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 (72) Inventors GLENN RICHARD THOREN,
 JAMES LEE LAMPEN and GEORGE JERINIC



(54) RADIO FREQUENCY POWER COMBINER

(71) We, RAYTHEON COMPANY, a corporation organized under the laws of the State of Delaware, United States of America, of Lexington, Massachusetts, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to radio frequency power combiners which combine the power out of a plurality of coaxial oscillators.

It has been known for many years that radio frequency signals out of each one of a plurality of oscillatory circuits may, in effect, be added in so-called "combiner" circuits to produce a single radio frequency signal of high amplitude. With the development of solid state devices, such as IMPATT diodes, as the active elements in oscillatory circuits, the interest in combiner circuits has increased. The average and peak power levels of these devices are high enough so that useful transmitter power levels can be achieved by combining a practical number of devices in a suitable combiner circuit. Exemplary combiner circuits using solid state devices are shown in U.S. Patent No. 3,628,171 (Kurokawa et al) and U.S. Patent No. 3,931,587 (Harp et al).

Both of the just-cited patents show combiner circuits with a plurality of IMPATT diodes operated as continuous wave (CW) oscillators, each one of such diodes being in an oscillatory circuit which is coupled to a common cavity. The requisite frequency and phase relationship between the radio frequency oscillations of the different CW oscillators is determined in operation by the characteristics of the common cavity.

It has been suggested by Kurokawa et al that a combiner circuit may be made with a common rectangular cavity operating in a mode other than the TE_{01N} mode, where N is an integer corresponding to half the number of combined devices. The specific example given by Kurokawa et al is a common rectangular

cavity operating in the TE_{02N} mode. Kurokawa et al also suggests that conventional mode suppressors may be used when the common cavity is dimensioned to support the TE_{02N} (or higher) mode. The common cylindrical cavity shown by Harp et al is operated in the TM_{010} mode, although, presumably, mode suppressors could be incorporated to allow higher modes, e.g. the TM_{020} mode, to be supported. In any event, because of the fact that the longitudinal axes of the diode oscillators and the cavity shown by Harp et al are parallel to each other, the maximum number of diode oscillators which may be coupled to a common cylindrical cavity with a given circumference is determined by the ratio of that dimension to the outside diameter of a diode oscillator. Such a limitation on the maximum number of diode oscillators in turn places an unwanted upper limit on the amount of radio frequency energy which may be combined.

According to the present invention, there is provided a power combiner for radio frequency energy utilizing the combination of a cavity with a plurality of coaxial oscillators coupled to the cavity around the periphery thereof, wherein the cavity is a cylindrical cavity and each one of the oscillators includes a first and a second length of coaxial line having different radii of their centre conductors and of their outer conductors but having the same characteristic impedance, the first and second length being separated by a coaxial matching section formed by inner and outer conductors which taper the radii from one said length to the other while preserving the uniformity of the characteristic impedance.

An embodiment of this invention will now be described by way of example, with reference to the accompanying drawings, wherein:

Fig. 1 is a perspective view of a power combiner, and

Fig. 2 is a partial cross-sectional view on the line 5c-5c of Fig. 1.

Referring now to Figs. 1 and 2, an arrangement is shown to increase the number of

diode oscillators which may be coupled to a cylindrical cavity of a given size. The number of diode oscillators is limited by the ratio of the diameter of each such oscillator to the circumference $2\pi R^1$ of a circle greater than the circumference $2\pi R$ of the cavity.

To effect the foregoing, advantage is taken of the well known fact that the dimensions (meaning the radii of the inner and outer conductors) of a coaxial line may be changed without affecting the characteristic impedance of such a line. That is so long as the ratio between the inner radius of the outer conductor and the radius of the inner conductor is constant, the characteristic impedance of a coaxial line is constant. Therefore, it is possible to proportion the radii of the inner and outer conductors of a coaxial line so that one portion of such line (here the portion extending from a termination load past a cavity) is relatively small and a second portion (here the portion including an IMPATT diode) is sized to accommodate the diode in an oscillatory circuit.

With the foregoing in mind it may be seen in Figs. 1 and 2 that an upper body block $71U^1$ is machined to support a probe and tuning arrangement 80 (which allows injection and extraction of RF energy from a cavity 70B and tuning of the cavity) and a plurality of bores centred on a circle of radius R and parallel to the longitudinal axis of the upper body block $71U^1$. Such bores are extended into a lower body block $71L^1$. The radius of each bore is less than one-half the diameter required to accommodate an IMPATT diode 40 and the bores will be called narrow bores.

The walls and bottom side of the cavity 70B are formed by a counterbore of radius R in the lower body block $71L^1$. That block in turn is flared at a convenient angle, say 45° to its longitudinal axis. A plurality of shaped bores is formed (Fig. 2) in the flared portion of the lower body block $71L^1$, each one of the shaped bores intersecting a corresponding one of the plurality of bores through the upper body block $71U^1$ and a portion of the lower body block $71L^1$. The surfaces of each shaped bore and its corresponding narrow bore make up the outer conductor of a coaxial line.

The radially outer portion of each shaped bore is machined to accommodate an IMPATT diode 40 and a first and a second impedance transformer.

A depression (not shown) is formed in the free end of the centre conductor 44B to accommodate one terminal of the IMPATT diode 40. A conducting epoxy resin may be used to provide a low resistance contact between the centre conductor and the IMPATT diode 40. The second electrode of the IMPATT diode 40 is soldered in an opening in a heat sink 46 which is held in place by a

threaded member 52. An insulating sleeve 56^1 is bonded to the heat sink 46 and fitted around the centre conductor 44B, thereby forming a first quarter wave impedance transformer.

The centre conductor 44B is passed through a sleeve 58^1 which is a sliding fit on the centre conductor. A slot (not shown) may be formed through the wall of the lower body block $71L^1$ adjacent to the sleeve 58^1 for adjusting the position of the sleeve 56^1 along the length of the centre conductor.

The sleeve 58^1 forms a second quarter wave impedance transformer. The two impedance transformers match the low impedance of the diode to the high impedance of the cavity 70B.

The inner portion of each shaped bore is the same size as the narrow bore with which it connects. Between the inner and the outer portion of each shaped bore there is a transition comprising a conical flaring portion.

A centre conductor 44B having the cross-sectional shape shown in Fig. 2 is supported in a coupling relationship with the cavity 70B within each pair of a narrow bore and a shaped bore. The upper end of the centre conductor 44B is supported by a termination load 60^1 and the lower end of the centre conductor 44B is supported by the insulating sleeve 58^1 and the insulating sleeve 56^1 . The centre conductor 44B is shaped so that, along its whole length, the ratio of its radius to the radius of the bore is constant. The tapered portions of the inner and outer conductors form a matching section between the two lengths of the coaxial line.

It will now be apparent that, with a given diameter as determined by the IMPATT diode 40 and a cavity 70B of a given circumference, a greater number of diode oscillators may be coupled to the cavity 70B than would be the case if the diode oscillators were straight and arranged wholly along lines parallel to the axis of the cavity.

WHAT WE CLAIM IS:—

1. A power combiner for radio frequency energy utilizing the combination of a cavity with a plurality of coaxial oscillators coupled to the cavity around the periphery thereof, wherein the cavity is a cylindrical cavity and each one of the oscillators includes a first and a second length of coaxial line having different radii of their centre conductors and of their outer conductors but having the same characteristic impedance, the first and second length being separated by a coaxial matching section formed by inner and outer conductors which taper the radii from one said length to the other while preserving the uniformity of the characteristic impedance.

2. A power combiner according to Claim 1, wherein the first length of coaxial line in each one of the coaxial oscillators has a

smaller radius than the second length of coaxial line, each such first length being parallel to the longitudinal axis of the cylindrical cavity to provide the coupling relationship between each coaxial oscillator and the cylindrical cavity.

3. A power combiner according to Claim 1 or 2, wherein the longitudinal axis of the second length of coaxial line in each one of at least some of the coaxial oscillators in the plurality thereof is inclined to the longitudinal axis of the cylindrical cavity.

4. A power combiner according to Claim 1, wherein the first lengths of coaxial line are

parallel to the axis of the cavity and have a smaller radius than the second lengths, the second lengths being inclined so as to fan away from the said axis, and each oscillator including a diode at the outer end of the second length of the coaxial line.

5. A power combiner substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

REDDIE & GROSE,
16, Theobalds Road,
London WC1X 8PL.
Agents for the Applicants.

