3. High-Power Microwave-Tube Transmitter RF Circuit

Never do anything at high level that you can do at low.

Figure 3-1 shows what might be considered a typical transmitter for a high-power microwave-tube radar system that uses a pair of microwave tubes whose outputs are combined in a single-output waveguide channel. All these transmitter components, if multiplied, would be appropriate even for a phased-array transmitter, except the outputs of the high-power amplifiers would not be combined in a waveguide but would be directed to separate antenna elements, and the phase control would be variable with electronic speed. The interconnections shown are also expandable in order to accommodate many more parallel output devices, which, as we will see quite dramatically later, do not have to grow as powers of two.

The system shown has been implemented in rectangular (1:2 aspect ratio) dominant-mode ($TE_{0,1}$) waveguide. At lower microwave frequencies the components and interconnections are often made of coaxial transmission lines, which can grow in diameter and power-handling capacity until the mean circumference between conductors is equal to a wavelength at the highest operating frequency where the first waveguide mode that is *not* the dominant TEM mode is possible. (This mode is the transverse electric wave, $TE_{1,1}$.) Inner-conductor heating limits coaxial-line average-power capability, which can be enhanced by cooling (but not very easily). Voltage breakdown and/or tracking along the dielectric supports between inner and outer conductors usually limits peak-power handling, which can be enhanced by pressurization or use of a dielectric gas, such as nitrous oxide or sulfur hexafluoride.

Almost all high-power systems that operate above approximately 400 MHz use dominant-mode rectangular (1:2 aspect ratio) waveguide transmission lines and RF components. As average-power levels increase, waveguides, even though they are designed for low loss, can dissipate enough heat to require cooling. Natural convection air cooling can be enhanced by affixing metal fins transverse to the direction of the waveguide run. (Such fins also stiffen the broad wall, minimizing its deflection if waveguide pressurization is needed.) Eventually, as average power is increased, water cooling of the guide is required. This is usually accomplished by soldering or brazing copper tubing to the copper waveguide along the broad wall, where the RF currents are the highest.

RF breakdown in waveguides operated at high power is quite common, even when the electric-field intensity produced by the peak power is but a fraction of the theoretical breakdown value. The culprit in such cases is almost always imperfect mating of the flanges that connect waveguide sections. If the metallic contact around the entire periphery of a waveguide joint is not complete, the RF

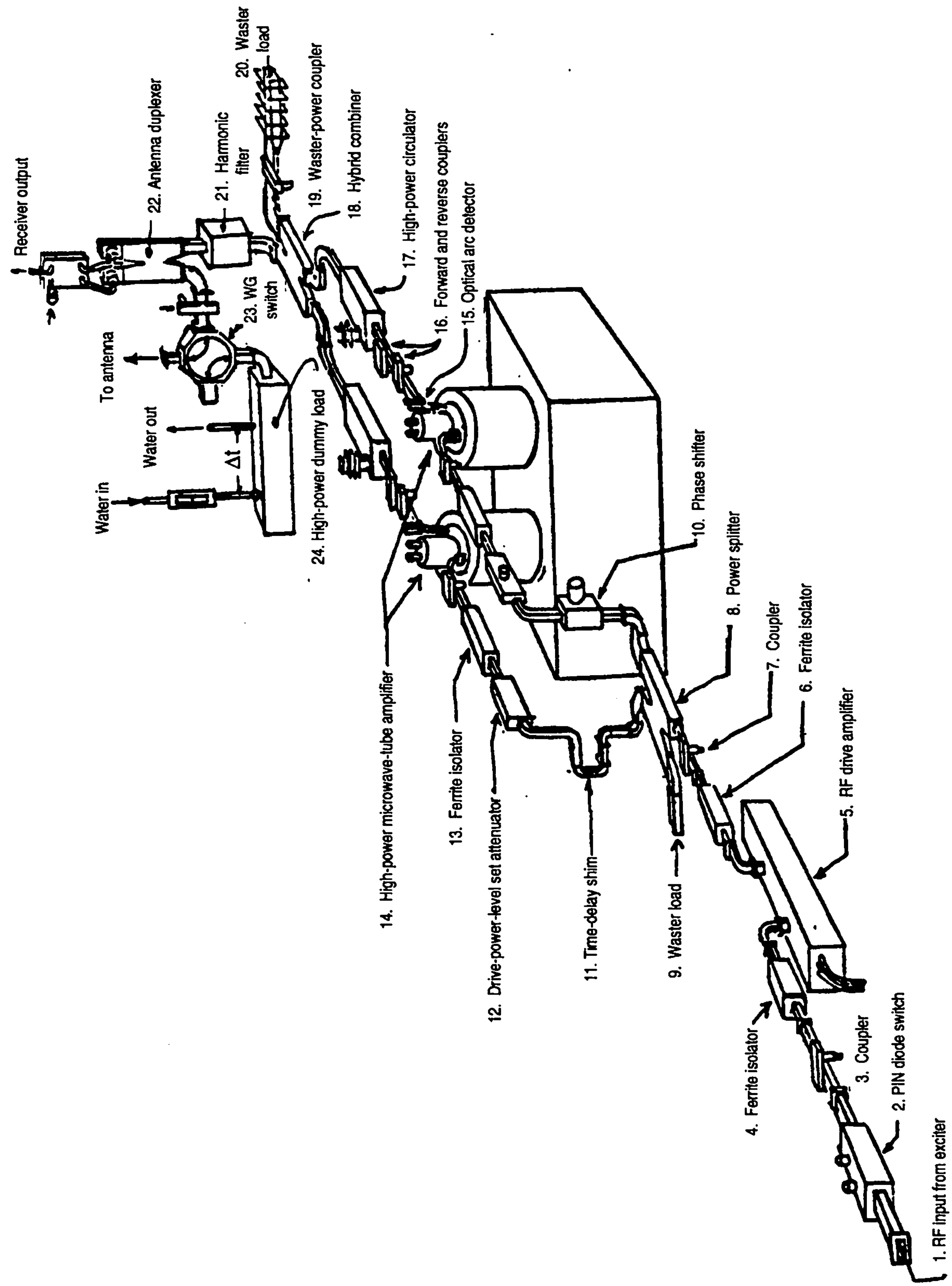

Figure 3-1. High-power microwave-tube transmitter RF circuit.

current distribution will not alter itself to avoid the spots with questionable continuity but will rather ionize the air within the void, producing great local heating and a supply of free ions. This phenomenon is called a series arc, which does not stay just a series arc for long, however. A cross-guide arc, which is a very troublesome kind, almost always immediately follows. The corrective solution for cross-guide arcs is not complicated: make sure there are no peripheral voids. Tighten up the bolts and, as part of the original design, make sure that there are enough bolts in each flange to make void-free tightening possible in the first place. (Even better is to minimize the number of flanges.) Where a number of components are closely coupled together, it can pay long-term dividends to fabricate them as a group with no intermediate flange connections. (If the transmitter is to be manufactured in high volume, there may be no cost penalty associated with such a design strategy either.)

As the operating frequency of the transmitter goes up, so does waveguide loss rate. For instance, in the W-band, which encompasses the 94-to-96-GHz moisture-absorption dip band, the loss rate of the dominant-mode guide, WR-10, is approximately 1 dB/ft. At this loss rate, the antenna feed does not have to be very far from the transmitter output before you lose the first 10 dB of system sensitivity. This loss applies not only to the transmitter power before it reaches the antenna feed but also to the received power before it reaches the low-noise preamplifier. In such situations, over-moded sections of special waveguide are used. Often these are circular waveguides, which can have low-loss properties if the run is perfectly straight.

The ultimate low-loss, high-power waveguide is actually no waveguide at all—or at least no waveguide with walls. It is called a beam waveguide and has been used for over 20 years in C-band satellite-communication earth stations. These stations use the beam waveguide to direct power from a transmitter on the ground to an antenna feed on a tower. A beam waveguide uses quasi-optical techniques. From the transmitter output, a Gaussian beam is launched from a "scalar" horn, which has circular cross-section and a corrugated inner surface. The beam that emerges has circular symmetry and a Gaussian distribution for any cross section. The beam is not of constant diameter, and after reiteration and redirection by what is called a "clamshell pair" of reflecting mirrors, it converges toward a "beam waist" and then diverges again, as illustrated in Fig. 3-2. Only at the beam waist positions are the phase centers of all of the rays in a plane perpendicular to the center ray. The parameters of beam width, effective radius of the phase centers, and distance from beam waist are illustrated in Fig. 3-3. Beam width, $\omega_{(z)}$, is defined as

$$\omega_{(Z)} = \omega_0 \sqrt{1 + \left(\frac{Z}{\delta_0}\right)^2}$$

and the phase center, $R_{(z)}$, is defined as

$$R_{(z)} = z + \frac{\delta_0^2}{z},$$

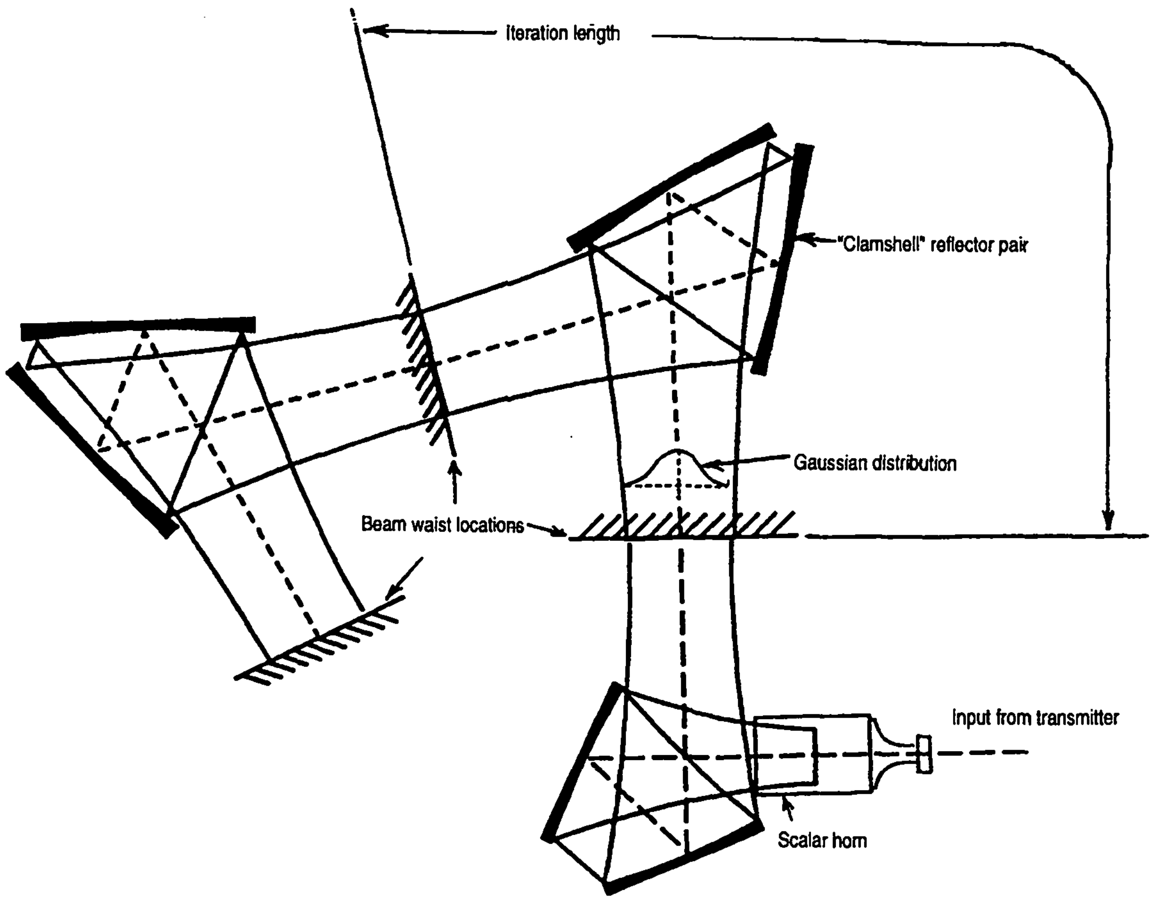

Figure 3-2. Basic properties of beam-waveguide RF transmission system.

where

$$\delta_0 = \frac{\pi \omega_0^2}{\lambda}.$$

Note that more than one mode is possible.

Only since 1990 has beam-waveguide technology been expanded to serve all of the functions of a sophisticated radar-tracking feed system. This feat was first achieved by the ALCOR/Millimeter-Wave Radar, which operated at a center frequency of 35 GHz. Figure 3-4 shows a simplified three-dimensional schematic diagram of the quasi-optical microwave components developed by MIT/Lincoln Laboratory for the project. Note that the polarization filters are grids of wire stretched across the beam wave space. They are designed to reflect one sense of polarization and be transparent to the orthogonal sense. The circular polarizer is more like a wide-open Venetian blind whose width creates the length of waveguide that generates a quadrature component from a linearly polarized wave. The 45° Faraday rotator performs the function of an antenna duplexer for the oppositely polarized received signal, which, without the total of 90° round-trip phase shift, would end up in the transmitter output waveguide.

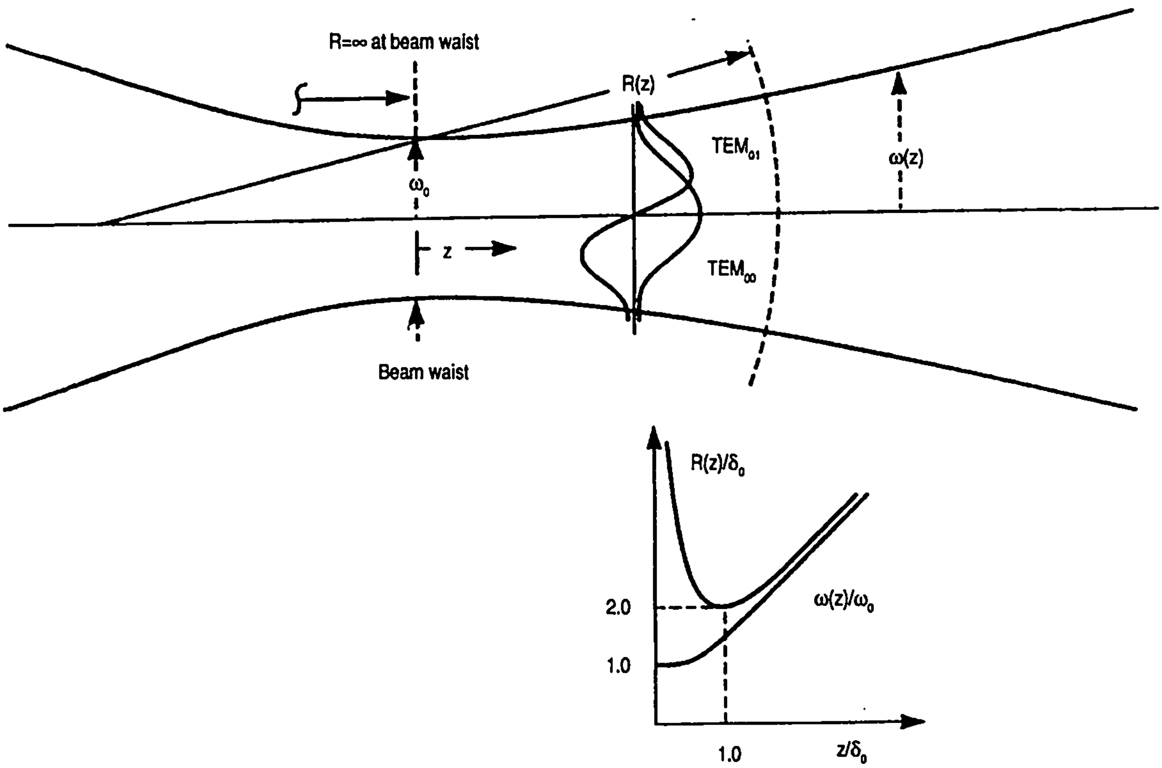

Figure 3-3. How width of beam and phase-center radius vary with distance from beam waist.

The rest of this chapter will briefly describe the transmitter components identified in Fig. 3-1.

3.1 RF input from the exciter

The RF input from the exciter is the transmitter's interface with the rest of the complex system, which can be a radar system, a communications system, or the RF source for a particle accelerator. When properly defined, the RF input will tell you what signal level to expect and whether the signal is broadband or has complex modulation. It will also define the signal's spectral and temporal characteristics.

Typical input interface signal levels are between 100 mW and 1 W (-10 dBW and 0 dBW). The people supplying you with this signal (often called "exciter people") will want to know from you—or will specify to you—the transmitter's complex load impedance. If they are clever, experienced, or both, they will insist that the sign of that impedance always be positive. (As will be explained later, it is by no means impossible for a transmitter to reflect more power than is incident upon it and yet operate quite normally, depending upon the *source* impedance of the exciter.)

3.2 PIN diode switch

This is a high-speed shut-off switch capable of interrupting, or greatly attenuating, the RF input signal within fractions of a microsecond. Its purpose is not to produce pulse modulation of the input RF signal—that is in the domain of the exciter—but to prevent damage to the microwave tube or tubes in the event of high reflected output power or waveguide arcing. The PIN diode switch is a necessary, but not always satisfactory, reactor to a fault condition. If, for instance, the output anomaly caused the microwave tube to self-oscillate, then turning off the RF drive, no matter how rapidly, will do no good. In this situation it is necessary to kill the microwave tube beam current as well, either by terminating a pulse modulator output pulse or by firing an electronic crowbar to dump the entire cathode voltage.

3.3 Signal couplers

Because signal couplers can be designed to house RF sensors, transmitter designers often say that you can't have too many signal couplers. Sensors are usually capacitive or inductive. The simplest of capacitive (paddle) or inductive (loop) probes, which barely protrude into the wave space, can often provide all of

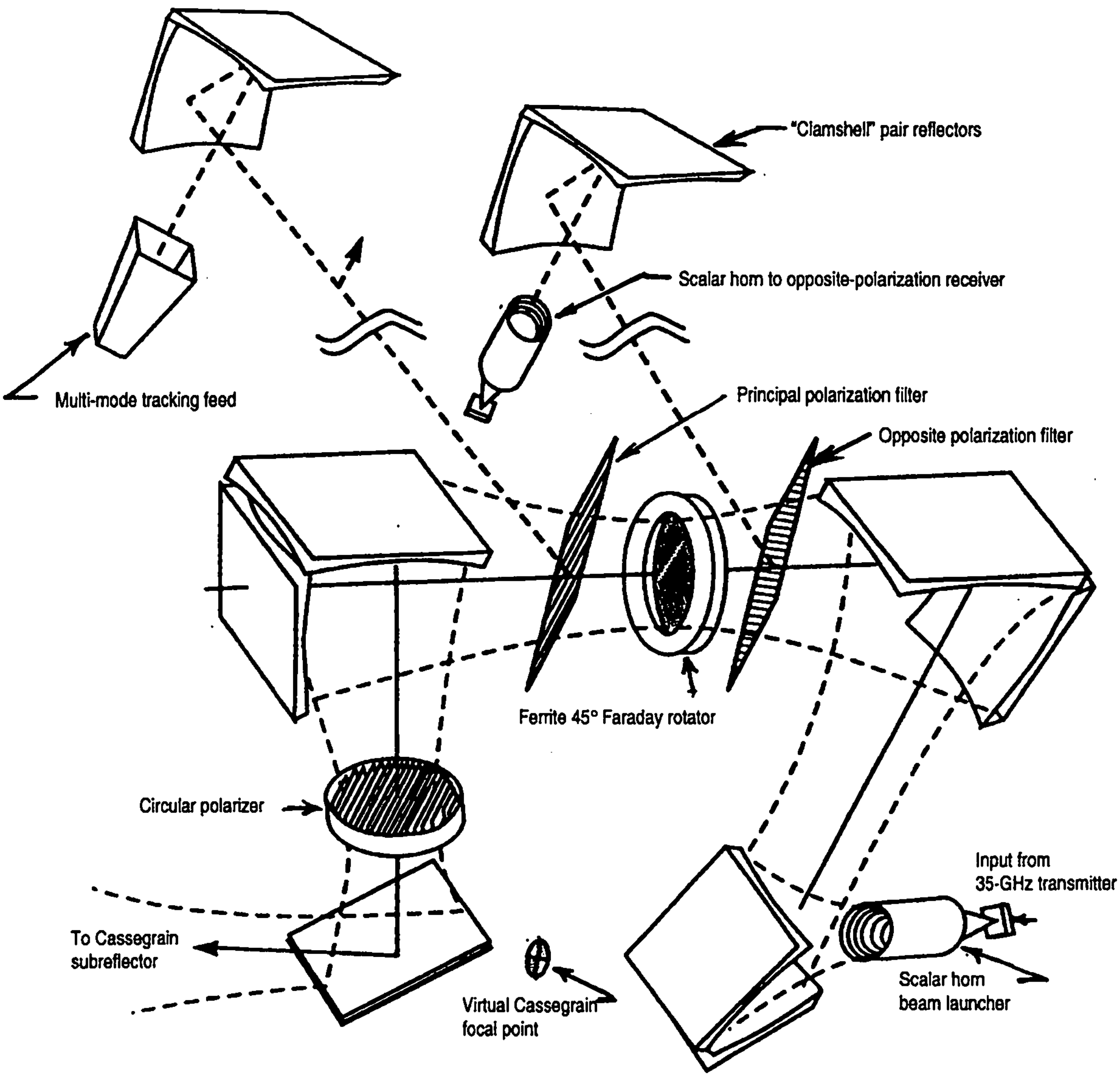

Figure 3-4. Simplified schematic of beam-waveguide components of tracking radar feed.

the information a transmitter designer needs: has the signal gotten this far or not? Often the awareness of the mere presence of RF field activity is sufficient for the designer. There is a special type of signal coupler known as the directional coupler, which can differentiate between forward and reflected RF vectors. There are instances where this kind of information can be useful to the designer. For instance, the first signal coupler illustrated in Fig. 3-1 may very well have to be dual-directional because the designer may want to know not only if RF power is getting past the PIN diode switch but how much of it is being reflected.

3.4 Ferrite isolator

This device may be an isolator if reflected power is small enough to be absorbed by the ferrite material of the device, or it may be a junction circulator if the power is too great to be absorbed by the ferrite. Circulators have three ports—input, output and load—with the reflected power being diverted to the load port. Remember that in some special cases the reflected power absorption or diversion capability of this device may actually exceed the incident power. In virtually all cases, however, this device will be responsible for meeting the input impedance requirement.

3.5 RF driver amplifier

Except in rare instances, the RF input from the exciter will be inadequate to drive the high-power amplifier stages directly. A driver or intermediate amplifier will usually be required. This could be a cascade or distributed-transistor amplifier, a reflection-type impact-avalanche-transit-time (IMPATT) diode amplifier (or locked-oscillator amplifier), a helix-type or low-power coupled-cavity TWT, or, in more mature designs, an amplifier comprising triodes and/or tetrodes that have cavity-type RF circuits. Typical drive amplifier power output ranges from 10 to 100 W (+10 dBW to +20 dBW).

3.6 Another isolator

This isolator functions like the isolator of 3.4, except here it isolates the driver amplifier output from high-power amplifier reflections.

3.7 Another coupler

This coupler functions like the coupler of 3.3, except here it is one stage further in the amplifier chain.

3.8 Power splitter

Because we will be driving two high-power amplifiers (HPAs) from a common drive source, we will need to split the drive line into two channels of equal amplitude. Several types of components can do this, but they differ with respect to the phasing of the output signals. It is not necessary that the outputs have identical phasing, so long as a device with similar phase-shift characteristics is used to recombine the channels after high-power amplification. (If the system is narrow-band or fixed-frequency, even that is not necessary.) Often, if not always, the splitter of choice is a short-slot-sidewall, 3-dB, 90°-hybrid coupler. It is reasonably broadband both in power-split ratio and 90°-output-phase difference, and it has high power-handling capability, which, although not important at this point in the chain, is important if we use a similar device for recombination. There is another, more subtle advantage to the 90° output-signal phase difference. It can be reasonably expected that the high-power amplifiers will have imperfect input matches and will reflect some of the incident drive signal. Even though the amplifiers may have imperfect input matches, if their reflection coefficients are similar—or better yet, identical—the reflected signals from them, when passing through the 90° hybrid in the reverse direction, will combine in the hybrid waster load (3.9) and will cancel at the input port, in which case the isolator (3.6) will have nothing to do.

3.9 Waster load

This is the resistive RF load mentioned above. Its power rating should be equal to the driver amplifier output-power capability in case of total reflection from the HPA inputs, which is by no means impossible.

3.10 Phase shifter

This device, often motor-driven, is used by an operator or an automatic servo system to maximize the combined RF output from the dual-channel system by making the phase delay of the two parallel channels as identical as possible at the operating frequency (or near the band center if it is a broadband system). It is desirable, but less than crucial, that phase changes do not produce changes in attenuation.

3.11 Time-delay shim

If the system is to operate over a significant band of frequencies, the channels must have equal time delay as well as equal phase delay at a single frequency. If the time delays are not equal, phase delay will accumulate more rapidly in one channel than the other as frequency is increased. (Time delay can be expressed as the quotient of incremental phase divided by incremental frequency, or Δ*phase*/Δ*frequency*.) This condition, known as "phase runout with frequency," can be statically corrected by replacing the high-power amplifier tubes with lengths of transmission line that approximate their time-delay contributions and by adding time-delay shims or incremental sections of transmission line to the channel that needs them.

3.12 Drive-power-level attenuator(s)

These attenuators are adjusted during initial system operation and only periodically thereafter, usually following the replacement of an HPA or drive-stage tube. These attenuators assure that both HPA tubes are operating at their maximum power outputs, even if their power outputs are not the same. Although an amplitude imbalance will produce some waster-load power, the loss in total combined output power will be greater than the loss caused by amplitude imbalance if the output of the higher-powered tube is deliberately reduced to match that of the lower-powered one.

3.13 More ferrite isolators

Although isolators in this location are quite common, they are clearly redundant with the one at (3.6). At first glance, it would appear that the isolator at (3.6) would have to have twice the reverse-power handling capability as either of the isolators at (3.13). This overlooks the action of the input 90° power splitter, however. The statistical likelihood is that more than half of the total reflected power from the two HPAs will be diverted to the hybrid waster load, in which case the (3.6) isolator sees less reflected power than either of the (3.13) isolators. If the HPA reflection coefficients are equal and the incident drive signals are equal, the (3.6) isolator does not see any reflected power at all, unless the (3.10) phase shifter has been grossly maladjusted.

3.14 High-power amplifiers

These HPAs may be any coherent power amplifiers. The classic examples are the klystron and the TWT, which, at the highest power levels, is usually of the coupled-cavity variety. If we stretch the concept of coherency a bit, we could also use crossed-field amplifiers, which many feel act more like locked oscillators than true amplifiers. (Speaking of locked oscillators, there is no fundamental reason why injection-locked magnetron oscillators could not be accommodated in these applications, except that the required input and output ports would be obtained by using a circulator connected to the single port of the oscillator.) As will be seen later, it is essential that both amplifier tubes be operated from the same high-voltage cathode bus and, if practical, from the same pulse-modulator bus as well.

3.15 Waveguide arc detector

The only important damage that an arc in the waveguide system can cause—apart from interrupting the orderly flow of RF power to its intended destination—is to the output window of the microwave vacuum tube. The most serious form of such damage is cracking, which usually results in a loss of vacuum within the power tube. The most frequently used protection against such arcs involves the use of an optical arc detector. Moderately fast (on the order of a microsecond) photo-sensitive solid-state diodes are the most commonly used transducers. They are positioned "to see" the window through a small hole in the wall of a waveguide bend that is in line with the window. The sensor mount is in the form of a small-diameter tube that acts as a waveguide beyond the cutoff. The tube prevents RF leakage either to the diode, which may be sensitive to it, or beyond. When the waveguide dimensions themselves are too small to permit the use of such a tube, a small-diameter fiber-optic cable is used to couple the light energy into the photodiode.

Perhaps the highest-performance optical arc detector design, however, uses a photomultiplier vacuum tube as the transducer. In its most sophisticated form, the photomultiplier is continuously self-checking. This is how it works. Through another aperture in the waveguide wall a low-intensity light illuminates the surface of the window. The reflected "background" illumination produces continuous photo current in the photomultiplier and a dynode output voltage proportional to it. The logic circuitry that the tube drives has two threshold levels: a low-level one, which must be exceeded by the continuous self-check output; and a high-level one, which is below the dynode output signal under arc conditions. If the output signal falls below the lower threshold, a fault in the circuit is indicated. If the signal output exceeds the upper threshold, an arc is indicated.

Other means have been used to detect arcs. Acoustic arc detection has been successfully employed in applications requiring low frequency (L-band and below) and long pulse duration (~1 ms)—and this includes continuous wave (CW), of course. Acoustic transducers are nothing more than loudspeakers acting as microphones. They are mounted to the waveguide broad walls. The same kind of matching transformer that is used to connect speakers to a "constant-voltage" bus in public address systems is often used to step up the feeble signal present directly at the terminals. Figure 3-5 is the schematic diagram of the protective circuit logic associated with an acoustic arc detector. It comprises a single ML-339 quad-voltage comparator. The circuit has bipolar thresholds to provide response within the first half-cycle, regardless of which direction the speaker cone starts to move in response to the sound caused by the arc.

Neither optical nor acoustic means are easily applied to coaxial transmission line systems, however. Instead, systems for coaxial lines have been employed that sense RF drive power, power amplifier beam current, and forward RF output power. These signals are sent to logic circuitry. If the first two signals are present and the third is not, an output RF fault is inferred and the RF drive is inhibited. Needless to say, in such systems a small delay must be incorporated in the search for RF output before the RF input is shut off. A somewhat similar scheme was once used in a family of high-power CW klystron amplifiers. Two forward-power couplers were built into the RF output line of the tube. One was positioned ahead of the output window, on the vacuum side, and the other was placed on the output side of the window. If the signals from both couplers were

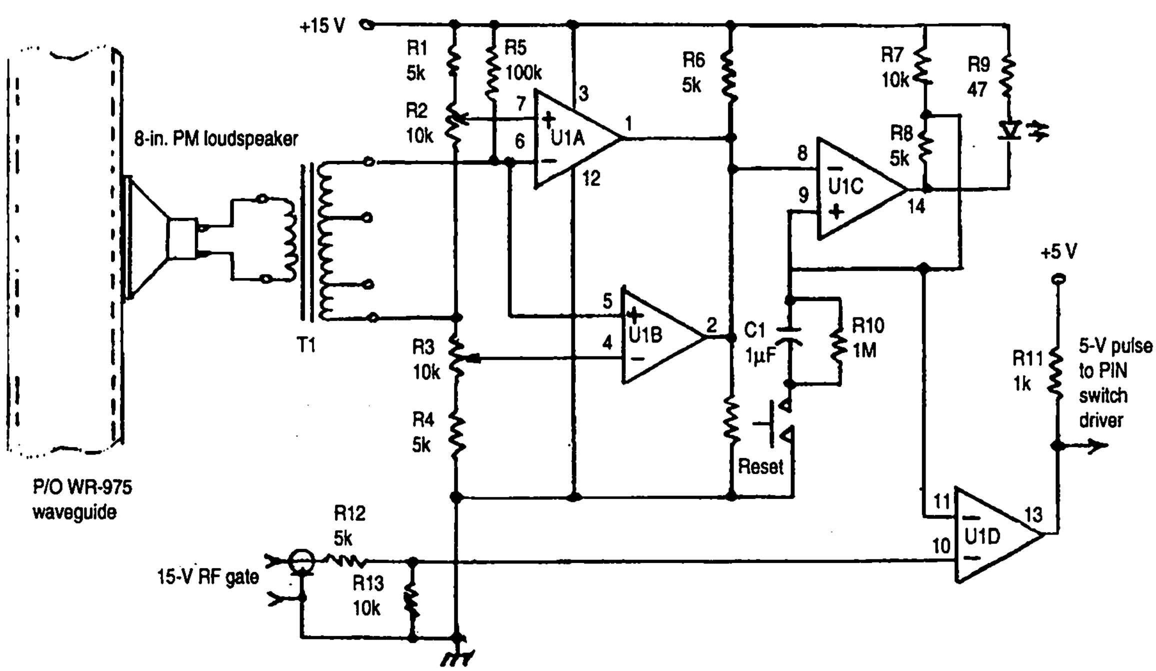

Figure 3-5. Schematic diagram of acoustic waveguide-arc detector.

not nearly identical, a window arc was inferred.

3.16 Forward and reverse couplers

It is at this point in the power-transport system that the performance of the individual power amplifiers can best be assessed. Here, reverse-power couplers give a full-time indication of the state of the remainder of the high-power transmission system, which may include rotary joints, radomes, switches, and other devices that can wear out, get water-logged, or get stuck halfway if they are two-position devices. The couplers also give early warning for arcs that may have started downstream and that, if permitted to persist, will propagate toward the source of power at the speed of sound.

3.17 High-power circulator

Whether or not to put a high-power circulator between a microwave power tube and its output load is one of the most agonizing decision that any transmitter designer must make. Tube manufacturers will make it easy for you. They usually insist that you use one or their warranty will be void. (The same thing goes for the arc detector and the electronic crowbar.) The decision, nevertheless, is the designer's.

A high-power circulator has only three traits that a designer can absolutely depend on:

- it will be one of the most expensive components in the system, usually second only to the tube itself;
- it will have one of the longest lead times; and
- it will absorb precious transmitter output power and convert it to heat, which must be carefully removed to avoid damaging the circulator.

What will it do in return? It will absorb reflected power from the load system. That's all.

There is no reason why a properly designed load system should have a voltage/standing-wave ratio (VSWR) greater than 1.5:1, and there is no reason why a properly designed microwave power tube should not tolerate a VSWR of 1.5:1. If, for whatever reason, either parameter cannot be realized, then and only then should the subject of the high-power circulator be broached—at which time it may be discovered that there are no credible high-power circulator sources, anyway. (It has been said that what makes a manufacturer a source of high-power circulators is the glue that he uses to fasten the ferrite material to the waveguide wall.)

3.18 Output hybrid combiner

In the system that we are describing, the output hybrid combiner is a short-slot, 90°, 3-dB hybrid coupler. The twin of (3.8), the splitter, it is identical to it in all respects, except for the tailoring of its edges to minimize electric-field enhancement. This is done in the interest of maximizing power-handling capability.

It should be mentioned again that it is not necessary for the outputs of the HPAs to be equal for them to be combined with 100% combining efficiency, or that the number of HPAs must follow a 2^n progression. (Later, a transmitter comprising 24 high-power TWTs whose outputs were combined in a single-output waveguide will be described.)

3.19 Waster power coupler

The output of this signal sampler most effectively indicates how well the outputs of the two power amplifiers are being combined. This measurement can best be taken when the phase shifter (3.10) and the time-delay shim (3.11) have been adjusted to minimize the frequency-averaged amplitude of this signal over the operating bandwidth of the system. Presuming that the reflection coefficient of the waster load is small (as it should be), the directivity of this coupler is not of primary importance.

3.20 Waster load

Assuming there is proper input phasing and reasonable amplitude balance, the nominal power dissipated in this load will be but a small fraction of the total combined RF power. Nevertheless, gross maladjustment of the phasing can put the total combined RF power into this load instead of the nominal output port of the combiner. In more than a few systems this effect has been exploited to obviate the necessity of placing a high-power switch between useful and dummy output loads, in which case this load is designed to perform accordingly. Where the waster load is sized to handle only the anticipated water power (with a prudent safety factor), the coupler (3.19) can be set up to shut off the RF drive to the transmitter if power in this line is above a safe threshold. The sudden loss of power output from one or the other HPAs will cause half of the power of the remaining one—or 1/4 of the total combined RF power—to be diverted to the waster load.

3.21 Harmonic filter

Among transmitter designers, placing a harmonic filter in the waveguide system is almost as controversial as including a high-power ferrite circulator. In situations where it is known that harmonics of the carrier frequency will coincide with known operating frequencies of other nearby RF facilities, the designer has no choice: the harmonics must be attenuated to the greatest extent possible. Moreover, the transmitter must absorb the harmonic components. Reflecting them may keep them from being radiated, but in the worst case they can still produce "trapped" undamped harmonic resonances within the waveguide system. The presence of such resonances in the waveguide system will cause RF breakdown even at a fraction of full power. Furthermore, in dominant-mode waveguide systems all harmonics are high enough in frequency to possibly cause the propagation of higher-order modes. And the higher the harmonic number, the larger the number of possible modes.

This can be either good or bad. If the problem is presented in terms of a maximum permissible level of total harmonic power in the waveguide system, then the filter must be capable of absorbing the power being propagated in all of the possible modes. If, on the other hand, the designer is only concerned with what is actually being radiated into space, the antenna and its feed structure may act as an effective mode filter, keeping harmonic power from being radiated at

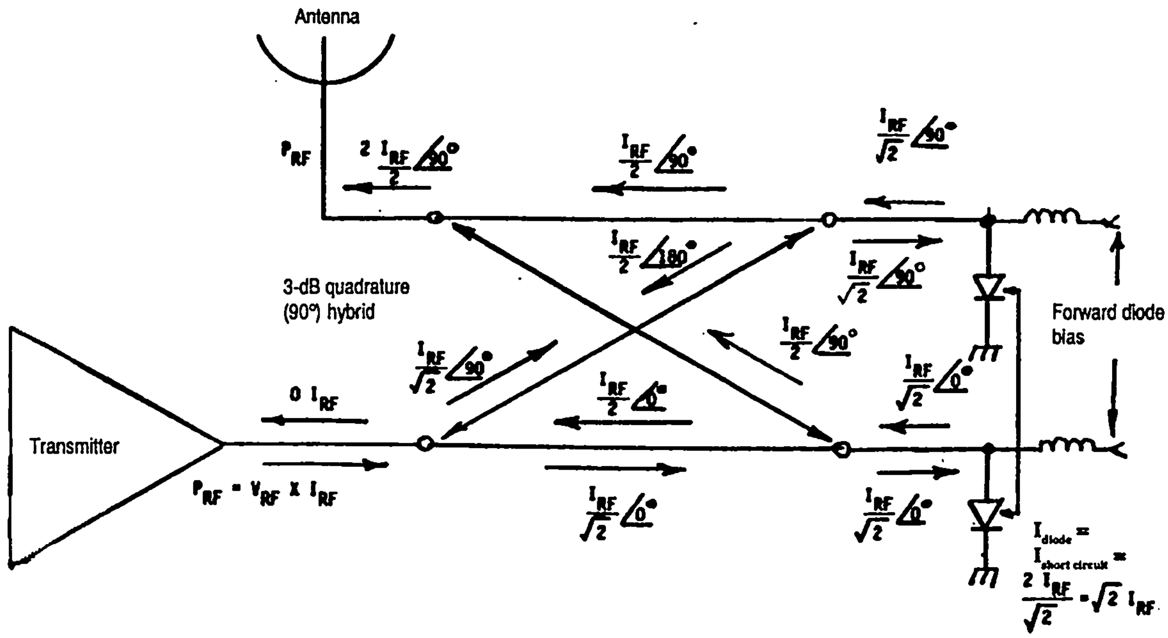

Figure 3-6. Vector relationships in the diode duplexer for RF current in transmit mode.

all. So-called leaky-wall filters have multi-mode absorptive capability. So do the "waffle" type filters. All filters will have some impact on the fundamental-frequency power-handling capability of the waveguide. Most of the time they reduce it. But if they are deployed ahead of line sections with harmonic resonances, they can actually improve the performance of the total system. Where there are specific interference problems that involve a high-order harmonic (such as the fifth or seventh), special traps can be used. In such traps, the miter wall of a right-angle bend is not solid but is reflective enough at the fundamental frequency so that the fundamental can negotiate the bend, whereas high-order harmonics pass through the virtual miter wall into an absorber.

3.22 Antenna duplexer

The microwave component depicted in Fig. 3-1 as the antenna duplexer is used in monostatic radar systems to permit time-sharing of a single antenna by both transmitter and receiver. There are two basic forms of such devices. One is called a branch duplexer and the other, the balanced duplexer.

The one shown in Fig. 3-1 is the balanced type, comprising high- and low-power, 3dB, 90° hybrid junctions and the equivalent of RF shorting switches. The transmission lines from the transmitter to the antenna are connected to adjacent ports of the high-power hybrid, whose output ports are also shunted by the high-speed RF shorting switches. Gas-filled cells are commonly used as the shorting switches. In them gas is ionized by incident transmitter power and the resulting plasma short-circuits the junctions, reflecting the incident transmitter power back through the hybrid.

Because of the 90°-phase shifts in both directions, the reflected signal components combine in the antenna arm and cancel at the transmitter arm, effectively connecting the transmitter to the antenna. Following each transmitter pulse, the gas de-ionizes, eventually returning to an open-circuit state (over a period called

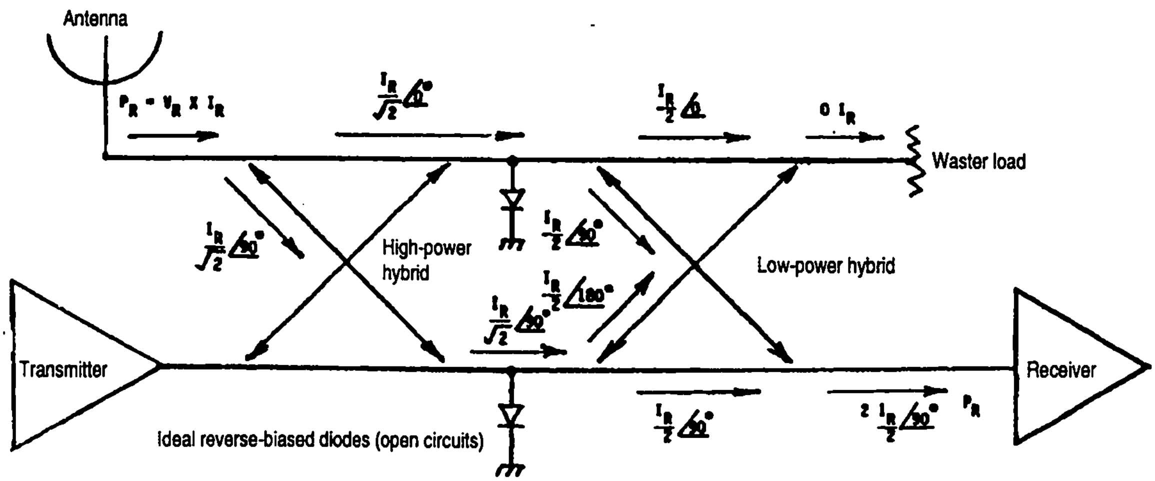

Figure 3-7. Vector relationships in dipole duplexer for RF current in receive mode.

the recovery time). At this time, the returning radar signals reflected from the target (called returns) travel from the antenna to the antenna port of the high-power hybrid. Here, they split. But this time they continue past the high-power hybrid output ports, which are no longer short-circuited by the ionized gas, to the low-power hybrid input ports. The receiver input is connected to one output port and a waster termination to the other. Assuming perfect amplitude split and exact 90°-phase shift in the two hybrids, all of the target return power will combine at the receiver input, which is diagonally opposite the high-power antenna terminal. Conversely, during the transmit pulse, signals that leak past the intended short-circuit impedance cancel at the receiver input port and combine at the waster-load port, which diagonally opposes the transmitter input port.

Unfortunately, gas cells absorb transmitter power in the process of ionization, which is not instantaneous. During this time there is a short-duration leakage, called spike leakage, past the gas cells. If all goes as intended, all of this leakage ends up in the low-power hybrid waster load. Often, however, enough of it does not end up there. In such cases, the unwanted power can burn out sensitive low-noise amplifiers in the receiver.

Solid-state PIN diodes can be made to exhibit low values of RF impedance when biased with current in the forward direction and relatively high values of RF impedance when biased with voltage in the reverse direction. Especially at the lower microwave frequencies, arrays of such diodes have been used as the RF switches in very high-power duplexers. As switches, they have the disadvantage of having to be actively biased. Even so, this presents the opportunity to start the forward current bias before the leading edge of the transmitter pulse, eliminating spike leakage altogether. Only the so-called flat leakage, which persists throughout the transmitter pulse, remains.

Figure 3-6 shows the vector relationships for RF transmitter output current when the duplexer diodes are forward-biased in the transmit mode. And Fig. 3-7 shows the same relationship for received-signal RF current when the duplexer diodes are reverse-biased in the receive mode. The relationships shown in Fig. 3-6 also hold true for reflections from the RF power amplifier tubes with regard to the input hybrid power splitter (3.8) and for reflections from the RF power amplifier output terminals with regard to the output hybrid power combiner (3.18). The vector relationships shown in Fig. 3-7 hold true for the splitting and recombining process involving the high-power RF amplifiers, except that the diode junctions are replaced with identical amplifiers so that the vectors to the right of the junctions are greater by the current gain of the amplifiers than those to the left.

Figure 3-8 shows the dimensions and arrangement of a practical multi-megawatt solid-state duplexer using PIN diode switches. The high-power hybrid junction is in a WR-2100 rectangular waveguide. Its two output ports are integrated with cross-bar-type waveguide/coaxial transitions to 9-1/8-in. rigid coaxial transmission line. Connected to each transition is a PIN diode stub, the details of which are shown in Fig. 3-9. The stubs are built into quick-step transitions between 9-1/8-in. and 7/8-in. rigid coaxial line. The 10 diodes in each stub are arranged in a circle concentric with the center line of the coaxial transmission lines, bridging that portion of the transition region where the electric and magnetic fields are radial rather than coaxial. The PIN diodes themselves, are so small that their total length occupies only a small fraction of the total height of the radial section. The remainder of the height is made up by the screw-in diode holders, which allow individual diodes to be removed without disassembly (other than removing the weather-proof top cover). Even at the relatively low operating frequency of 425 MHz, the capacitive susceptance of the back-biased diodes is so

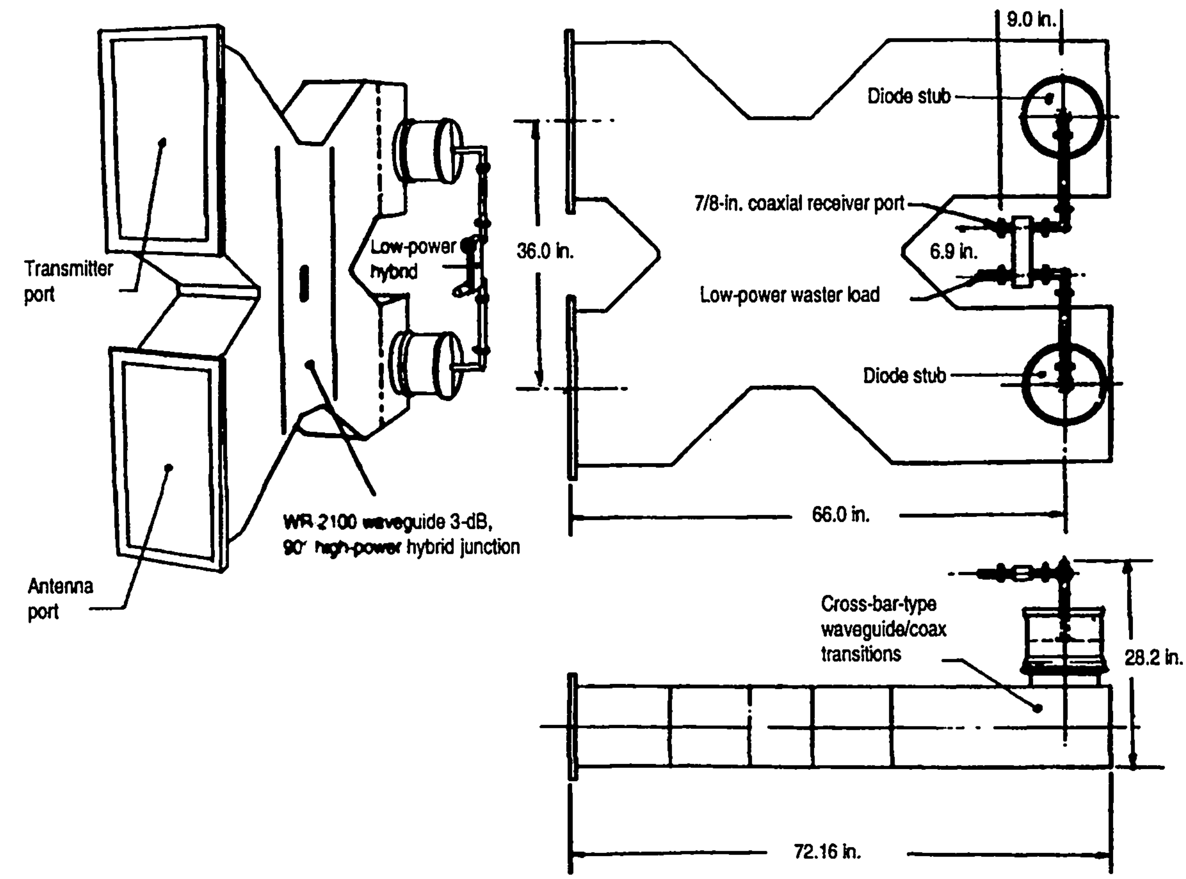

Figure 3-8. 30-megawatt UHF solid-state diode duplexer.

great that a very large mismatch occurs at their insertion radius. For that reason, the bias-insertion leads, which alternate circumferentially with the diode holders, have a length and a shape appropriate for the inductance required for parallel resonance with each diode. The forward and reverse diode bias signals are isolated from the UHF signal path by a segmented coaxial blocking capacitor. (This coaxial transmission line section has very low characteristic impedance and uses thin-wall Teflon tubing as dielectric.) The outer conductor is broken into 10 circumferential segments so that individual diode bias conditions can be monitored.

Connected to the diode stubs by 7/8-in. coaxial line is the low-power hybrid, the output ports of which connect to the receiver input and the waster load.

The design shown in Fig. 3-8 was tested for 30 MW peak power, 15-μs pulse duration, and 0.005 duty factor. It operated for many years at 20 MW peak power. Because of the small mass and thermal time-constant of the PIN junctions, the stress that limits diode performance is intrapulse temperature rise, which is proportional to individual pulse energy (the product of peak power and pulse duration).

Before leaving the subject of duplexing, however, it should be contrasted with the process of diplexing. According to the dictionary, both of these terms mean substantially the same thing. In RF system usage, the term "to duplex" means to separate functions in time; "to diplex" means to separate functions by frequency or wavelength. A common example of high-level diplexing is the sharing of a common antenna by the video and audio transmitters of a typical high-power television transmitter. The main signal is a single-sideband AM picture signal and the other a narrow-band (25-kHz deviation) FM sound signal, with carrier frequencies separated by 3.5 MHz. Both signals are coupled into the antenna through filters— one low-pass and the other high-pass—that function much like the cross-over network used in two-way loudspeaker systems.

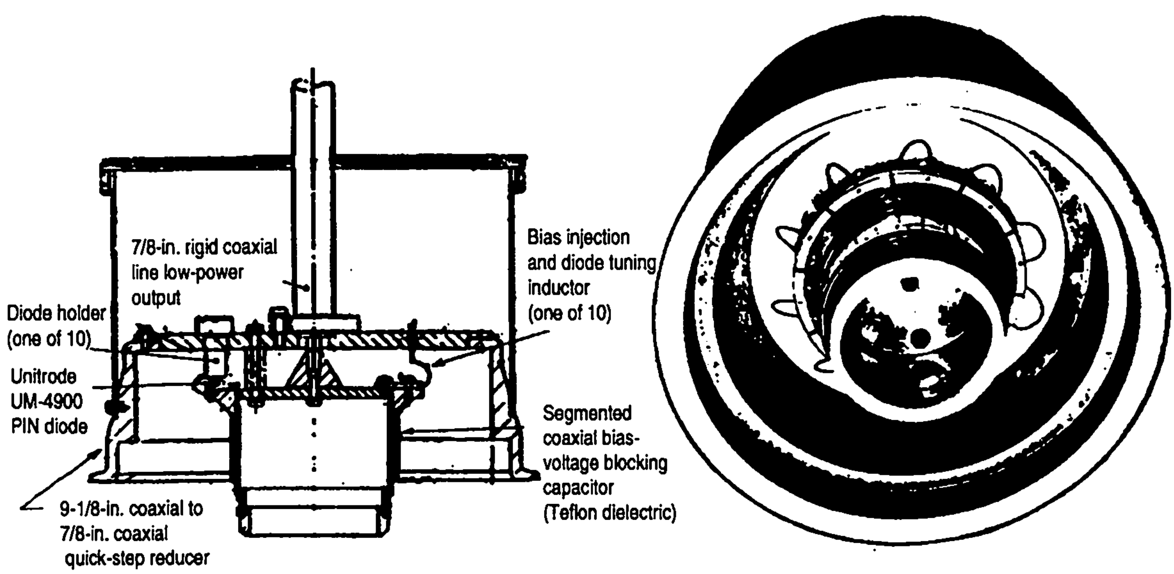

Figure 3-9. Details of 30-MW diode duplexer diode stub.

3.23 Waveguide switch

In many high-power RF systems it is necessary or desirable to be able to switch the transmitter output from the antenna to a dummy load. As mentioned before, this effect can be achieved by deliberately mis-phasing the two amplification channels so that most of the transmitter power combines in the hybrid combiner waster load. The key word is "most." There will always be a significant residue directed to the antenna—more, usually, than can be tolerated. The isolation of a mechanical waveguide or coaxial switch can be made much greater by using a waveguide switch. Moreover, the antenna port can be covered by a metal shutter as well.

3.24 High-power dummy load

At this location, a full-power dummy load (or "phantom antenna," as they were once called) can permit full-power transmitter operational diagnostics even when the antenna is unavailable or radiation is not permitted. If the load is water cooled, or is in fact a true water load where the water is the lossy medium as well as the coolant, it can be set up as a calorimeter in order to yield what some maintain is the most accurate measurement of average power output. (Yet this is another controversial subject).