A POWER COMBINER FOR STEP LEVEL HIGH POWER UHF SOLID STATE TRANSMITTERS

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Summary A combining network is described which satisfies the requirements of low loss, compact size and input port selection capability. This power combiner, which follows a basic network scheme suggested by E. J. Wilkinson, uses helical wound quarter wave lines for impedance matching, relays for switching inputs in or out, and thick film resistors in the isolation network. The combiner was designed for a UHF solid-state transmitter for a communications satellite. The power level is in excess of 300 watts. From 8 to 16 inputs, from coherently driven power amplifiers, can be selected by command. This step level feature provides a very useful means to achieve maximum utilization of prime power as well as an improvement in reliability through redundancy.

Design equations are given for the units. The results of a computer study of losses due to unequal input phases and amplitudes are presented. The equivalent circuit of the network, including parasitics, is described and the compensating elements are discussed.

Tests have been made on the completed flight unit, and these results are plotted and discussed.

Introduction The power combiner described herein is part of a UHF solid-state transmitter for a communication satellite. Sixteen amplifiers are used to drive a single antenna line. The number of amplifiers in use can be selected by command in accordance with the available prime power from the solar cell array. The power combiner must meet the following specifications:

Power output	in excess of 300 watts
Inputs	8 to 16
Single frequency, f_o	between 225-275 MHZ
Insertion loss	$\leq$ 0. 3 db
Isolation between ports	$\geq$ 35 db
VSWR (8 to 16 inputs)	$\leq$ 1. 5:1

The design was derived from a basic network described by E. J. Wilkinson. A schematic of this network with the design equations is shown in Figure 1.

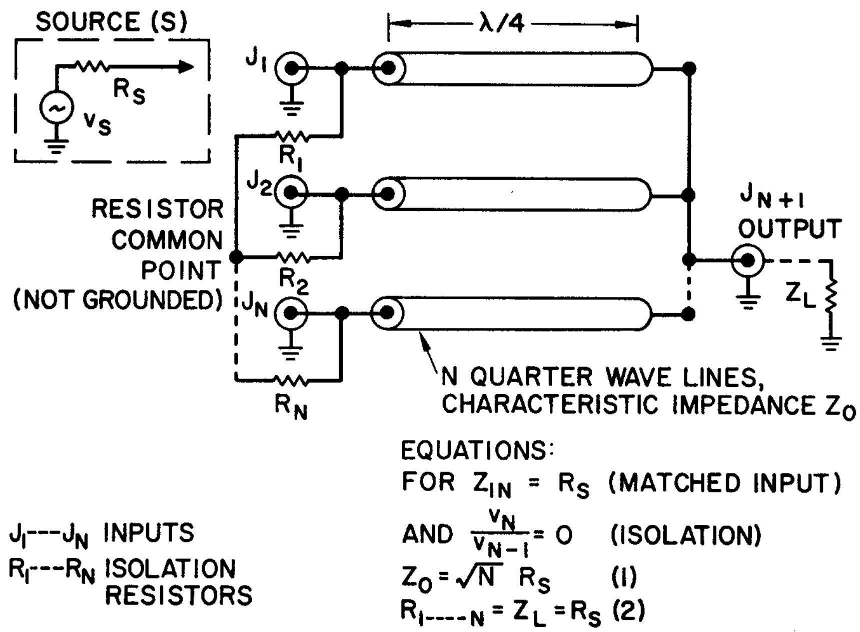


Figure 1. Schematic and design equations for the basic combiner

Design Let $R_S = Z_L = 50\Omega$, and let m be the number of active ports. Let m_o be the value of m at which the design is optimized. For this design, optimized at $m_o = 12$, the required quarter wave line impedance is $50 \times \sqrt{12} = 173$ ohms. If all the inputs have equal amplitude and phase, the voltage at each isolation resistor is the same and the isolation network draws no current. In this case the impedance seen by each amplifier is:

$$Z_{in} = \frac{1}{m} \cdot \frac{Z_o^2}{Z_L}$$

where

Z_{in} is the input impedance to each line
Z_o is the characteristic impedance of each line
Z_L is the common port load impedance

For this design

$$Z_o = 173$$
$$Z_L = 50$$

A plot of input VSWR versus m is shown in Figure 2. The input VSWR is simply m_o/m for $m \geq m_o$, or m/m_o for $m \geq m_o$. These VSWR's are the limiting factors on the possible variation of m in a stepped level combiner. The frequency dependent characteristic of the design is determined by the quarter wave lines and the lumped elements. This characteristic is shown in Figure 2b.

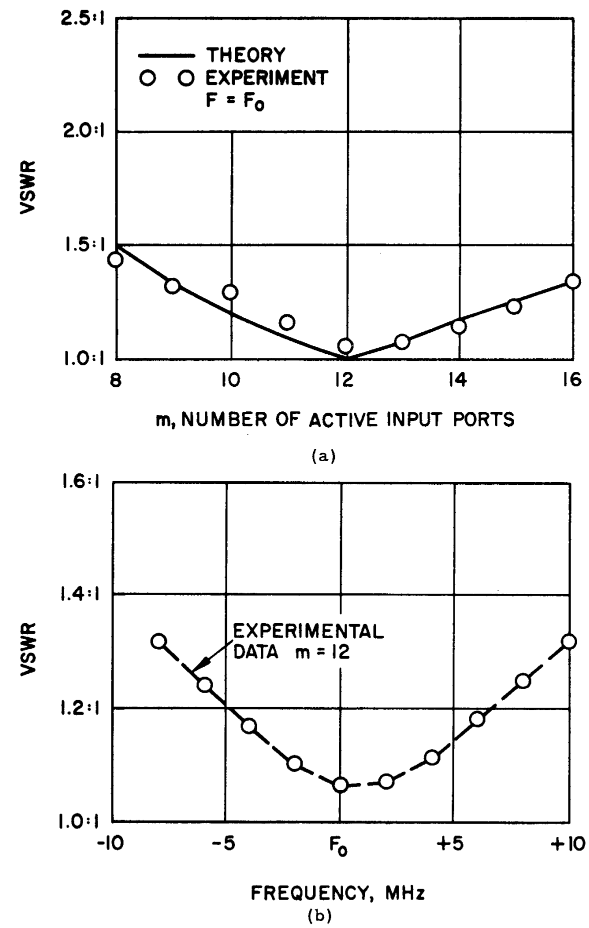


Figure 2. VSWR versus m and VSWR versus frequency

The loss encountered due to non-equal phase and amplitude of the inputs was investigated with a computer model of the combiner. The results are shown in Table 1. “Biphase” refers to a situation in which one-half the inputs are at one phase, φ_1, and the other half are at φ_2 , and $\varphi_2 - \varphi_1 = \theta$. This represents the worst case solution to the problem in which the phases of the input signals are randomly spaced between φ_2 and φ_1. The loss due to amplitude variation was computed in a similar manner.

The equivalent circuit of one of the 16 sections of the combiner is shown in Figure 3, including the relay used to switch ports in or out. A useful equivalent circuit for the relay was found to be the pi network composed of C_2, L_4, C_3. These parasitic reactances, as well as the resistor lead inductance, L_5, were shunt and series resonated by L_1, L_2, and C_1.

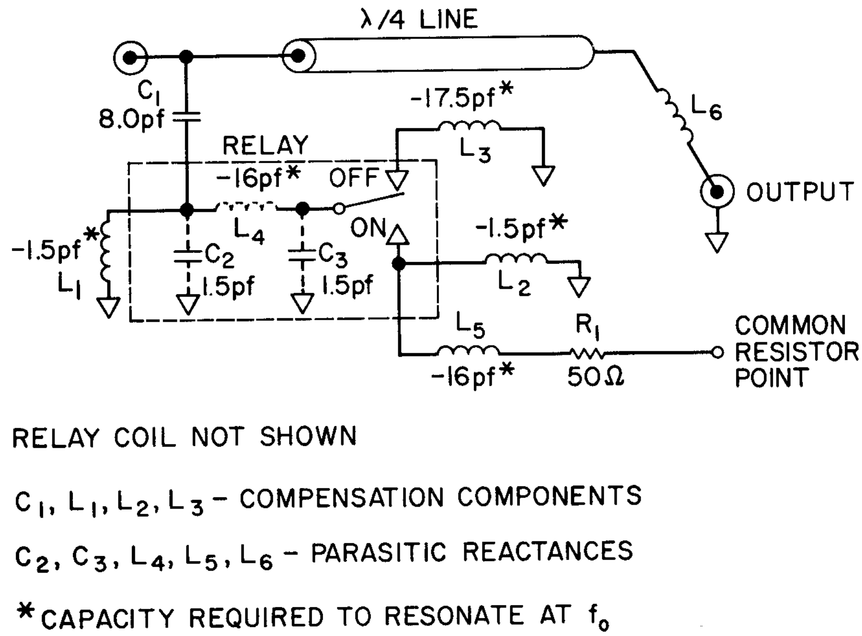


Figure 3. Equivalent circuit of one of the 16 combiner sections

Resistors The resistors are of the thick film type, deposited on a 20 mil thick alumina substrate. The substrate is metalized on the underside and soldered with SN 96(430°F) to a beryllia block which is also metalized on the top and bottom surfaces. The combination is then soldered to the base plate, using a SN63 (361°F) solder.

A resistor fabricated in this way has been tested at 45 watts in vacuum with no failure. Using an abrasive etching technique, the resistors are trimmed to a tolerance of 1 percent.

Quarter Wave Lines and Construction Air lines for this application are unsatisfactory because of multipactor breakdown in vacuum and because of the thermal rise in the thin center conductor, The combiner described here uses coaxial lines with helical center conductors. These lines shown in Figure 4 are only 1.3 inches long.

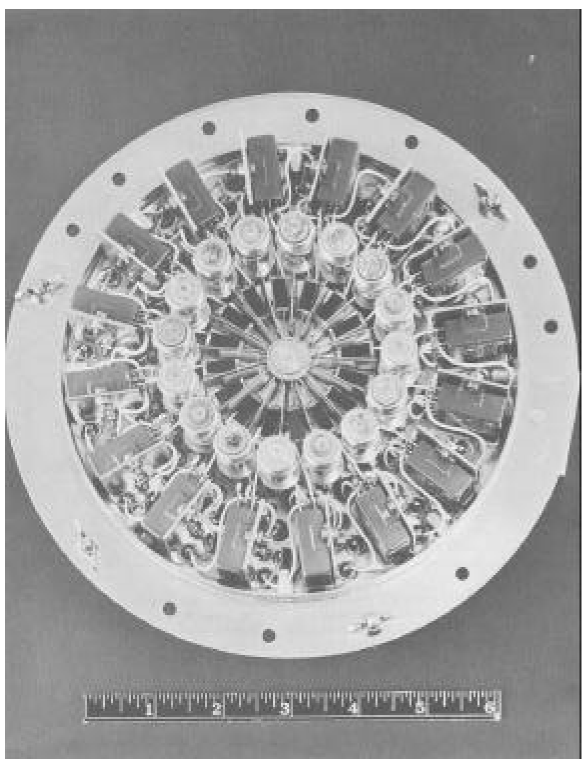
Because of the heat capacity and short length of helix wire and the teflon center support and sleeve, multipactor and thermal problems are greatly alleviated compared to an ordinary coaxial line.

A pho tograph of the flight unit is shown in Figure 5. All surfaces are copper and gold. plated, and the entire unit is foamed with a 4-pound closed cell foam for mechanical strength and breakdown resistance.

Test Results The unit has been operated at full power with satisfactory performance. Curves of common port VSWR versus m and frequency are shown in Figure 2. Insertion loss, isolation and input port VSWR are given in Table 2.

Left to right: Helical center conductor would on threaded teflon mandrel, teflon sleeve, threaded out tube.
Center: complete line

Figure 4. Helical quarter wave line



Top view, cover, output connector removed. From inside out: resistor common point, resistors, transmission lines, relays.

Figure 5. Photograph of completed combiner

Table 1. Losses due to non-equal input phases and amplitudes
Phase variation ("Biphase")

θ	Loss, DB = $10 \log \frac{P_{DISS}}{P_{AVAIL}}$
5°	0.01
10°	0.04
15°	0.06
20°	0.12

Amplitude variation

$\left(\frac{A_2}{A_1}\right)^2$, DB	Loss, DB = $10 \log \frac{P_{DISS}}{P_{AVAIL}}$
0.5	0.0035
1.0	0.013
1.5	0.029

Table 2. Test results

Average insertion loss (m = 16)	– 0.23 DB
Average isolation (m = 16)	– 37 DB
Average input port VSWR*	– 1.37:1

*This VSWR depends primarily on the resistor network. The average VSWR seen by each amplifier is equal to the common port VSWR if all amplitudes and phases are equal.

Conclusions The unit described here offers a flexible design for space age high power transmitters. In contrast to "rat race" hybrid type combiners, only n quarter wave lines are required for n inputs. The use of spiral lines offers the advantages of small size, good heat sinking, and resistance to breakdown problems. Experimental results check closely with the theory.

The step level command feature also provides a very useful means to achieve maximum utilization of prime power as well as an improvement in reliability through redundancy.

Reference E. J. Wilkinson, "An N-Way Hybrid Power Divider, IRE Transactions on Microwave Theory and Techniques, pp. 116-118, January 1960.