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MICROWAVE PULSER

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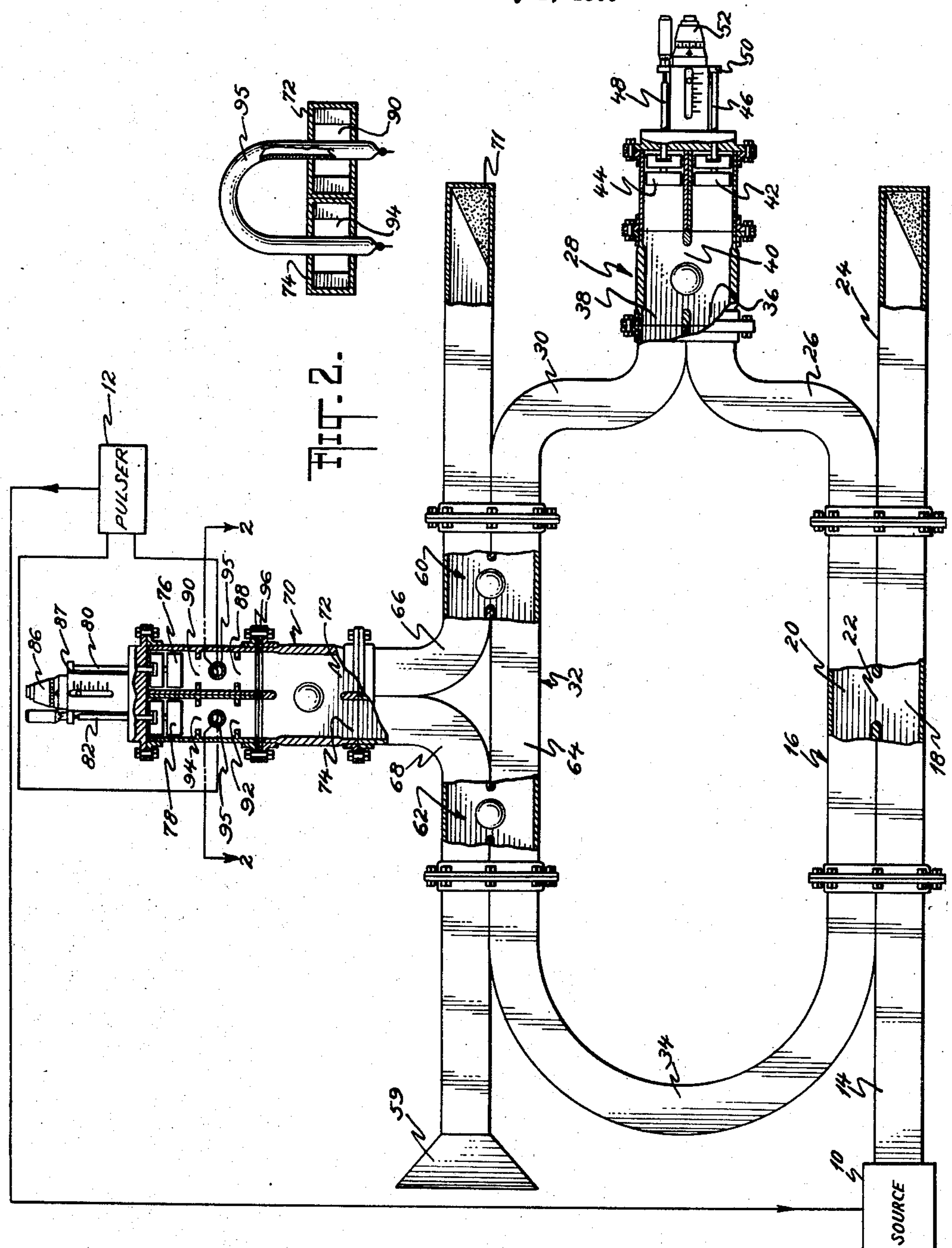

FIG. 2.

FIG. 1.

INVENTOR

FRANKLIN S. COALE

BY R. J. Craddock

ATTORNEY

2,930,004

MICROWAVE PULSER

Franklin S. Coale, Huntington, N.Y., assignor to Sperry Rand Corporation, a corporation of Delaware

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This invention relates to improved apparatus for generating pulsed microwave energy, and more particularly, is concerned with apparatus for generating extremely short high power pulses from a lower power C.-W. or pulsed microwave source.

In order to increase the peak power of a pulse radar system, considerable attention has been given to designing magnetron or klystron oscillators capable of delivering the required peak powers. A number of limiting factors are encountered in both magnetron and klystron design as higher and higher peak powers are attempted. The physical bulk of the oscillator tubes is greatly increased by the demand for larger focussing coils, increased radiation area and enlarged water cooling jackets, shielding against X-rays, and the like. Moreover, there is loss in efficiency because of increased power supply demands and pulser requirements. The increased accelerating voltage potentials required are more difficult to pulse with the extremely fast pulse duration time desired for high target resolution.

It is a general object of this invention to avoid the foregoing and other limitations in and objections to the prior art practices by the provision of an improved pulsed microwave source which achieves higher peak powers with shorter pulse times and yet is more efficient in performance, less complex in design, and more compact in proportion to its output power.

Another object of this invention is the provision of apparatus for producing a pulsed high peak power microwave output from a C.-W. source, or a source of output pulses of long duration compared to the output pulse.

Another object of this invention is to provide apparatus which produces relatively high peak power output pulses from a relatively low power microwave source.

These and other objects of the invention which will become apparent as the description proceeds are achieved by the provision of apparatus including a microwave source to which is coupled, through a directional coupler, a wave guide loop forming a continuous closed conductive path. Energy is coupled into the loop in one direction of propagation from the source, the loop being an integral number of wavelengths long at the frequency of the source. A gas tube operated switch periodically diverts energy stored in the loop to utilization means, such as a radiating antenna, the energy being dissipated from the loop in an interval of time determined by the propagation time around the loop.

For a better understanding of the invention reference should be had to the accompanying drawing, wherein:

Fig. 1 is a plan view, partially in section, of a preferred embodiment of the invention; and

Fig. 2 is a sectional view taken on the line 2—2 of Fig. 1.

Referring to Fig. 1 of the drawing, the numeral 10 indicates generally a source of microwave power, such as a magnetron or klystron oscillator of medium power. The source may operate C.-W. or may be pulsed at a predetermined repetition frequency by a pulser 12. The output from the source 10 is coupled through a section of wave guide 14 to a directional coupler indicated generally at 16. The directional coupler includes a primary section 18 and secondary section 20 of hollow wave guide having a directional coupling aperture 22 in the common wall between. The input end of the primary wave guide section 18 is coupled to the wave guide 14 while the other end of the wave guide section 18 is coupled to a non-reflective termination indicated generally at 24.

The secondary wave guide section 20 of the coupler 16 has the respective ends thereof coupled together through a closed conductive loop consisting of an S-shaped section of wave guide 26, a phase shifter indicated generally at 28, a second S-shaped section of wave guide 30, a microwave switch indicated generally at 32 and a U-shaped section of wave guide 34.

The phase shifter 28 is provided to vary the effective path length around this closed conductive loop and is illustrated as a type described in copending S.N. 360,327, filed June 8, 1953, in the name of Kiyo Tomiyasu. The phase shifter includes two wave guide sections 36 and 38 having a common narrow wall in which is provided a coupling slot 40. The slot 40 is proportioned to coupled 50% of the incident energy. Thus, the wave guide sections 36 and 38 with the coupling slot 40 constitute a so-called hybrid coupler. Adjustment of the effective length of the closed loop path by the phase shifter 28 is accomplished by a pair of short circuiting plungers 42 and 44 positioned respectively in the end of the wave guide sections 36 and 48. The plungers 42 and 44 are supported by adjusting rods 46 and 48 connected at one end to a yoke 50. The yoke 50 is longitudinally positioned by a micrometer screw adjustment operated by a control knob 52, whereby the plungers 42 and 44 are accurately positioned to adjust the amount of phase shift introduced by the phase shifter 28, in the manner taught in the above-mentioned copending application.

Assuming for the moment that the switch 32, to be hereinafter more fully described, couples all the incident energy in the wave guide section 30 to the wave guide section 34, a completely closed conductive loop is provided including the secondary wave guide 20 of the directional coupler 16. As pointed out and described in copending application S.N. 482,076, filed January 17, 1955, now U.S. Patent 2,875,415 in the name of Peter J. Sferrazza, with the phase shifter 28 set to provide a path length around this loop of an integral number of wavelengths, maximum energy build-up occurs in the closed loop. Assume an incident wave from the source 10 travelling along the wave guide 14. A portion of this energy is coupled into the wave guide 20 as a coupled wave, and a portion continues down the wave guide 18 as a direct wave to the termination 24. The ratio of coupled energy to direct energy depends on the coupling coefficient of the coupler. The coupled wave travels around the closed loop and, on reaching the coupling aperture 22, is again divided, a portion being coupled to the termination 24 and a portion recirculating around the closed loop.

If the phase of the portion recirculating in the loop is such as to add to the coupled wave from the source 10, the energy in the closed loop in the second cycle will be larger than during the first cycle of energy around the loop. This build-up of energy will continue with each cycle around the loop until the losses within the loop and absorption of energy by the termination 24 exactly balance the output of the source 10. With substantially zero attenuation around the loop, a steady state condition is reached when the energy coupled to the termination 24 is exactly equal to the energy output of the source 10.

Under such circumstances, the smaller the amount of coupling, the greater is the total energy stored in the form of a travelling wave around the closed loop, and the more cycles of the wave in the closed loop before the steady state condition is reached. This is so because of the relatively small increment of energy that is coupled out of the closed loop for each cycle. It has been found by keeping the attenuation around the closed loop very small and by making the coupling coefficient of the coupler 16 quite small, energy build-up in the closed loop of the order of 10 or 12 db above the energy level of the incident energy from the source 10 can be achieved.

According to the principles of the present invention, this energy build-up in the closed loop is periodically directed out of the loop by the switch 32 to utilization means, such as a radiator 59. A preferred switch for this purpose is illustrated in Fig. 1 and includes a pair of hybrid couplers 60 and 62 having a common main wave guide section 64 coupled between the wave guide sections 30 and 34. Secondary wave guide portions 66 and 68 of the respective hybrid couplers 60 and 62 include 90° bends by which they are coupled to a phase shifter indicated generally at 70. The other ends of the secondary wave guide portions 66 and 68 are respectively terminated in a non-reflective load 71 and the radiator 59.

The phase shifter 70 is substantially identical to the phase shifter 28 and includes a pair of wave guide sections 72 and 74 connected respectively to the secondary wave guide sections 66 and 68 of the respective hybrid couplers 60 and 62. As in the phase shifter 28, the wave guide sections 72 and 74 are terminated in short circuiting plungers 76 and 78 adjustably supported by rods 80 and 82 joined by a yoke 87. The yoke 87 and associated plungers 76 and 78 are adjustably positioned by a micrometer screw arrangement controlled by a knob 86.

The phase shifter 70 is modified by the provision of resonant cavities positioned in the respective wave guide sections 72 and 74 between the hybrid coupler and the short-circuiting plungers. The cavities are formed by inductive irises indicated at 88, 90, 92 and 94, spaced slightly less than a half length along the respective wave guides to provide a structure exhibiting parallel resonance at the operating frequency of the system. Extending through the wave guide sections 72 and 74 within the resonant cavities is a U-shaped gas tube 95. See Fig. 2. The ends of the gas tube are provided with electrodes which are connected to the pulser 12, the latter serving to periodically ionize the gas tube and produce a glow discharge therein. When the gas discharge tube is thus fired, the cavities are effectively detuned, providing a short-circuiting type mismatch substantially in the plane of the irises 88 and 92. By spacing the irises 88 and 92 substantially three quarters of a wavelength from the shorting plungers 76 and 78, with firing of the gas tube 95, the phase of energy coupled through the phase shifter 70, is shifted by a wavelength and a half. The operation of the switch 32 is as follows:

The hybrid couplers 60 and 62 inherently introduced a 90° phase lag in the coupled wave relative to the direct wave. Thus, incident energy from the wave guide section 30 divides at the hybrid coupler 60, half the energy being coupled directly down the wave guide section 64, and half the energy being coupled into the secondary wave guide section 66. The coupled wave in the section 66 lags the direct wave in the section 64 by 90°. The coupled wave passes through the phase shifter 70 to the secondary wave guide section 68 of the hybrid coupler 62 where it is divided equally into two portions, one portion being coupled back into the main wave guide section 64 with an additional 90° phase lag. Similarly, the direct wave down the main wave guide section 64 divides in the directional coupler 62, with half the energy continuing on down the main wave guide section 34 and half the energy being coupled into the secondary wave guide section 68.

It will be seen that if the path length between the two hybrid couplers through the phase shifter 70 is equal to or is related according to an integral ratio of wavelengths to the path length along the wave guide section 64, due to the two 90° phase shifts produced by the couplers 60 and 62, the portion of energy finally coupled back into the main section 64 lags by 180° the energy coupled directly along the main wave guide section 64. Shims 96 may be inserted in a joint in the wave guide sections 72 and 74 to adjust the path length to obtain the required ratio of path lengths. This 180° phase shift produces complete cancellation between the direct energy wave and the coupled energy wave in the wave guide section 34. However, the energy propagating directly down the main wave guide section 64 coupled by the hybrid coupler 62 into the secondary wave guide section 68 is in phase with the energy from the phase shifter 70, providing reinforcement. Thus with the phase shifter providing an integral ratio of path lengths in terms of wavelengths for the direct and coupled waves from the hybrid coupler 60, the output at the antenna 59 is of the same magnitude as the incident energy from the wave guide section 30.

If the effective path length of the coupled wave through the phase shifter 70 is shifted by a half wavelength or integral multiple thereof, then it will be seen that cancellation takes place between the direct and coupled waves in the secondary wave guide section of coupler 62, with reinforcement taking place in the wave guide section 34. No energy is delivered to the antenna 59 but all is recirculated in the storage loop. Thus, it will be seen that by proper setting of the phase shifter 70, energy from the source 10 can be caused to recirculate in the closed loop path until the gas tube is fired. Firing of the gas tube 95 shifts the phase the required amount to cause the energy to be diverted from the closed loop path to the antenna 59. The output of the antenna then has an energy content determined by the energy stored in the closed loop before firing of the tube 95 and has a pulse time duration determined solely by the propagation time around the loop.

From the above description it will be seen that the various objects of the invention have been achieved by a pulsing apparatus which is capable of building up the power level of transmitted pulses derived from a source of moderate power. The pulses can be made of extremely short duration and are not influenced in duration by the deionization time of the gas tube or similar factors.

The apparatus as described can also be utilized as a duplexer in a radar system by replacing the non-reflecting load 71 by a radar receiver. Received energy normally cancels out in the closed loop path, with all the energy going to the termination 71.

While the gas tube has been shown as being fired by an external signal derived from a pulsing circuit, the gas tube can be designed to be fired by the incident microwave energy so that the storage loop is discharged whenever the power level reaches a predetermined critical level.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. Microwave pulsing apparatus comprising a directional coupler having primary and secondary wave guide sections, a source of microwave energy coupled to the primary wave guide section, wave guide means coupling together opposite ends of the secondary wave guide section to form a closed loop conductive path, the closed loop path being an integral number of wavelengths long at the frequency of the microwave source, and switching

means for periodically coupling out energy circulating in the closed loop path including first and second hybrid couplers each having primary and secondary wave guide sections, the respective primary wave guide sections being connected in series with said wave guide means as part of the closed loop conductive path, a third hybrid coupler having a pair of wave guide sections connected respectively to the secondary wave guide sections of the first and second hybrid couplers, each of the pair of wave guides of the third hybrid coupler being terminated in a short circuit, inductive iris means defining a parallel resonant cavity region in each of said pair of wave guide sections of said third hybrid coupler spaced an odd multiple of a quarter wavelenth from the short circuit terminations, the cavities being resonant at the operating frequency of the source, and glow discharge means positioned in the cavity regions for detuning the cavities when said glow discharge means is fired.

2. Microwave pulsing apparatus comprising a directional coupler having primary and secondary wave guide sections, a source of microwave energy coupled to the primary wave guide section, wave guide means coupling together opposite ends of the secondary wave guide section to form a closed loop conductive path, the closed loop path being an integral number of wavelengths long at the frequency of the microwave source, and switching means for periodically coupling out energy circulating in the closed loop path comprising first and second hybrid couplers each having primary and secondary wave guide sections, the respective primary wave guide sections being connected in series with said wave guide means as part of the closed loop conductive path, and phase shifting means for intercoupling the respective secondary wave guide sections of the first and second hybrid couplers, said phase shifting means including means for occasionally shifting the phase of the energy flowing through the intercoupled secondary waveguide sections of the first and second hybrid couplers.

3. Microwave pulsing apparatus comprising a microwave source, a wave guide loop forming a continuous closed conductive path, directional coupling means for coupling microwave energy into the loop in one direction of propagation from the source, the loop being an integral number of wavelengths long at the frequency of the source, power divider means connected in said loop for coupling out half the incident power, four-terminal hybrid coupling means connected in the loop by two terminals of said hybrid coupling means, means coupling the third terminal of said hybrid coupling means to the output of the power dividing means, said coupling means including means for abruptly shifting the phase of the energy coupled to the third terminal of the hybrid coupling means by a half wavelength, and utilization means coupled to the fourth terminal of the hybrid coupling means.

4. Microwave pulsing apparatus comprising a microwave source, a wave guide loop forming a continuous closed conductive path, directional coupling means for coupling microwave energy into the loop in one direction of propagation from the source, the loop being an integral number of wavelengths long at the frequency of the source, microwave switching means coupled in said wave guide loop, utilization means coupled to said switching means, and means periodically actuating said switching means for opening the loop and diverting the energy stored in the loop to the utilization means.

5. Apparatus comprising a directional coupler having primary and secondary waveguide sections, a source of microwave energy coupled to the primary waveguide section, waveguide means coupling together opposite ends of the secondary waveguide section to form a closed loop conductive path, the closed loop path being an integral number of wavelengths long at the frequency of the microwave source, switching means having at least a low and a high coefficient of coupling for coupling out energy circulating in the closed loop path, and means for periodically actuating said switching means whereby to change the coefficient of coupling of said switching means from said low coefficient of coupling to said high coefficient of coupling to vary the level of the energy circulating in the closed loop path.

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