating parameters are voltage, power output, heat dissipation, frequency, and power gain. Of these, excessive voltage is most dangerous to transistor life. A momentary voltage overload of 25% may destroy a transistor.

BV_{ceo} – breakdown voltage, collector to emitter, base open – defines an absolute emitter peak voltage rating established by the transistor manufacturer using pulse techniques. For the user, however, VCC_{max} is usually a more useful figure. VCC_{max} is the maximum safe dc voltage that can be applied between the collector and the emitter of a transistor under any condition of operation.

Typical rated dc VCC_{max} values are 80% of BV_{ceo} for continuous wave (CW) and frequency modulated (FM) services and half that value for high-level amplitude-modulated (AM) service.

Also critical is the transistor base-to-emitter voltage. It has a breakdown rating of three to five volts for virtually all rf power transistors. Fortunately, base voltages are normally quite low in properly operated amplifiers. In class-C amplifiers, for example, the base is often grounded for dc through a low-resistance rf choke, or the base may be slightly reverse biased for highest amplifier output. Conversely, transistor rf linear amplifiers (class-B service) are often slightly forward biased for lowest distortion.

As forward bias increases steady collector direct current rapidly, it may be necessary to reduce the collector dc voltage somewhat to prevent excessive transistor heating, current "run-away," and "second breakdown" when the transistor base is forward biased.

Power input and heat: Each transistor has a maximum dissipation rating; but, in most units, the maximum rating applies only if heat sinks or other precautions keep the transistor case temperature to a maximum of 25 degrees, *centigrade*. Higher case temperatures require reducing the power input, improved case cooling, or greater transistor output efficiency.

In itself, the maximum direct current rating of a transistor is seldom too important, as other maximums are usually reached before maximum current flows. As a matter of interest, however, peak rf collector currents in power amplifiers are normally three to four times the indicated dc value.

Current runaway: All transistors tend to draw increased current as they become hotter. And as the current increases, the transistor gets hotter, and so on. Normally, current and temperature values rapidly stabilize. But if the transistor overheats, current increases so rapidly that the transistor may be destroyed.

Something like current runaway but more rapid is "second breakdown." It results from the emitter current being concentrated in a small area of the emitter to produce a pin-hole short in the emitter junction. Second breakdown problems increase with frequency and seem particularly troublesome in single sideband amplifiers.

One way to control second breakdown in rf power transistors is "balanced-emitter" construction. It consists of dividing the transistor emitter into up to 100 or more segments and connecting the segments together via internal, low-ohmage resistors. As the current in one segment begins to increase beyond the current in the other segments, the corresponding increase in voltage drop across its associated resistance limits the current through that segment.

Besides helping to control second breakdown, balanced emitter construction introduces a small amount of negative feedback into the transistor amplifier. This feedback improves linearity and stability. Power gain is also decreased slightly, but this is of no practical importance in most rf power amplifiers.

Gain, frequency, and stability: The current gain of a transistor is usually measured at a frequency of 1 kHz. As illustrated in Fig. 2, however, the gain varies with frequency. The shape of the gain-frequency curve is similar for all transistors, although the frequencies involved may be different.

Following the curve, the 1 kHz current gain remains essentially constant as the frequency is increased until a knee in the curve is reached. The point in the knee where the transistor current gain has dropped to 70.6% of its 1 kHz value is called the transistor "cut-off frequency." In terms of power, the point represents a 3 dB loss in gain. Beyond the knee of the curve, the transistor current gain decreases at the rate of 50% per octave.

In applications (such as high-fidelity amplifiers) where uniform amplification of frequencies over many octaves is required, a cut-off frequency at least as high as the top frequency to be amplified is required. While many power transistors have low cut-off frequencies, it is not difficult to find audio power transistors with cut-off frequencies of around 20 kHz.

It is difficult, however, to construct transistors that have both high-power capabilities and high cut-off frequencies. Consequently, power transistors with cut-off frequencies are very rare; nevertheless, transistor rf power amplifiers for frequencies up to and above 500 MHz are common. Obviously,

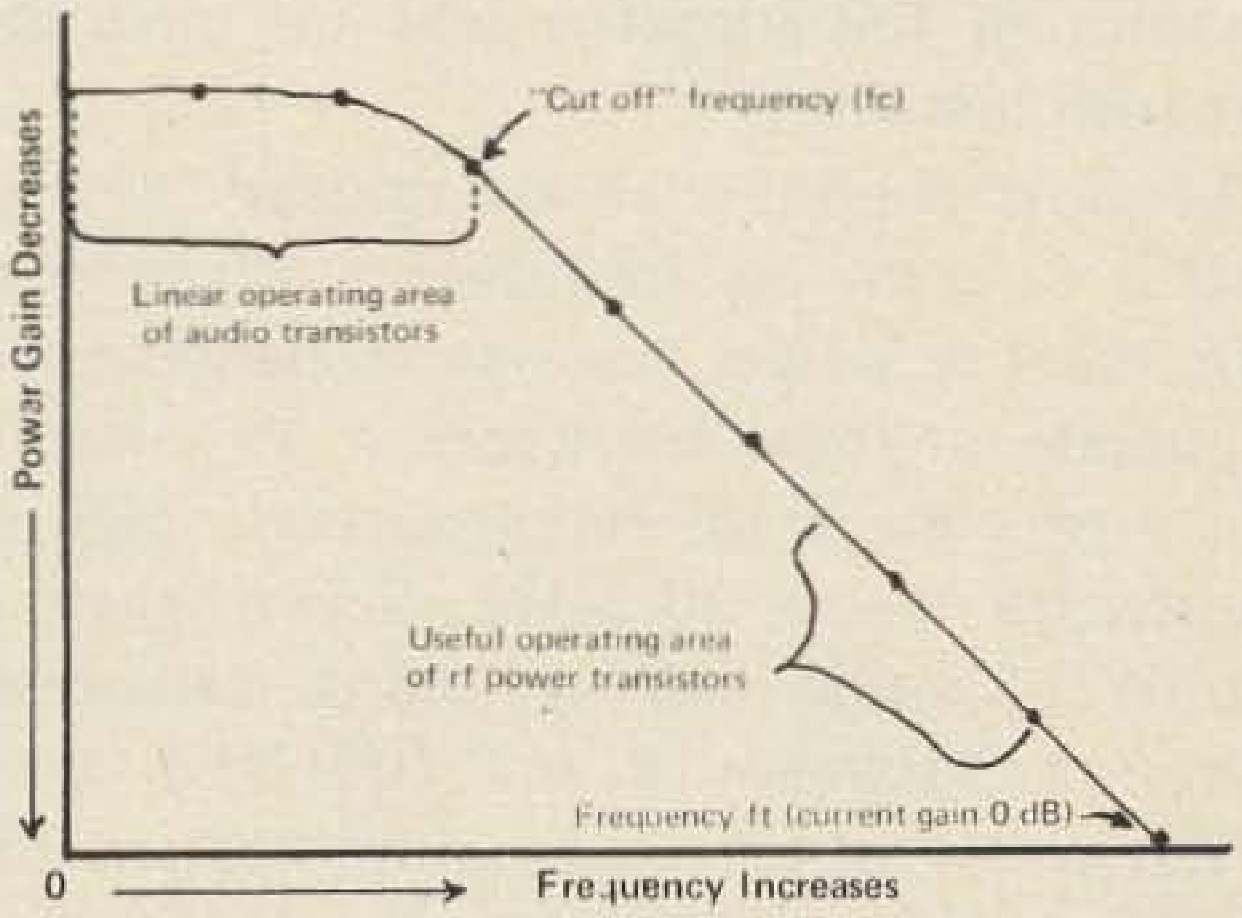

Fig. 2. Typical gain-frequency curve of all transistors. Their power gain is essentially constant from dc to the transistor cut-off frequency (fc), where it has dropped 3 dB. From fc to frequency ft, the power gain decreases at the rate of 6 dB per octave – equivalent to a 3 dB per octave decrease of current gain.

transistors are useful far above their cut-off frequencies. The story is this:

Above its cut-off frequency, the current gain of a transistor continues to decrease at the rate of 3 dB per octave (equivalent to a 6 dB decrease in power gain) until the current gain has decreased to unity or 0 dB. The frequency at which the current gain drops to 0 dB is called the "current-gain, bandwidth product," for the reasons illustrated, and is identified by the symbol *Ft.*[1]

Although the transistor gain varies inversely with frequency above its cut-off frequency, a conventional signal is so narrow, compared to an octave, on frequencies above a MHz or so that all components of the signal are amplified equally. On the other hand, the fact that transistor gain does decrease above its cut-off frequency is one reason that rf power amplifiers are practical.

You see, the dynamic characteristics of large-signal transistors change so radically during each operating cycle that neutralization to control self-oscillations in transistor rf power amplifiers is ineffective. But experience has shown that, if power gain is held to a maximum of approximately 15 dB per stage, a well-designed transistor rf power amplifier is stable without neutralization.

Power gain is controlled by selecting a transistor that is operating approximately two octaves below its *Ft* frequency. Commercial practice is to aim for a gain of around 10 dB per stage for a typical transistor; so that inserting a particularly "hot" transistor in the amplifier will not push the stage into instability.

As most commercial and military mobile services operate on frequencies above 100 MHz, most rf power transistors are designed to operate at these frequencies. As a result, their power gains are embarrassingly high at frequencies below 30 MHz. Nevertheless, a number of audio and switching transistors with *Ft's* between 10 and 100 MHz work satisfactorily as rf power amplifiers in the lower-frequency amateur bands.

Why the frequency *Ft* is called the "current gain bandwidth product:" Assume that a transistor has a current gain of 1 dB at 400 MHz. One times 400 MHz equals a product of 400 MHz. At 200 MHz (one octave lower in frequency) the transistor current gain is 2. Two times 200 MHz equals 400 MHz. at 100 MHz, the product is 4 X 100 MHz = 400 MHz, etc. As power varies as to the square of the current, the power gain of this hypothetical transistor is 4 (6 dB) at 200 MHz and 16 (12 dB) at 100 MHz.

Coupling circuits: A transistor or tube is useless as an rf amplifier without means of coupling power into and out of it. To do the job efficiently, the coupling devices must match the impedances of the transistor or the tube to its source and load impedances. In the process, the coupling circuits provide selectivity to prevent distortion products generated in the amplifier from reaching its load – especially important when the load is an antenna.

An output circuit Q of 10 to 12 is usually sufficient in vacuum tube rf amplifiers. But rf power transistors normally generate more distortion products than tubes do; therefore higher Q, resulting in greater selectivity, is desirable in transistor coupling circuits.

Simple parallel-resonant or *pi* net coupling circuits normally work well with the high impedances of vacuum tubes. But transistor impedances are so low that other types of coupling circuits are desired in rf power amplifiers. A simple *L* network, for example, can be designed to match virtually any resistance or impedance to virtually any other impedance or resistance. Unfortunately, when the ratio between the two impedances or resistances is low, the resultant Q of the *L* network is low.

Fortunately, two or more networks may be combined to obtain the desired Q and impedance match. In Fig. 1, for example, the input circuit is a simple *L* network, and the output circuit is a combined *L-pi* network.

The second part of this articles continues the discussion of the design of transistor rf power amplifiers. It also contains all component values for practical transistor amplifiers for the amateur frequencies between 3.5 and 148 MHz.

. . .W9EGQ

---

[1] *The transistor still has power gain at frequency ft, even though its current gain is unity there. This follows because the transistor output resistance is greater than its input resistance. This fact is of minor importance, except when an effort is made to make a transistor operate at the highest possible frequency.*