# Phase Combined Amplifiers as a Means of Achieving High Output Power and Redundancy

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## ABSTRACT

High RF output power capacity and reliability are key requirements of earth station amplifiers that transmit multi-carrier traffic to satellite. This paper discusses some of the common techniques used to phase combine power amplifiers and maintain a degree of redundancy for maximum system reliability. Two classes of phase combined amplifier systems from Paradise Datacom are introduced.

## Amplifier Phase Combining

Phase combining amplifiers has long been a popular means of increasing the output power of an amplifier system. Under high power microwave conditions it is common to utilize some form of waveguide hybrid coupler to combine the output power of two amplifiers. This coupler is generally a waveguide tee such as a four port magic tee. On the input side, common coaxial power splitters can be utilized to divide the power due to the lower power levels at the input of the system. Figure 1 shows a typical block diagram of a phase combined amplifier pair. As long as the electrical delay, phase and amplitude of the two paths are kept within close tolerance of each other, the output power of the system will be twice the output power (+3dB) of a single amplifier.

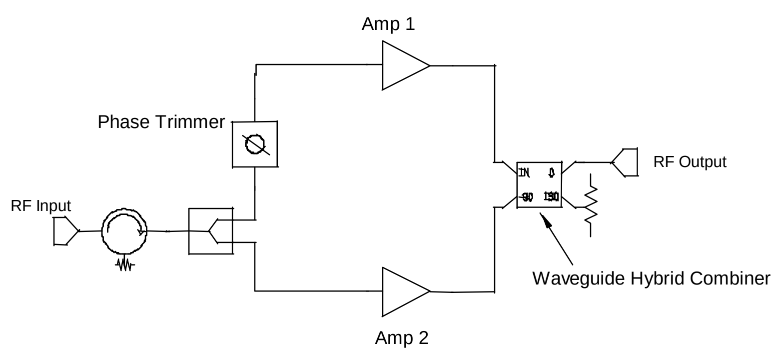


**Figure 1. Phase Combined Amplifier**

The main drawback of this approach is that in the event of an amplifier failure, the total output power decreases by 6 dB, or a factor of 4. This does not offer the system much in the way of redundant capability with such a large decrease in output power capability. The power decrease is due to the fact that with only one amplifier active, the output combiner acts as a power divider. The output power from the remaining amplifier is divided between the output of the system and the terminated port of the hybrid combiner. Thus only one half of the power from one amplifier reaches the output port which is 6 dB less than the combined output power from both amplifiers. A high power system requiring a degree of redundancy needs some means of bypassing the combiner in the event of an amplifier failure. This would allow the full output power capacity of the remaining amplifier to reach the output. In this case the total RF output power would only decrease by 3 dB from the phase combined output power. A 3 dB reduction in output power is generally more tolerable to a system's link budget thereby giving the system a degree of redundancy.

## Variable Phase Combining

The redundant phase combining of high power microwave amplifiers has historically been achieved using variable phase combiners or VPCs. The variable phase combiner has the fundamental ability to power combine two amplifiers or direct either amplifier's output to the system output. This is accomplished by placing a polarization changing device between two fixed orthogonal (three port) waveguide tees. This forms a four port hybrid with variable phase capability. By changing the polarization between the orthogonal tees, the microwave energy can be redirected among the four ports of the waveguide orthomode tees. The polarizer is a complex mechanical device that is typically controlled by a form of Geneva drive. The Geneva drive is a device that translates continuous rotary motion into fixed incremental step positions. The driven wheel is then locked into position between movements. This is similar to the mechanism used in cameras to advance the film. The VPC is then used among four basic positions of the Geneva drive, typically $0^o$, $22.5^o$, $45^o$, and $67.5^o$. The RF truth table is given in Table 1.

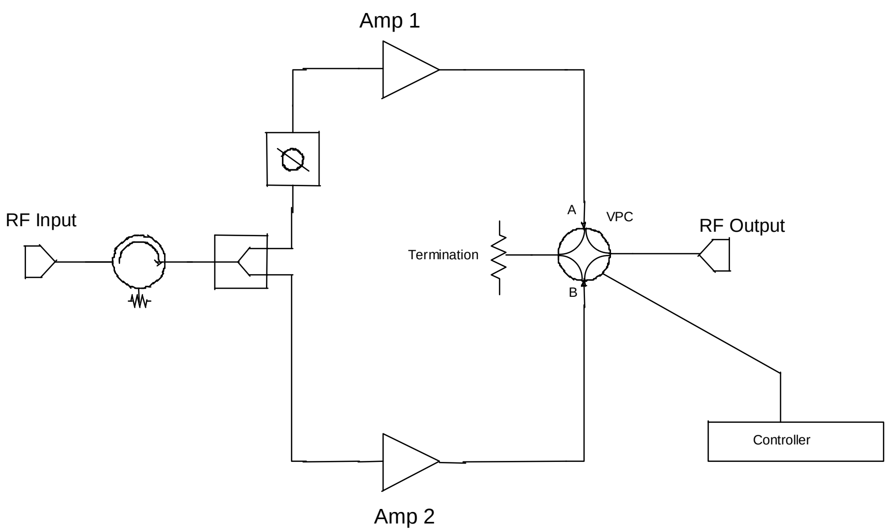


**Figure 2. Variable Phase Combined (VPC) Amplifier System**

**Table 1. VPC Polarizer Position vs. System Operation**

| VPC Position | Amplifier System Operation |
|---|---|
| $0^o$ | Amplifier 1 to RF Output , Amplifier 2 to termination |
| $22.5^o$ | Amplifier 1 and Amplifier 2 phase combined to RF output |
| $45^o$ | Amplifier 2 to RF Output, Amplifier 1 to termination |
| $67.5^o$ | Amplifier 1 and Amplifier 2 phase combined to termination |

As Table 1 shows, the VPC accomplishes the goal of either phase combining the amplifiers or switching them individually to the RF output of the system. There are, however, some drawbacks to the VPC operation. One drawback is the size of the VPC controller. The VPC itself can be quite large depending on the frequency band of operation. For example, a C Band unit is approximately 18 inches (457 mm) in length by 6.25 inches (158 mm) in width. This is nearly the size of a Paradise Datacom Compact Outdoor Solid State Power Amplifier itself. The complexity of the drive mechanism makes it difficult to weatherize the unit for outdoor usage. It is also difficult to conveniently locate a manual override control for the VPC. Due to the nature of its design, the Geneva drive mechanism has lower reliability than a waveguide transfer switch. This is a troublesome concern when considering the device's effectiveness in a redundant system. Finally the high cost associated with the VPC can be prohibitive.

## 1 for 1 Fixed Phase Combined Redundant System

The disadvantages of the VPC naturally lead the system designer to search for a technique of accomplishing the goal of phase combining and providing redundancy with common waveguide transfer switching. A technique has been developed which accomplishes this task with two simple waveguide transfer switches. A block diagram of such a system is shown in Figure 3. This type of system is sometimes referred to as a "Fixed Phase" combined system to differentiate it from the Variable Phase Combiner. This system uses a standard (four port) waveguide hybrid combiner as shown in the system of Figure 1. In the fixed phase combined system, the waveguide switches allow the amplifier outputs to either be directed into the combiner or bypass the combiner and connect directly to the RF output.

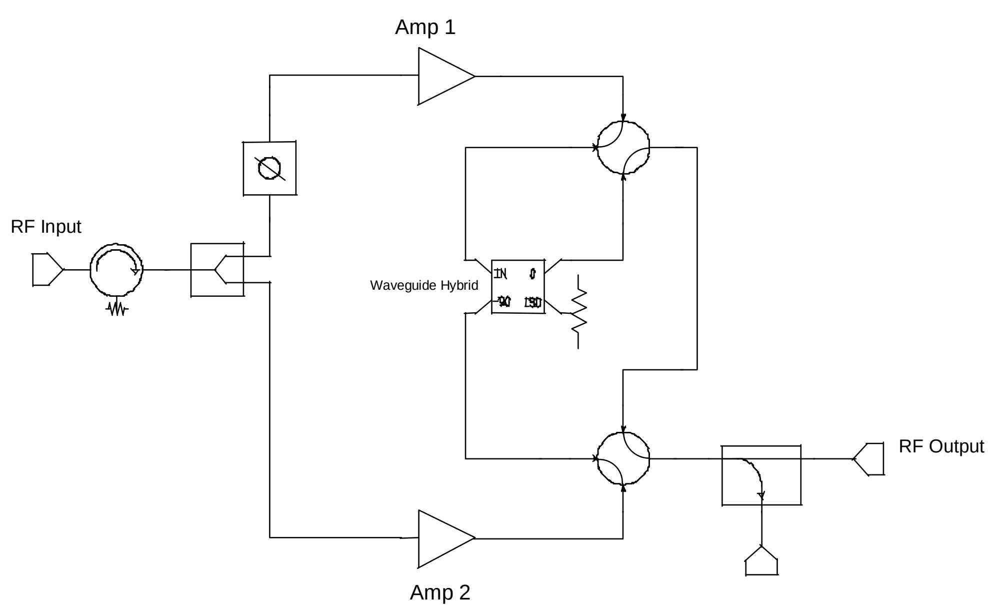


**Figure 3. 1 for 1, Fixed Phase Combined Amplifier System**

The 1 for 1 Fixed Phase Combined amplifier system uses much more commonly available components which allow this system to be manufactured at lower cost and achieve higher reliability than the VPC based system. Weatherized waveguide transfer switches can be utilized making this system very attractive in outdoor applications. Paradise Datacom has developed a controller that greatly enhances the operation of the system. The FPRC-1100 controller is the first of its kind to be designed specifically to control 1 for 1 Fixed Phase Combined redundant amplifier systems. The FPRC-1100 is a 1 RU high indoor controller that can remotely monitor and control the system. It can be used in either manual or automatic mode to monitor the amplifiers for faults and operate the transfer switches. The controller has a very user friendly interface that allows the operator to monitor the composite output power of the system and adjust the gain of the amplifiers in 0.1 dB increments over a 20 dB range. The controller adjusts each amplifier in the system and keeps the amplitude of each balanced for optimal power combining. To the operator, the system appears as a single amplifier. The operator can choose between using the system as a phase combined system or a traditional 1:1 redundant system. Using Solid State Power Amplifiers from Paradise Datacom, 1 for 1 phase combined systems can be configured from power levels of 200W to 2kW at C Band and 80W to 850W at Ku Band. A complete listing of configurable output power levels are summarized in Tables 1 and 2.

The 1 for 1 phase combined redundant system is an excellent cost effective means of achieving high output power with redundancy. In many cases the system is used as a traditional 1 for 1 redundant system with the ability to occasionally phase combine the system during periods of operation that may require higher output power.

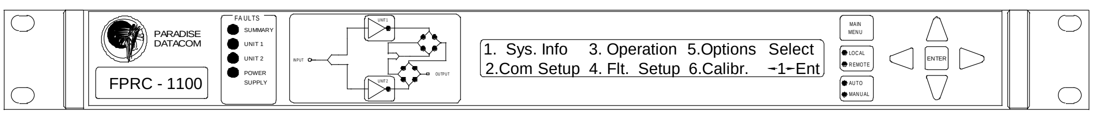


**Figure 4. FPRC-1100, 1 for 1 Fixed Phase Combined Redundancy Controller**

**Table 2. FPRC-1100 System C- Band Output Power Levels vs. Single Thread Amplifier Model**

| Amplifier Model | 1:1 Redundant Output Power | | Phase Combined Output Power | |
|---|---|---|---|---|
| | $P_{sat}$ dBm (W) | $P_{1dB}$ dBm (W) | $P_{sat}$ dBm (W) | $P_{1dB}$ dBm (W) |
| HPAC-2100A | 49.9 (98) | 49.4 (87) | 52.8 (191) | 52.3 (170) |
| HPAC-2140A | 51.4 (138) | 51.1 (129) | 54.3 (269) | 54.0 (251) |
| HPAC-2200A | 52.9 (195) | 52.3 (170) | 55.8 (380) | 55.1 (323) |
| HPAC-2250A | 53.8 (240) | 52.9 (195) | 56.7 (468) | 55.8 (380) |
| HPAC-2300A | 54.6 (288) | 53.9 (245) | 57.5 (562) | 56.8 (479) |
| HPAC-2400A | 55.9 (389) | 54.9 (309) | 58.8 (759) | 57.8 (603) |
| HPAC-2500A | 56.9 (490) | 55.9 (389) | 59.8 (955) | 58.8 (759) |
| HPAC-2600A | 57.7 (590) | 56.9 (490) | 60.6 (1148) | 59.8 (955) |
| HPAC-2750A | 58.6 (725) | 57.8 (603) | 61.5 (1413) | 60.7 (1175) |
| HPAC-2900A | 59.4 (871) | 58.4 (692) | 62.3 (1700) | 61.3 (1349) |
| HPAC-21100A | 60.3 (1071) | 59.4 (871) | 63.2 (2089) | 62.3 (1700) |

**Table 3. FPRC-1100 System Ku- Band Output Power Levels vs. Single Thread Amplifier Model**

| Amplifier Model | 1:1 Redundant Output Power | | Phase Combined Output Power | |
|---|---|---|---|---|
| | $P_{sat}$ dBm (W) | $P_{1dB}$ dBm (W) | $P_{sat}$ dBm (W) | $P_{1dB}$ dBm (W) |
| HPAK-2040A | 45.9 (39) | 44.9 (31) | 48.8 (76) | 47.8 (60) |
| HPAK-2050A | 46.9 (49) | 45.9 (39) | 49.8 (96) | 48.8 (76) |
| HPAK-2070A | 48.4 (69) | 47.4 (55) | 51.3 (135) | 50.3 (107) |
| HPAK-2100A | 49.9 (98) | 48.9 (78) | 52.8 (190) | 51.8 (151) |
| HPAK-2125A | 50.9 (123) | 49.9 (98) | 53.8 (240) | 52.8 (190) |
| HPAK-2200A | 52.9 (195) | 51.9 (155) | 55.8 (380) | 54.8 (302) |
| HPAK-2250A | 53.9 (246) | 52.9 (195) | 56.8 (479) | 55.8 (380) |
| HPAK-2350A | 55.4 (347) | 54.4 (275) | 58.3 (676) | 57.3 (537) |
| HPAK-2450A | 56.4 (437) | 55.4 (347) | 59.3 (851) | 58.3 (676) |

## 1 for 2 Fixed Phase Combined Redundant System

Although the 1 for 1 Fixed Phase Combined Redundant System can be an attractive configuration for many systems, certain applications are sensitive to any decrease in output power capability in the event of an amplifier failure. For such applications the 1 for 2 Fixed Phase Combined Redundant System has been developed. This system is comprised of three amplifiers in which one operates in continuous standby for two phase combined units. A block diagram of this system is shown in Figure 5. The 1 for 2 System overcomes the 3 dB decrease in RF output power in the event of an amplifier failure. Normal operation of the system has amplifier 1 and amplifier 2 phase combined through the waveguide hybrid combiner. The standby amplifier can be switched in place of either amplifier 1 or amplifier 3 and no loss of system output power is experienced. The system operation is completely automatic, requiring no adjustment of amplifier amplitude or phase.

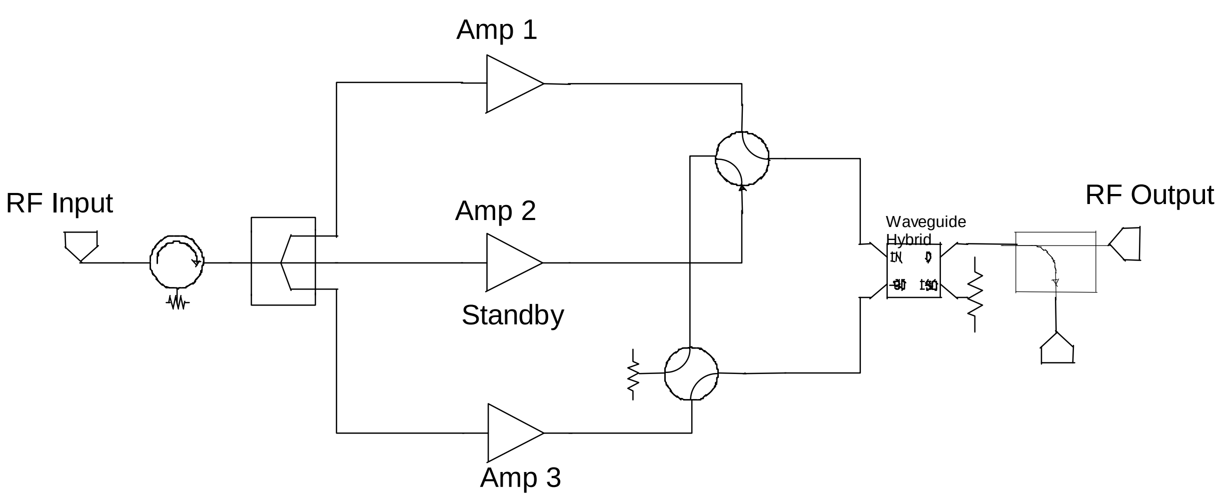


**Figure 5. 1 for 2, Fixed Phase Combined Amplifier System**

The 1 for 2 System is controlled by the FPRC-1200 system controller. The FPRC-1200 is a 1 RU high indoor controller that can provides both local and remote control of the system. It can be used in manual or automatic mode to monitor the amplifiers' fault status and operate the transfer switches. Like the FPRC-1100 the FPRC-1200 can monitor the system output power and control the amplifiers. The simply programs a single overall gain level for the system and the controller handles the task of adjusting each of the three amplifier's gain and maintain optimum output power combining. These systems are configurable with the same phase combined output power levels given by Tables 1 and 2. However in the event of a failure, there is no reduction in RF output power capability. Figure 7 shows a 1 for 2 phase combined system using (3) 200W C Band Compact Outdoor Amplifiers. The composite system output power is 400W. The simplified construction and robust nature of this phase combining technique make it ideally suited to outdoor installations such as new gathering vehicles.

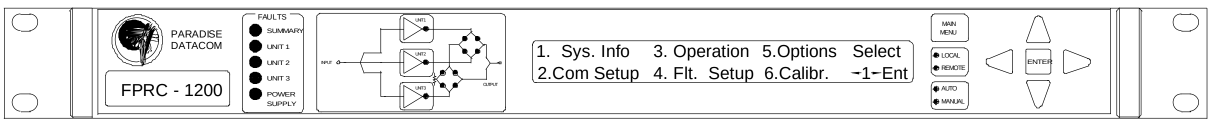


**Figure 6. FPRC-1200, 1 for 2 Fixed Phase Combined Redundant Controller**

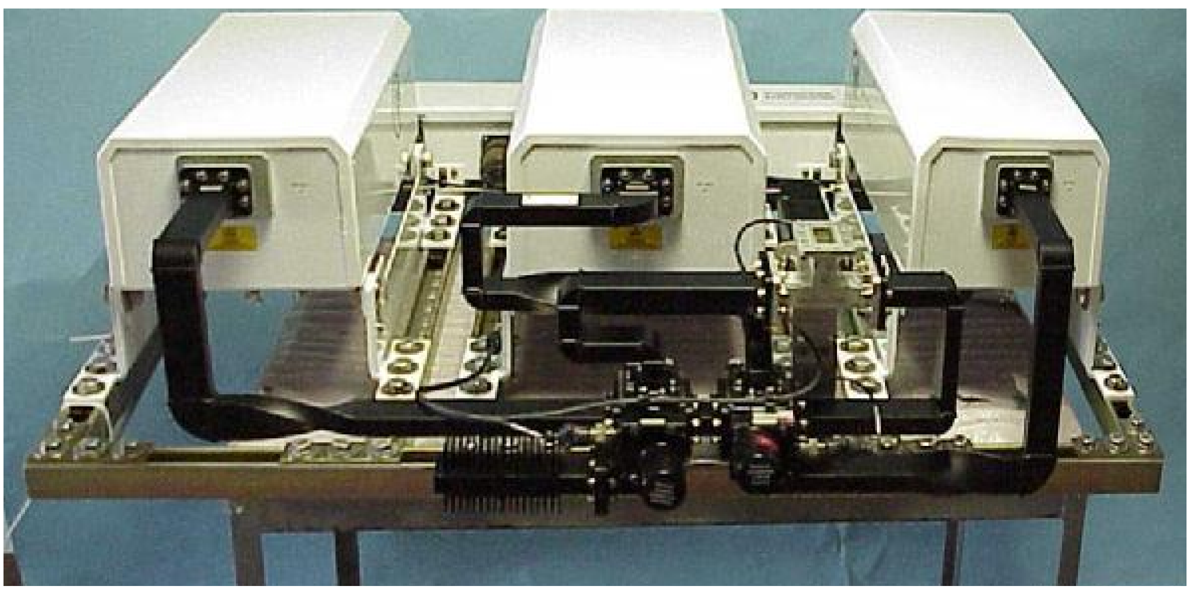

**Figure 7. C Band 400W, 1 for 2 Fixed Phase Combined Redundant System**

## 1 for 2 Fixed Phase Combined Redundant System Cost Advantages

At first it might seem that the 1 for 2 Fixed Phase Combined System may be cost prohibitive because it requires a third amplifier. There is however a cost advantage to the 1 for 2 system topology. If it is intended that a 1 for 1 redundant system should be specified for a given earth station application, the user should compare this to a 1 for 2 Fixed Phase Combined System using amplifiers of one half the required output power. The 1 for 2 system has a two-fold cost advantage from both the initial purchase price of the equipment and the electricity to operate the system based on the efficiency advantage of the 1 for 2 system. When using the 1:2 Fixed Phase Combined System in place of a traditional 1 for 1 system, there is typically a 10% to 20% savings in the initial purchase price of the system. Table 4 summarizes this comparison for one C Band and one Ku band system.

**Table 4. 1 for 2 Phase Combined System Costs vs. Traditional 1 for 1 System Costs**

| Amplifier System | Approximate Initial Equipment Costs | System AC Input Power | 5 Year Cost of Electricity |
|---|---|---|---|
| C Band 500W 1 for 1 Redundant System comprised of (2) 500W Indoor SSPAs | $105,000.00 | 5778 W | $33,500.00 |
| C Band 500W 1 for 2 Fixed Phase System comprised of (3) 250W Indoor SSPAs | $94,000.00 | 4384 W | $25,128.00 |
| Ku Band 200W 1 for 1 Redundant System comprised of (2) 200W Indoors SSPAs | $113,000.00 | 5646 W | $28,000.00 |
| Ku Band 200W 1 for 2 Fixed Phase System comprised of (3) 100W Indoor SSPAs | $108,000.00 | 4250 W | $23,454.00 |

## Summary

Two classifications of Phase Combined Redundant Systems have been presented. The 1 for 1 Phase Combined System is a cost effective alternative to the traditional 1 for 1 redundant system. It is beneficial to have the extra 3 dB power reserve that can be utilized when needed. Alternatively it can be viewed as a high power system with a degree of soft fail capability similar to the older generation VPC systems. The 1 for 2 Phase Combined System can be used in applications where no reduction in output power can be tolerated. Alternatively it can be viewed as a cost effective substitute for a traditional 1 for 1 redundant system. Together they give the earth station engineer greatly flexibility in configuring reliable high power microwave amplifier systems.

Paradise Datacom designs and manufactures a variety of Phase Combined Redundant Systems in S, C, X, and Ku bands. High power Phase Combined Systems using solid state power amplifier technology are an effective and reliable replacement for TWTA and Klystron tube amplifiers. These systems are assembled in both indoor and outdoor systems. They can also be configured with block up converters at the RF input so that the system can accept L band inputs in the 950 to 1750 MHz range. Contact the factory for more information or a quotation at +1.814.466.6275 or email **sales@paradisedata.com**.

## REFERENCES


[1] Redundant System Controller Operations Manual, "201138 Revision C", Paradise Datacom LLC, September 2002.
[2] Solid State Power Amplifier Operation Manual, 201627, Paradise Datacom LLC, December 2002.


Author Biography

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Stephen Turner is the VP of Engineering for Paradise Datacom LLC in Boalsburg, PA. USA. He has been involved in the design of microwave components including: oscillators, amplifiers, and converters for over twenty years. He has developed some of the industry's first C band solid state power amplifiers producing power levels in excess of 1kW. Stephen received the BS degree in Electrical Engineering from the University of Pittsburgh and the Master of Engineering degree from the Pennsylvania State University. A registered Professional Engineer in Pennsylvania, Stephen is a member of the IEEE Microwave Theory and Techniques Society, Radio Amateur Satellite Corporation (AMSAT) and the Quarter Century Wireless Association (K3HPA). He can be reached at **sturner@paradisedata.com**.