THE ART OF ELECTRONICS

Second Edition

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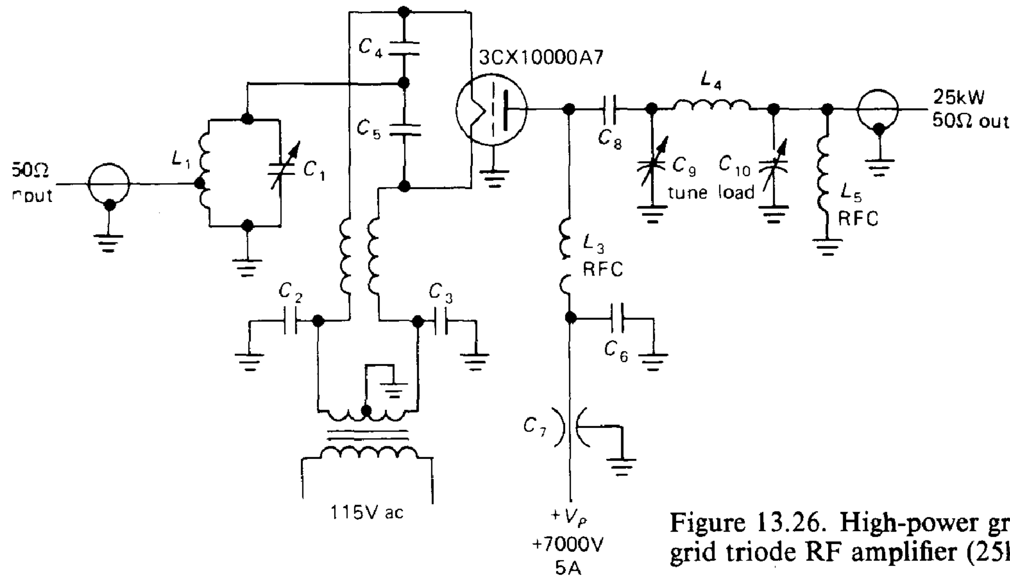

Figure 13.26. High-power grounded-grid triode RF amplifier (25kW output).

in the gigahertz range uses a dielectric "pill" resonator as the feedback element for a GaAs FET (or bipolar) oscillator. Oscillators using this "dielectrically stabilized" technique are simple and stable and have low noise.

For high stability, the best kind of oscillators use quartz crystals to set the operating frequency. With off-the-shelf garden-variety crystals, you can expect overall stabilities of a few parts per million, with tempco of order 1 ppm/degree or better. A temperature-compensated crystal oscillator (TCXO), which uses capacitors of controlled tempco to offset the crystal's frequency variation, can deliver frequency stability of 1 ppm over a temperature range of 0°C to 50°C or better. For the utmost in performance, oscillators with the crystal maintained in a constant-temperature "oven" are available, with stabilities of a few parts per billion over time and temperature. Even the so-called atomic oscillators (rubidium, cesium) actually use a high-stability quartz oscillator as the basic oscillating element, with frequency adjusted as necessary to agree with a particular atomic transition frequency.

Crystal oscillators are commercially available in frequencies ranging from about 10kHz to about 100MHz in all of the variations just mentioned. There are even little DIP and transistor can (TO-5) oscillators, with logic outputs. Only a slight electrical adjustment of frequency is possible, so the frequency must be specified when the oscillator or crystal is ordered.

To get both adjustability and high stability, a frequency synthesizer is the best choice. It uses tricks to generate any desired frequency from a single source of stable frequency, typically a 10MHz crystal oscillator. A synthesizer driven from a rubidium standard (stability of a few parts in 10^{12}) makes a nice signal source.

Mixers/modulators

A circuit that forms the product of two analog waveforms is used in a variety of radiofrequency applications and is called, variously, a modulator, mixer, synchronous detector, or phase detector. The simplest form of modulation, as you will see shortly, is amplitude modulation (AM), in which the high-frequency *carrier* signal is varied in amplitude according to a slowly varying *modulating* signal. A multiplier obviously performs the right function. Such a circuit can also be used as a variable gain control, thinking of one of the inputs as a dc voltage. There are convenient ICs to do this job, e.g., the MC1495 and MC1496.

A mixer is a circuit that accepts two signal inputs and forms an output signal at the sum and difference frequencies. From the trigonometric relationship

$$\cos\omega_1 t \cos\omega_2 t = \frac{1}{2}\cos(\omega_1 + \omega_2)t + \frac{1}{2}\cos(\omega_1 - \omega_2)t$$

it should be clear that a "four-quadrant multiplier," i.e., one that performs the product of two input signals of any polarity, is in fact a mixer. If you input two signals of frequency f_1 and f_2, you will get out signals at $f_1 + f_2$ and $f_1 - f_2$. A signal at frequency f_0 mixed with a band of signals near zero frequency (band-limited to a maximum frequency of f_{max}) will produce a symmetrical band of frequencies around f_0, extending from $f_0 - f_{max}$ to $f_0 + f_{max}$ (the spectrum of amplitude modulation, see Section 13.15).

It is not necessary to form an accurate analog product in order to mix two signals. In fact, any nonlinear combination of the two signals will produce sum and difference frequencies. Take, for instance, a "square-law" nonlinearity applied to the sum of two signals:

$$(\cos\omega_1 t + \cos\omega_2 t)^2 = 1 + \frac{1}{2}\cos 2\omega_1 t + \frac{1}{2}\cos 2\omega_2 t + \cos(\omega_1 + \omega_2)t + \cos(\omega_1 - \omega_2)t$$

This is the sort of nonlinearity you would get (roughly) by applying two small signals to a forward-biased diode. Note that you get harmonics of the individual signals, as well as the sum and difference frequencies. The term "balanced mixer" is used to describe a circuit in which only the sum and difference signals, not the input signals and their harmonics, are passed through to the output. The four-quadrant multiplier is a balanced mixer, whereas the nonlinear diode is not.

Among the methods used to make mixers are the following: (a) simple nonlinear transistor or diode circuits, often using Schottky diodes; (b) dual-gate FETs, with one signal applied to each gate; (c) multiplier chips like the MC1495, MC1496, SL640, or AD630; (d) balanced mixers constructed from transformers and arrays of diodes, generally available as packaged "double-balanced mixers." The latter are typified by the popular M1 series of double-balanced mixers from Watkins-Johnson spanning the frequency range to 4000MHz with 20dB to 50dB of signal isolation, or the inexpensive SBL-1 mixer (1–500MHz) from Mini-Circuits Lab. Mixers are widely used in the generation of radiofrequency signals at arbitrary frequencies; they let you shift a signal up or down in frequency without changing its spectrum. You will see how it all works shortly.

The equations above show that the simple quadratic-law mixer produces outputs of equal amplitudes at both sum and difference frequencies. In communications applications (e.g., the "superheterodyne" receiver), where mixers are often used to shift frequency bands, it is sometimes desirable to suppress one of those mixer products. We'll see in Section 13.16 how to make such an *image-reject* mixer.

Frequency multipliers

A nonlinear circuit often is used to generate a signal at a multiple of the input signal's frequency. This is particularly handy if a signal of high stability is required at a very high frequency, above the range of good oscillators. One of the most common methods is to bias an amplifier stage for highly nonlinear operation, then use an *LC* output circuit tuned to some multiple of the input signal; this can be done with bipolar transistors, FETs, or even tunnel diodes. A multiplier like the 1496 can be used as an efficient doubler at low radiofrequencies by connecting the input