HIGH POWER TWT AMPLIFIERS

Power combining of TWT amplifiers may be the simplest and most practical way to meet the high power RF testing requirement of modern weapons systems.

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INTRODUCTION

In recent years, power combining of TWT amplifiers has proven to be a practical way to meet the high power RF testing requirements of modern weapons systems. Amplifiers have been designed using this power combining technique and several models are available covering the frequency range from 1 to 18 GHz in octave bands and providing nominal CW saturated output powers of 400 to 800 watts. The 400 watt systems are based on power combining two each 200 watt medium power TWT amplifiers. To get to 800 watts, two pairs of 400 watt power combined amplifiers are combined. A major advantage of the power combining approach is that it is forced air cooled, eliminating any need for heat exchangers, pumps, piping, etc.

POWER COMBINING

When two signals of identical phase and amplitude are applied to the inputs of a magic tee or 180° hybrid, the sum of the two is produced at one of the output ports (the sum port), and no signal is produced at the other output port (the difference port).

In a theoretically perfect system, the RF output power at the sum port would equal the exact sum of the RF powers at the input ports of the magic tee (Figure 1). In actual practice, losses and phase/amplitude differences between the signals applied to the combiner result in a power gain of about 2.7 instead of 3 dB.

A practical system requires that proper attention be given to the phase and amplitude matching of the signals to be combined, including variations in bandwidth, time, environmental conditions and TWT replacement. In order to minimize combining losses, both the amplitude and phase of the two signals appearing at the inputs of the hybrid must be as nearly identical as possible. Shown in Figure 2 are the combining losses which occur when either the amplitude or phase of the two signals differ.

As shown in Figure 2, phase mismatch is by far the most critical problem. A 10° phase difference results in approximately 1 dB of combining loss; whereas, a 2.5 dB difference in amplitude results in less than 0.1 dB combining loss. It is impossible to match both phase and amplitude exactly at any given frequency; however, a practical system must be designed to match both phase and amplitude over its entire operating range.

For amplitude, quality TWT amplifiers will have broadband gain variations that match quite well from amplifier to amplifier. Fine grain ripple is random, but relatively small. Experience has shown that two amplifiers selected at random from different lots will be broadband amplitude matched to better than 2 dB when both amplifiers are driven to produce the same RF power output level at midband.

Phase match across the band is more difficult. The major contributing source of phase mismatch is the TWT. One manufacturer has gener-

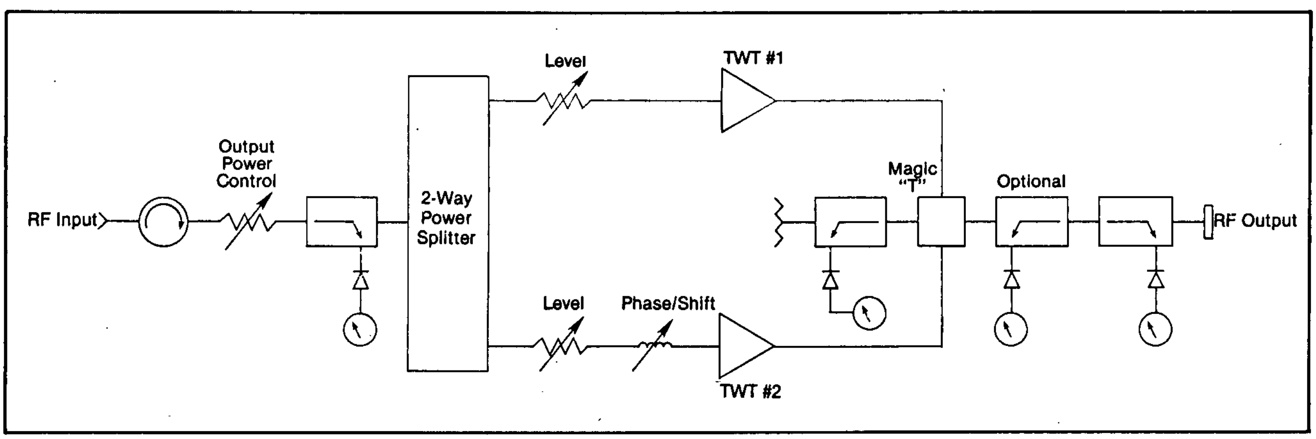

Figure 1. Block Diagram of Basic Power Combined TWT Amplifier System.

ated a great deal of statistical data concerning the phase mismatch between TWTs of the same type and has determined that standard same-type TWTs produced for test equipment applications will fall within a window of about 100° from design center phase length at midband, even though the actual electrical length is 10,000° to 40,000°.

This means that it is not necessary to actually phase trim individual tubes in order to stay within a 100° window; however, it is necessary that the tubes be from the same manufacturer and lot.

The window of 100° refers to variations from tube to tube at a fixed frequency, usually midband. Across the full bandwidth, same-type tubes usually track each other within a 20° window. That is to say, if the tubes are adjusted so that the phase difference at midband is zero, then the maximum variation across the band will be 20°, including the effect of fine grain ripple.

Obviously, as shown in Figure 2, a phase mismatch of 100° is not satisfactory since it would result in about 4.5 dB combining loss. One solution is to trim the tubes during manufacture to produce a closer match. This has an obvious cost penalty and does not provide compensation for mismatches in the rest of the system.

A preferred approach is to install phase shifters at the amplifier input. Broadband phase shifters are extremely stable with time and temperature and very flat across the band. The use of a phase shifter in each line permits easy adjustment to virtually perfect balance at midband and can provide adequate compensation of the worst case conditions.

Input Power Splitter	± 5°
Input Components	±20°
TWTA	±50°
Output Components	±10°
Total	±85°

Table 1. Budget of Phase Tolerances.

Based on Table 1, a 180° phase shifter in each input chain would provide sufficient range to compensate for the worst case tolerance buildup. Note that when combining, the fine grain structure for both gain and

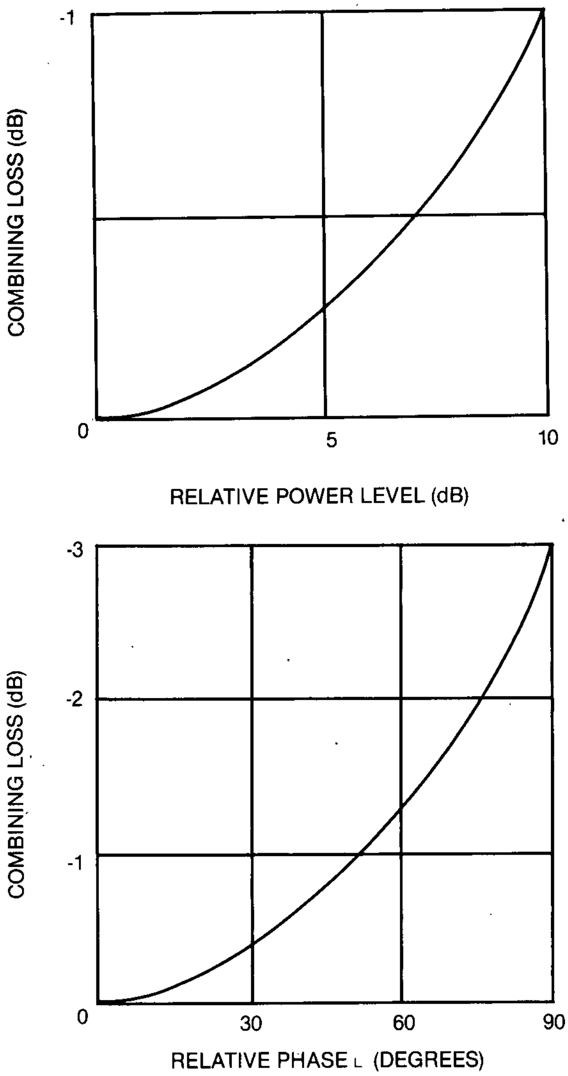

Figure 2. Power Combining Loss Curves.

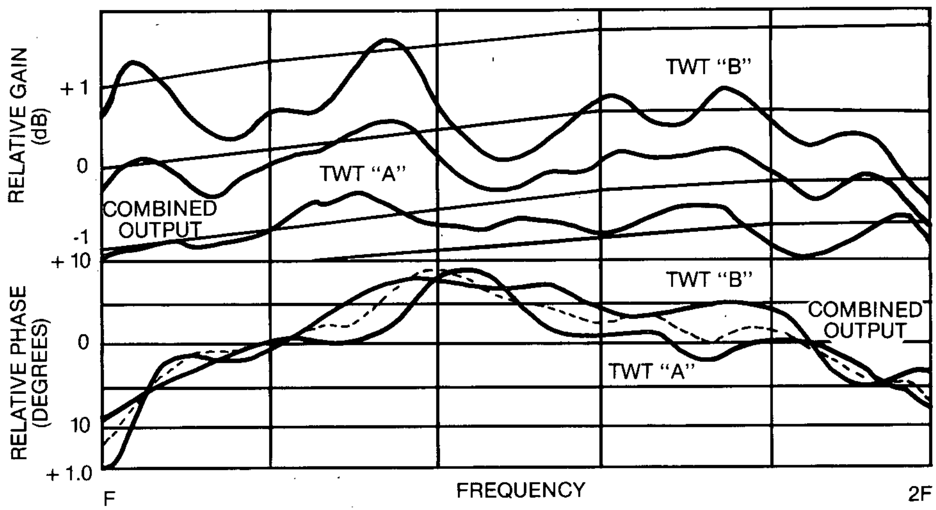

Figure 3. Operating Performance of Two Power Combined TWTs.

phase is always smoother than for an amplifier. Figure 3 shows the actual measured small signal gain for two individual TWT amplifiers and the resulting combined output. These curves clearly show the smoothing effect of combining output in the fine grain structure. The combined output gain at saturation for this particular system is +61.2 dBm at midband. The curves in Figure 3 were taken from a complete combined HPA system, including an SSIPA, not just the two TWT amplifiers. The absolute reference point for the gain of the combined system is 78 dB. The phase linearity curves clearly show the smoothing effect resulting from combining.

EQUIPMENT DESCRIPTION

The high power TWT amplifiers offered in the marketplace are power combined systems using two or four TWTAs with level and phase shift adjust components on the input branch lines. The combining tees and associated high power components are in double-ridged waveguide to ensure full octave bandwidth operation and to ensure that losses will be minimized.

Input Signal Level	+25 dBm
First Signal Split Level	+16 dBm
Second Signal Split Level	+11 dBm
TWTA Input Signal Level	+ 7 dBm
TWTA Output Signal Level	+53 dBm
First Combined Output	+56 dBm
Second Combined Output	+59 dBm

Table 2. Typical Signal Levels of an 800 Watt Power Combined System.

As shown in Figure 4, the input signal is split equally into two main branches. Each of the two branches is, in turn, applied to the input of two additional power splitters and then through a 360° phase shifter to adjust overall phase-matching.

The outputs of the power splitters are applied to the input of the TWTAs through level adjusting attenuators. The outputs of each pair of TWTAs are then combined in a magic tee to produce a nominal 400 watt output. A pair of 400 watt power combined systems can be further combined to produce an 800 watt output.

The typical relative signal levels of an 800 watt power combined system without the SSIPA option, calculated at midband, are found in Table 2. Due to the TWT characteristics, the combined power output at the band edges will be around a nominal 57.5 dBm (560W) level, increasing to around 59 dBm (800W) at 25 percent above or below the band edges. This approach results in the simplest and most reliable high power TWTA system available on the market today. ■

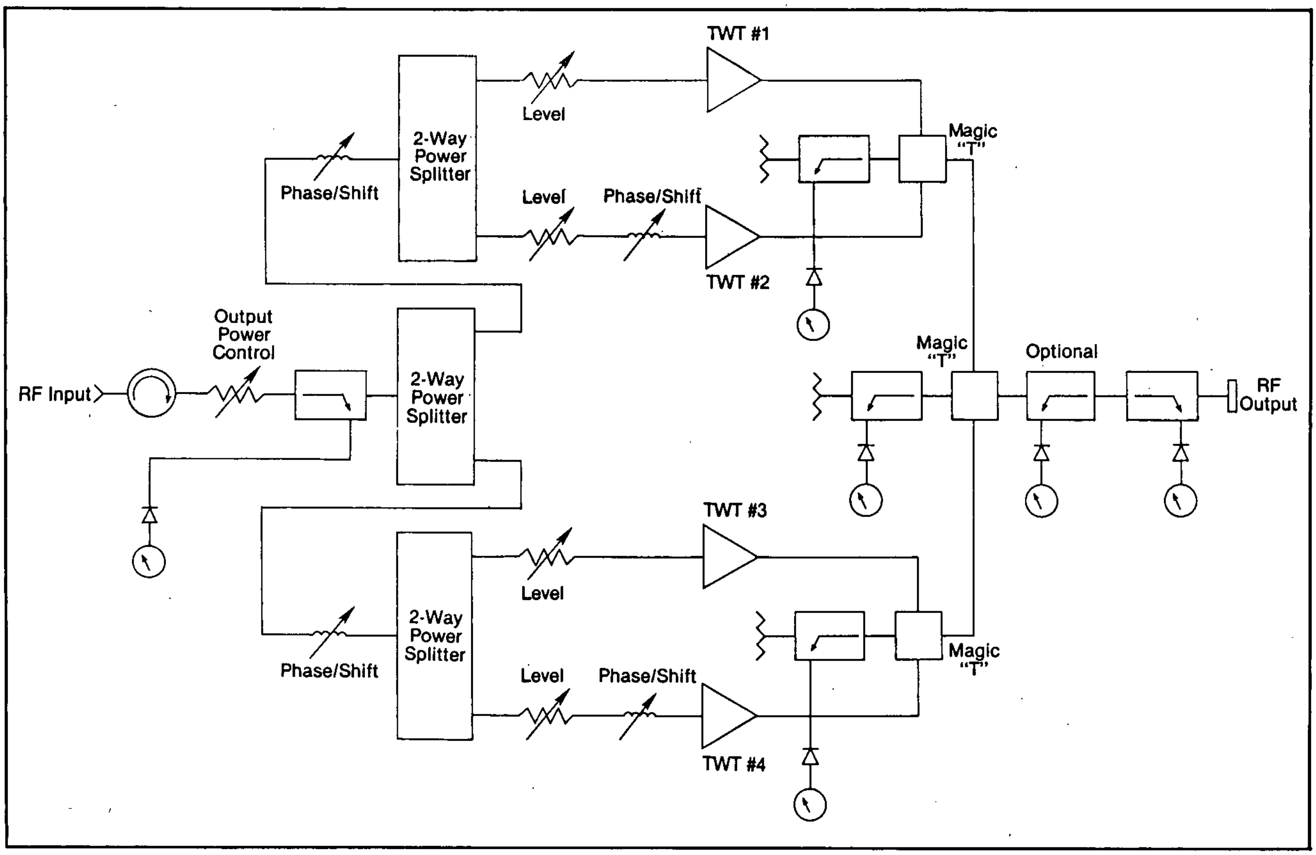

Figure 4. Block Diagram of 800 Watt Power Combined System.