

MULTIWAY PLANAR MICROSTRIP POWER COMBINER / DIVIDER FOR SOLID-STATE MICROWAVE POWER AMPLIFIER APPLICATIONS.

Field of the Invention

The invention relates to a microwave planar microstripline power divider/combiner for application in parallel combined power amplifiers.

Background of the Invention

There are many microwave radar and communication applications which require the transmission of levels of microwave power of the order of hundreds of Watt. In the past, this has been achieved by the use of microwave vacuum tubes, such as the Magnetron, Travelling Wave Tube, etc. The current trend is to supersede vacuum tubes with solid-state microwave transistors, such as the GaAs FET. Unfortunately, the power levels that can be obtained from GaAs Power FETs at microwave frequencies are limited to the order of a Watt; far short of that which can be obtained from the vacuum tube counterparts. To overcome this output power limitation of microwave transistors, power combining is thus necessary to obtain high output powers.

A parallel combined power amplifier consists of a power divider at the input, followed by n identical amplifier modules, and finally a power combiner. The input signal is first divided equally n ways by the power divider. The n equal signals are then amplified by n identical amplifier modules. The signals appearing at the outputs of the n amplifier modules are then combined in-phase at the output using the power combiner. Using this approach, the burden of amplification can be shared between n identical amplifier modules. To ensure in-phase combining at

the output, it is necessary that the n forward transmission paths are identical in both magnitude and delay (phase). This requires that the amplifier modules are identical, the input signals to the amplifier modules have equal amplitude and phase, and that equal signals appearing at the outputs of the amplifier modules add constructively at the output. This approach has been proven in practice using waveguide type power dividers and combiners.

Since waveguide components are heavy, bulky, and expensive to manufacture, it is desirable to use power combiners and dividers realised in microstripline. Microstripline technology consists of a dielectric layer, with a thin conductor layer bonded to one side etched to form the planar circuit geometry, and another conductor layer bonded to and entirely covers the reverse side forming the ground plane (current return). Microstripline structures are therefore fabricated similar to conventional printed circuit boards (PCBs), making them light-weight and economical. Further, dividers and combiners realised in microstripline would be compatible with the solid-state amplifiers modules since they are also realised in a microstrip medium, therefore allowing integration of divider, combiner and amplifier modules.

For the sake of convenience, for the rest of this document (unless otherwise stated), the term power divider will be used. It is however understood that a divider can be used as a combiner when the roles of the input port and output ports are reversed.

With reference to Figure 1, a multiway tapered planar microstripline divider 1, typical of the prior art (M. D. Abouzahra & K. C. Gupta, "Multiport power divider-combiner circuits using circular-sector-shape planar components", IEEE Trans. on Microwave Theory and Techniques, Vol. 36, No. 12, Dec, 1988, pp 1747-1751.), consists of an input port 2, connected to the narrow end 6 of a tapered section of microstripline 3, and a plurality of external output ports 4 connected via a plurality of microstriplines 9 to a plurality of internal output ports 7 evenly spaced around the wide end 5 of the tapered section of microstripline 3. As the wavefront of the

signal propagates from the input 2 to the wide end 5, it will become curved in the plane of the divider 1. To ensure that the output signals are in-phase, the wide end 5 is necessarily curved, and the length of the microstriplines 9 are all equal in length. Although only five output ports are shown in Figure 1, any number greater than one is possible.

There have been several variations of this basic planar structure (M. D. Abouzahra & K. C. Gupta) that have been reported in the scientific literature (eg. M. Miyazaki, O. Ishida & T. Hashimoto, "N-Way Sectorial Hybrid Power Divider Design Using Boundary Element Method", *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering*, Vol. 3, No. 3, 1993, pp175-182 ; P. S. Kooi, M. S. Leong, T. S. Yeo & S. M. Krishnaswami, " A Multi-way Broadband Sectorial Power Divider Using Exponential Taper", 1995 Asia-Pacific Microwave Conference, KAIST, Taejon, Korea, 9 - 13 October 1995, pp48 - 51.) and patented (eg. J. M. Schellenberg & W. Yau, "Power Divider/Combiner Circuit", US Patent No. 4,835,496, 30 May 1989; P. W. Hoare, "Broad Bandwidth Planar Power Combiner/Divider Device", US Patent No. 4,968,958, 6 Nov. 1990.). Such modifications include different taper functions for the tapered section 3 to increase the bandwidth (eg. J. M. Schellenberg & W. Yau; M. Miyazaki, O. Ishida & T. Hashimoto; P. S. Kooi, M. S. Leong, T. S. Yeo & S. M. Krishnaswami), addition of resistances to reduce output port coupling (eg. J. M. Schellenberg & W. Yau; M. Miyazaki, O. Ishida & T. Hashimoto), or forking of the tapered section 3 to improve the frequency response (eg. J. M. Schellenberg & W. Yau; P. W. Hoare). A common feature with these previously proposed structures is that the internal output ports 7 must be located on a curved periphery at the wide end 5 if the output signals are to be in-phase. Further, the previously proposed dividers have only been demonstrated for a maximum of 5-way division.

With reference to Figure 2, the problem encountered with the previously proposed dividers becomes apparent in the parallel combined power amplifier application. To ensure in-phase power combining, the interconnection transmission lines 10a and 10b, that connect the individual amplifier modules 12

to the power combiner and dividers, must be of equal length. Since the internal output ports (Figure 1, 7) are located on a curved boundary (Figure 1, 5), meandering of the interconnection transmission lines 10a and 10b is therefore necessary and becomes more exaggerated for the central amplifier modules. This problem is exacerbated when the number of amplifier modules 12 to be combined increases.

Object of the Invention

It is the object of the invention to provide a multiway tapered planar microstrip power divider whose equal-amplitude, in-phase output ports are co-linearly located such that meandering of interconnection transmission lines is not required when employed as the divider and combiner in a parallel combined power amplifier. Another object of this invention is to provide a multiway tapered planar microstripline divider with many output ports (greater than say 6). Another object of the invention is to provide a multiway divider whose input reflection coefficient is minimised. Another object of the invention is to provide a multiway divider whose performance is not dependent on additional resistances.

Summary of the Invention

The proposed divider can be realised in either microstripline or stripline technology. The conductor pattern of the divider 1 essentially consists of a tapered section 3 with symmetrically disposed holes 8, with the input port 2 at the narrow end 6, and the internal output ports 7 equally spaced and symmetrically disposed across the linear wide end 5. The symmetrically disposed holes 8 ensure that the output signals obtained from the co-linear internal output ports 7 have equal amplitude and are in-phase over the bandwidth of the divider. In effect, the holes 8 ensure that a wavefront propagating from the narrow-end 6 to the wide end 5 will essentially remain uniform and perpendicular with the divider

axis (centre line). The taper function used to define the outline of the tapered section 3 is chosen to minimise input port 2 reflection coefficient.

The purpose of this invention is therefore to eliminate the necessity of meandering of the interconnection transmission lines between the amplifier modules and the divider and combiner as highlighted in Figure 2. In addition the proposed invention does not require the use of resistances, therefore: i) improving the graceful performance degradation in the event of individual amplifier module failure; ii) lowering the cost; and iii) ensuring repeatability during manufacture. Further, to improve efficiency, the reflection coefficient of the input port is minimised over the bandwidth of the divider. An additional objective of this invention is that it is suitable for the realisation of n -way power division where n is a large number (10 or more).

For efficient operation of the parallel combined power amplifier, the input reflection coefficient of the divider should be as small as possible over the required bandwidth, and the n transmissions from the input port to the n output ports should be identical in magnitude and delay over the required bandwidth.

Brief Description of the Drawings

The present invention will be now explained and described with reference to the following drawings:

Figure 1 is a plan view of the conductor outline of a known example of a multiway tapered planar microstripline power divider/combiner (M. D. Abouzahra & K. C. Gupta). Note that the in-phase internal output ports 7 are located on a curved boundary.

Figure 2 is a diagram depicting the application of the known example of a multiway tapered planar microstripline power divider 1a and power combiner 1b in

a parallel combined power amplifier. This diagram illustrates the need for meandered interconnection transmission lines **10a** and **10b**.

Figure 3 is a plan view of the conductor outline of an embodiment of a multiway tapered planar microstripline power divider/combiner made in accordance with the present invention. Note that the in-phase divider output (combiner input) internal output ports **7** are co-linear.

Figure 4 is a diagram depicting the application of the embodiment **1a** and **1b** in a parallel combined power amplifier. Note that the interconnection transmission lines **10a** and **10b** are not required to be meandered.

Figure 5 is a diagram depicting the application of the embodiment **1a** and **1b** in a parallel combined power amplifier with an alternative layout used to accommodate wide amplifier modules **12**. Note that the interconnection transmission lines **10a** and **10b** can be routed in a uniform manner without the need for meandering.

Modes for Carrying Out the Invention

Figure 3 shows an embodiment of the proposed planar microstripline divider **1**, and consists essentially of a tapered section of microstripline **3** with symmetrically disposed holes **8** and has a linear wide end **5** which is perpendicular to the axis; an input port **2** connected to the narrow end **6**; and a plurality of external output ports **4** connected via a plurality of microstriplines **9** to a plurality of internal output ports **7** evenly spaced across the said linear wide end **5**. As the wavefront of the signal propagates from the input **2** to the wide end **5**, the symmetrically disposed holes **8** (etched in the conductor pattern) ensure that it will essentially remain uniform and perpendicular to the centre line. At least one such hole **8** is required with the total number being arbitrary and sufficient to ensure that the output signals have equal amplitude and delay at the given frequency or band of frequencies. The shape of the holes is arbitrary and are shaped such that

symmetry about the centre line is maintained and to ensure that the output signals have equal amplitude and delay at the given frequency or band of frequencies. An alternative way to interpret the role of the holes 8 is to note that they act as obstacles to the otherwise shortest (central) transmission paths, therefore equalising all transmission paths. The length of the microstriplines 9 connecting the external output ports 4 to the internal output ports 7 on the wide end 5 are all equal in length. The taper function of the outline of the tapered section 3 is arbitrary but is chosen to ensure smooth transition from the narrow end 6 to the wide end 5, and to a large extent influences the frequency response and hence bandwidth of the input match of the divider input port 2. Although only 5 output ports are shown in Figure 3, any number greater than one is possible.

The previous paragraph highlights the essential features. Variations include:

- i) Step change in microstripline width between the input port 2 and the narrow end 6 of the tapered section 3. This step change in microstripline width can be optimised to improve the bandwidth of the input match at the input port 2.
- ii) Tapering of the microstriplines 9 which connect the external output ports 4 to the internal output ports 7, to make a smooth transition to the wide end 5 of the tapered section 3. The purpose of this modification is to improve output port match.

Further, the divider structure described above can be realised in stripline technology consisting of a thin conductor pattern, with planar geometric attributes as described above, that is sandwiched between two dielectric layers of equal thickness which are in-turn sandwiched between two conducting layers which form the ground planes.

With reference to Figure 4, the advantage of the proposed divider over the previously proposed dividers becomes apparent in the parallel combined power

amplifier application. When the proposed divider is employed in a parallel combined power amplifier, there is no need to meander the interconnection transmission lines 10a and 10b.

When the amplifier modules 12 are too wide for the parallel combined power amplifier layout suggested in Figure 4, alternative layouts can be used, such as that suggested in Figure 5. Referring to Figure 5, the interconnection transmission lines 10a and 10b are routed in such a manner so as to accommodate wide amplifier modules 12 as well as ensuring equal transmission paths between the output ports 4a of the divider 1a, and the input ports 4b of the combiner 1b. The co-linear location of the output ports 4a of the divider 1a, and the input ports 4b of the combiner 1b, allows such routing of the interconnect transmission lines 10a and 10b to be achieved with a uniform layout geometry.

During the design of such divider structures (Figure 3, 1), the *planar circuit (contour integral)* approach for the analysis can be used (T. Okoshi & T. Miyoshi, "The planar circuit - an approach to microwave integrated circuit", IEEE Trans on Microwave Theory and Techniques, Vol. 20, No. 4, April 1972, pp 245-252.), which can be incorporated into an optimisation loop. Theoretically any optimisation algorithm can be used but optimisation based on the so called *simulated annealing*, is recommended.

Industrial Applicability

Microwave power dividers are used in applications where it is necessary to split a microwave signal two or more ways. Hence microwave dividers are used in applications where the microwave signal must be distributed among several microwave devices. Microwave power combiners are used in applications where it is necessary to combine two or more microwave signals, to be available at one port. Hence microwave combiners are used to compose one microwave signal from a number of microwave signals. But more commonly, microwave power

combiners are used to compose a microwave signal of high power level, from a number of low power level microwave sources. To ensure that the signals from the low power level microwave signals add constructively, the combiner must be designed such that in-phase signals connected to its input ports combine in-phase. The parallel combined microwave power amplifier uses both the concepts of microwave power division and combining to share the burden of power amplification among several microwave power amplifier modules. The parallel combined power amplifier consists of an n-way power divider to distribute the input microwave signal equally among the inputs of n identical amplifier modules. The output microwave signals of the n amplifier modules are then combined in-phase by an n-way power combiner.



Claims

1. A broadband tapered planar power divider/combiner for microwave or millimetre-wave signals comprising of:
 - (a) a dielectric substrate;
 - (b) a layer of electrical conducting material bonded to and entirely covering one side of the said substrate;
 - (c) a thin layer of electrical conducting material bonded to the other side of the said substrate and etched so that it consists of tapered section whose wide end is linear and perpendicular to the centre line;
 - (d) a means of connecting electrical signals to / from the narrow end of the said tapered section;
 - (e) a means of connecting a plurality of electrical signals from / to the said linear wide end of the said tapered section which are equally spaced and symmetrically disposed across the said wide end; and
 - (f) a plurality of holes etched in the said tapered conductor section being symmetrically disposed, whose shape and position ensure that the signals appearing at the said electrical connections across the said linear wide end will have equal amplitude and phase when a signal is connected to the said narrow end of the tapered section, and the said electrical connections across the wide end are each terminated in non-reflecting loads.
2. A power divider/combiner as defined in claim 1 with a further step change in the conductor width at the said narrow end to improve the electrical match at the connection to the narrow end.
3. A power divider/combiner as defined in claim 1 with a plurality of equal length conductors that taper down from the said connections across the



said linear wide end to the external connections to ensure improved electrical match at these connections.

4. A power divider/combiner as defined in claim 2 with a plurality of equal length conductors that taper down from the said connections across the said linear wide end to the external connections to ensure improved electrical match at these connections.
5. A broadband tapered planar power divider/combiner for microwave or millimetre-wave signals comprising of:
 - (a) a first dielectric substrate;
 - (b) a layer of electrical conducting material bonded to and entirely covering one side of the said first substrate;
 - (c) a thin layer of electrical conducting material bonded to the other side of the said first substrate and etched so that it consists of tapered section whose wide end is linear and perpendicular to the centre line ;
 - (d) a means of connecting electrical signals to / from the narrow end of the said tapered section;
 - (e) a means of connecting a plurality of electrical signals from / to the said linear wide end of the said tapered section which are evenly spaced and symmetrically disposed across the said wide end;
 - (f) a plurality of holes etched in the said tapered section being symmetrically disposed, whose shape and position ensure that the signals appearing at the said electrical connections across the said linear wide end will have equal amplitude and phase when a signal is connected to the said narrow end of the tapered section, and the said electrical connections across the wide end are each terminated in non-reflecting loads;
 - (g) a second dielectric substrate covering entirely the surface of the first said dielectric substrate on the side of the etched conductor layer; and



- (h) a second electrically conducting material that covers entirely the outward facing side of the said second dielectric substrate.
6. A power divider/combiner as defined in claim 5 with a further step change in conductor width at the said narrow end to improve the electrical match at the connection to the narrow end.
 7. A power divider/combiner as defined in claim 5 with a plurality of equal length conductors that taper down from the said connections across the said linear wide end to the external connections to ensure improved electrical match at these connections.
 8. A power divider/combiner as defined in claim 6 with a plurality of equal length conductors that taper down from the said connections across the said linear wide end to external connections to ensure improved electrical match at these connections.