

Nov. 21, 1950

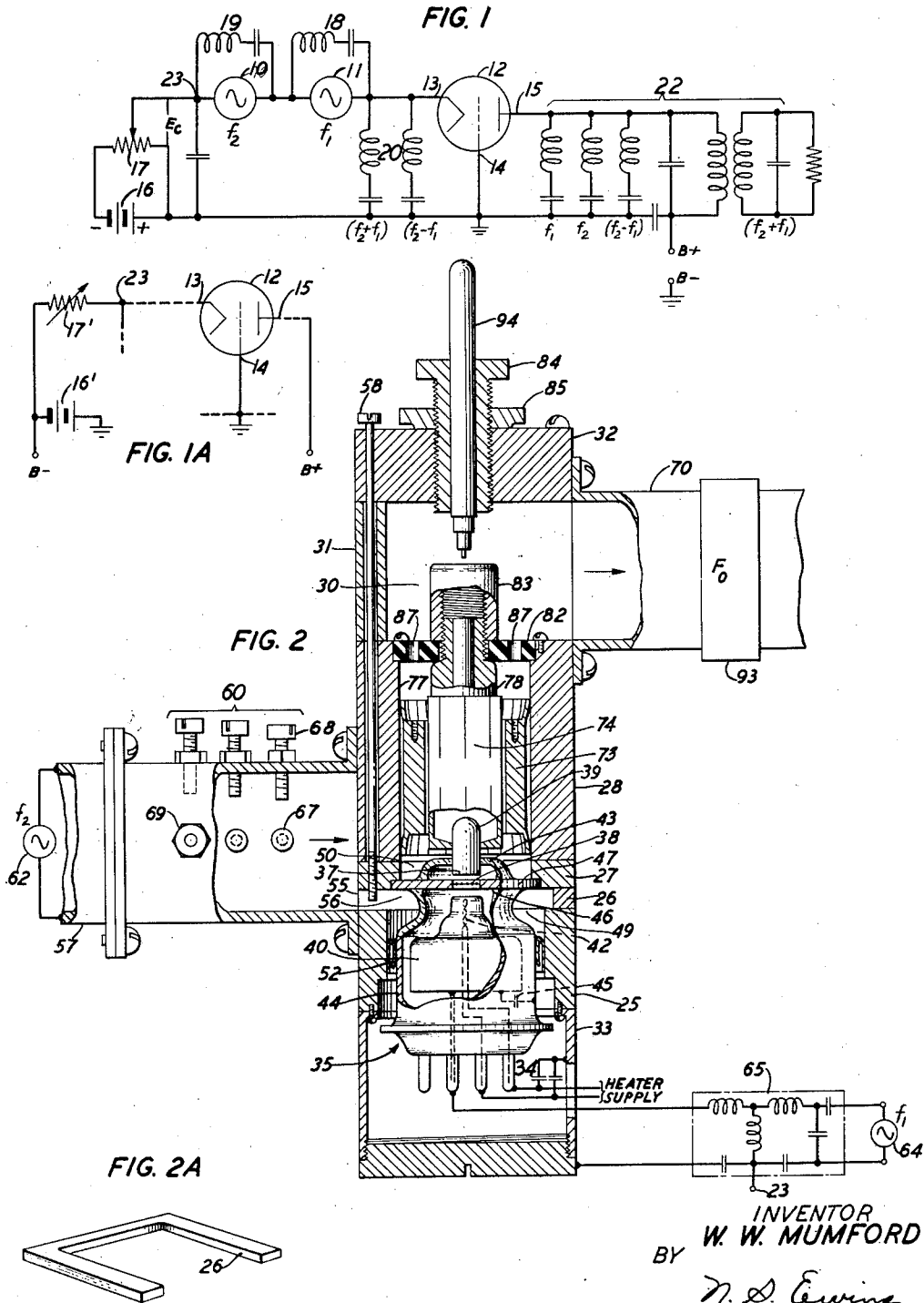
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2,530,836

GROUNDING GRID MICROWAVE MODULATOR

Filed July 1, 1949

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FIG. 4

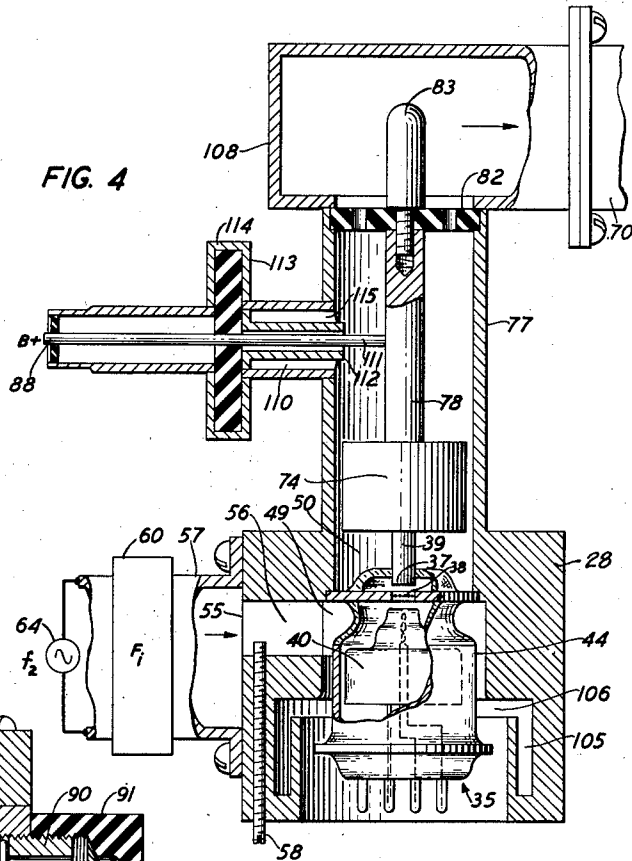


FIG. 3

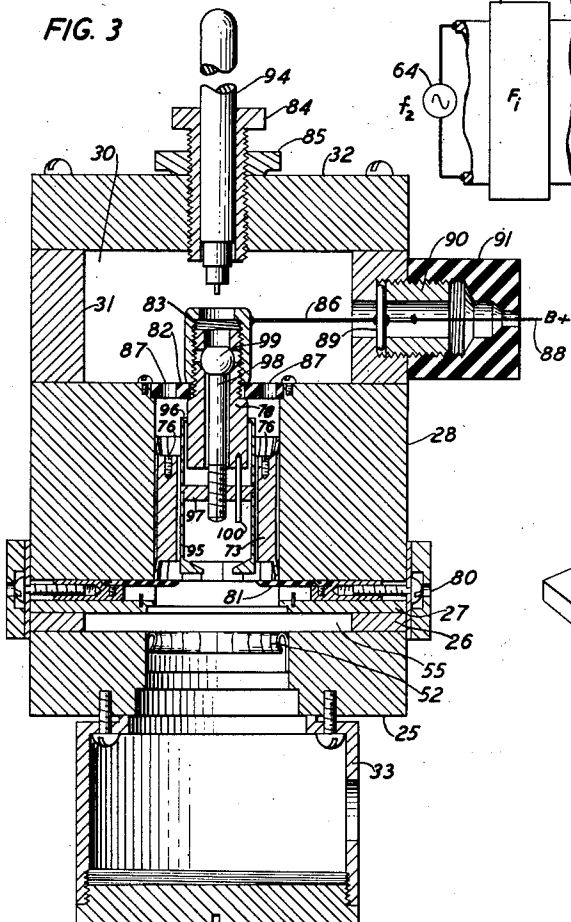
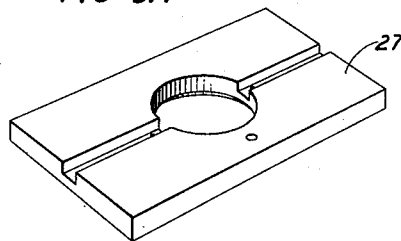


FIG. 3A



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GROUNDED GRID MICROWAVE
MODULATOR

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9 Claims. (Cl. 332-63)

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This invention relates to microwave apparatus and more particularly to microwave modulators employing electron discharge devices for operation at frequencies in the order of several thousand megacycles and higher.

The invention aims at improving the operation of microwave vacuum tube modulators, or converters, used to raise signal energies to a desired microwave frequency band.

A general object of the invention is to improve the structure of microwave vacuum tube modulating apparatus and in other respects to effect improvements in systems and apparatus of this general character.

A more specific object of the invention is to conserve or utilize most effectively the ultrahigh frequency wave power involved in microwave systems employing thermionic discharge devices as the modulating element.

A modulator in accordance with the invention and hereinafter to be described in detail includes a grounded grid triode having a non-linear cathode-voltage plate current characteristic. The grid of the triode forms a common boundary of a pair of resonant chambers or cavities which are coupled to an input and an output wave guide, respectively. Beating oscillations are impressed on the input wave guide coupled to the input cavity for intermodulation with waves of signal frequency impressed on the cathode of the triode with the resulting modulated sidebands conveyed to the output wave guide.

A feature of the invention is the use of a reflection type filter in the input wave guide to preserve the power content of the modulated sideband energy appearing in the input cavity by preventing its absorption in the beating oscillator branch of the modulator. The filter is positioned in the input wave guide so as to reflect the modulated sideband energy appearing in the input cavity into the output cavity in phase with the modulated sideband energy appearing therein.

Another feature resides in the use of a coaxial coupling circuit for coupling the output cavity to the output wave guide. The coupling circuit includes a movable quarter-wave coaxial transformer which forms a part of the boundary of the output cavity and serves also for matching and tuning purposes.

A more particular feature of the invention relates to an externally adjustable tuning mechanism associated with the coaxial coupling circuit and arranged to vary the position of the quarter-wave transformer and thereby affecting the tuning of the output cavity.

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The invention is further characterized by trap and by-pass circuits to isolate the input and output energies from various parts of the modulator thereby improving the conversion gain and efficiency of the system. A maximally flat filter in the output wave guide selectively transmits waves of the wanted sideband frequency only and reflects the unwanted energies back into the modulator to conserve and translate their power content into wanted sideband power.

Other objects, advantages and features of the invention will be apparent from the following detailed description and drawings and from the appended claims:

Fig. 1 illustrates schematically the equivalent circuit of the modulator of the present invention;

Fig. 1A illustrates schematically an alternative form of cathode biasing arrangement that may be employed in the circuit of the present invention;

Figs. 2 and 3 are side and front sectional elevations of a preferred form of the modulator to be described herein, the latter figure showing the driving mechanism for tuning the output cavity;

Figs. 2A and 3A are details of a pair of members of the housing assembly; and

Fig. 4 illustrates a modulator using alternative forms of coupling and trap circuits.

Fig. 1 schematically illustrates one method of using a triode as a modulator. Beating oscillator 10 of frequency f_2 and signal source 11 of frequency f_1 are each impressed on the cathode 13 of a triode 12 having a grounded grid 14. The tube is operated over a non-linear portion of its cathode-voltage plate current characteristic and the resulting modulation products including the sideband frequencies ($f_2 \pm f_1$) are obtained in the plate circuit. Other components of energy in the plate circuit include the frequencies f_2 , f_1 , $2f_2$, $2f_1$, ($f_2 \pm 2f_1$), etc. Due to the inherent feedback of a grounded grid circuit arrangement these frequencies will also appear in the input or the cathode circuit together with the sideband frequencies ($f_2 \pm f_1$). By-pass circuits 18 and 19, tuned to the beating oscillation and signal frequency f_2 and f_1 , respectively, are provided to prevent the flow of beating oscillator power in the signal circuit and vice versa. Input filter 20 tuned to the sideband frequencies ($f_2 \pm f_1$) prevents absorption of the modulated sideband energy by the beating oscillator and concentrates the sideband power in the output circuit thereby increasing the efficiency and improving the conversion gain of the modulator. Output filter 22 prevents transmission of all but the wanted sideband frequency ($f_2 + f_1$) in the output circuit.

Fig. 2 illustrates in cross-section a side view of a preferred embodiment of the modulator. The enclosure block or housing assembly containing the modulating element and coaxial coupling circuit is constructed of suitable conducting material such as brass and is composed of several rectangular sections including a bottom block 25 and a central block 28, each of the latter having a cylindrical bore extending centrally there-through. The cylindrical space within block 28 opens into a rectangular cavity 30 formed by top block 31 and its removable cover plate 32 and affords a path whereby the output energy may reach the output wave guide 70. Rectangular cavity 30 is of the same cross-section as the output wave guide. A metal can 33 is fitted to the bottom of block 25 to accommodate the terminal connection leads, by-pass condensers 34 and transformer 65 for the modulating element.

Rectangular plates 26 and 27 are interposed between blocks 25 and 28. Plate 26 is a thin U-shaped element as illustrated in Fig. 2A and forms a part of the input cavity 49. The open end of plate 26 forms a rectangular aperture 55 extending partially across one side of the housing assembly (see Fig. 3) and serves to admit microwave energy from the input wave guide 57 upon the modulating element 35. Plate 27 is shown in detail at Fig. 3A as a thin rectangular block with a cylindrical central bore and a square slot across its upper surface to accommodate the loading resistances 81 of Fig. 3 which may be inserted into the plate circuit cavity to provide for a limited adjustment of the band width of the circuit as described hereinafter.

The modulating element 35 employed in the modulator is an ultra-high frequency, close-spaced, parallel-plane microwave triode and may be of the Western Electric type 416A or 1553, for example. These tubes may operate as amplifiers at a plate voltage of 200 volts and a plate current of 30 milliamperes and as modulators at a plate voltage of 200 volts and plate current of 14 milliamperes. A description of the 1553 triode appears at page 171 of the April 1949 issue of "Electronics" published by McGraw-Hill in an abstract entitled "New Microwave Triode." Briefly, the elements of the triode comprise a cylindrical anode 37, a finely spaced wire grid 38 and an inverted cylindrical cup-shaped cathode member 40 shown encompassing heater elements 42. The anode terminal 39 is an extension of the cylindrical anode 37 into the space within block 28 through the glass seal 43 enclosing the grid and anode elements of the tube. The cylindrical cathode member 40 is enlarged where it extends downward parallel with the metal shell 44 of the tube forming a capacitance 45 (shown schematically) therewith. The microwave input energy passes through the glass seal 46 between grid flange 47 and metal shell 44 to effect the modulation process within the tube.

The grid flange 47 of the triode may be soldered into a recess in the lower face of plate 27 and separates the cylindrical interior of the housing assembly into lower and upper chambers 49 and 50, respectively. The metal shell 44 of the tube forms a part of the lower chamber or cathode cavity 49 and is secured therein by means of the springy contacts 52 circumferentially disposed about and fixed in the bottom of the chamber. The heater and cathode leads are brought out through eyelets in the base of the tube to a standard connector (not shown) in connecting can 33.

The heater leads are by-passed to the connecting can 33 through condensers 34.

U plate 26 provides in addition to the rectangular coupling orifice 55 a short interconnecting low impedance passage 56 of the same cross-section as the coupling orifice leading from the input wave guide to the cathode cavity. As shown in Fig. 2 the height or vertical dimension of passage 56 is considerably less than that of the input wave guide 57. In a particular instance in which the internal wave-guide dimensions were $\frac{7}{8}$ by $1\frac{1}{8}$ inches, the passage dimensions were $\frac{1}{8}$ by $1\frac{1}{8}$ inches. The impedance discontinuity presented to the flow of waves from wave guide 57 into the modulator input cavity 49 by passage 56 is compensated for by means of tuning screw 53 located at the top of the enclosure block and extending down into the coupling orifice 55 centrally across its opening. The tuning screw introduces a variable capacitance which can be adjusted to improve the match between the input wave guide and the cathode cavity over a 500-megacycle band. Since the length of the interconnecting passage 56 is short compared with the electrical wavelength, its presence may be considered either as a portion of the cathode cavity or as a portion of the coupling iris 55. In either case the tuning screw is provided to establish an impedance match between the cathode cavity and the input wave guide.

In those cases where it is desired to obtain an impedance match over a very wide frequency band a broad match may be obtained by means of an input tuner (not shown) located in the input wave guide between filter 60 and the enclosure block. A tuner of this type is described by C. F. Edwards in his article entitled "Microwave Converters" appearing in the Proceedings of the I. R. E., volume 36, No. 10, for November 1947. This tuner is, in effect, two variable shunt tuned circuits approximately an eighth of a wavelength apart in the wave guide and is capable of tuning out a residual mismatch corresponding to six decibel standing wave ratio of any phase. Each variable shunt tuned circuit is made up of a fixed inductive post and a variable capacitive screw located off center in the wave guide.

Reflection filter 60, described below, is shown at the end of the guide 57 coupled with the cathode cavity through coupling orifice 55. A suitable ultra-high frequency source 62 of radio frequency power, shown schematically in Fig. 2, supplies beating oscillations at a frequency f_2 of 3905 megacycles, for specific example, to the cathode cavity by way of the input wave guide 57 and coupling orifice 55.

Source 64 impresses intermediate frequency signals f_1 in the range of 65 megacycles, for example, on the cathode member 40 of the triode through an intermediate frequency impedance transforming network 65 for intermodulation with the beating oscillations impressed upon the input cavity. The impedance transforming network 65 is contained within connecting can 33 and proposes to match the input impedance of the modulator to the signal source 64, which drives the modulator, in order to eliminate any degradation of the system performance due to impedance mismatch. The design of the network 65 takes into account the capacity of the tube and of by-pass capacitance 45, the resistance of the electron stream, and the lead inductance measured at the base of the tube. A particular network which lends itself readily to the existing tube circuit is the simple T network equivalent

of parallel resonant coupled circuits illustrated at Fig. 2.

A conventional biasing arrangement consisting of a battery 16 and a low resistance potentiometer 17 (as indicated schematically in Fig. 1) may be connected to terminal 23 in Fig. 2 to supply the appropriate positive potential to the cathode 13 thereby maintaining the grounded grid 14 negative with respect to the cathode. This cathode biasing arrangement maintains the cathode at a relatively constant positive potential. The direct-current plate current then varies with the level of the beating oscillator power.

Fig. 1A illustrates a modification of the cathode biasing arrangement of Fig. 1 which has been found to have a greater stabilizing effect on the direct-current plate current. This network minimizes small variations in gain due to power line variations and other disturbing influences by producing a large amount of negative feedback for the direct current path. In this arrangement the negative terminal of the B+ plate supply is connected to ground through a battery 16' of opposite polarity. The cathode 13 of the grounded grid triode is connected to the junction of the B- terminal and the battery 16' through a variable resistance 17'. The space current to the cathode causes a potential drop in the variable resistance which tends to cancel the voltage of the battery 16', thereby maintaining the cathode potential nearer to ground (grid) potential. Any change in the level of the beating oscillator power which tends to change the space current will tend to change likewise the cathode potential in such a sense as to counteract the change in space current. The space current is thereby held nearly constant at a value determined by the cathode resistor 17' and the characteristics of the tube. This space current can be adjusted to the desired operating value by varying the cathode resistor.

Capacitance 45, mentioned earlier, acts as a portion of the impedance matching network 65 through which the intermediate-frequency signal power is applied to cathode 40 when the tube is used as a modulator and also serves as a radio frequency trap to isolate the microwave energy from the signal circuit by effectively grounding the cathode at the beating oscillator frequency f_2 . The signal energy is isolated from the beating oscillator branch of the modulator by wave guide 57 whose dimensions prohibit the propagation of signal energy therethrough.

The aforementioned reflection filter 56 located in the input wave guide 57 prevents the modulated energy appearing in the input cavity from flowing into the input guide where it would be absorbed by the beating oscillator. It serves to reflect the modulated energy back into the output cavity where it will be utilized to best advantage, viz., to increase power output. The spacing of filter 60 along the input wave guide is so fixed that the energy reflected into the output cavity will be in phase with the modulated energy appearing therein.

Filter 60 may assume the form of a band reflection filter which reflects only the wanted sideband and passes all other frequencies, or a band-pass filter which passes only the beating oscillation frequency and reflects all others. Whatever type filter is employed, it should have a high standing wave ratio at the desired sideband frequencies. Fig. 2 illustrates the use of the former or band reflection-type filter employing resonant rods 67 with adjustable coupling 68 and tuning screws 69. The structural features and performance of a

filter of this type are shown and described by W. D. Lewis and L. C. Tillotson in the Bell System Technical Journal, vol. XXVII for January 1948 at page 91, Fig. 8. The band-pass filter may be of the resonant iris type, the performance and design considerations of which are described in the above publication at pages 684-713 in an article entitled "Maximally-flat Filters in Wave Guide" by the present inventor.

Turning now to the output circuit of the modulator, the output chamber or plate circuit cavity 59 is coupled to the output wave guide 70 through a coaxial conductor coupling circuit extending through the central space in block 28. The upper portion of the coaxial coupling circuit includes a coaxial line formed by the cylindrical interior of block 28 and by an inner conductor 78 which terminates in a wide band coaxial-to-wave-guide transducing probe 83 located in rectangular cavity 39 in the top of the housing assembly. The lower end of the coaxial coupling circuit includes a quarter-wave resonant section of coaxial line comprising a hollow cylindrical slug or contact member 73 surrounding or in juxtaposition with a tubular central member 74.

Slug member 73 is slidably mounted within block 28 and in contact therewith by means of conductive contact fingers at its extremities, and its inner face together with the cylindrical wall of block 28 forms the outer conductor 77 of the coaxial coupling circuit. The outwardly pressing spring contact fingers at the extremities of slug 73 should insure not only a low resistance electrical connection with the wall of block 28 but should also provide a complete closure so as to minimize losses due to electromagnetic leakage radiation past slug 73. The tubular central member 74, of slightly lesser diameter than the surrounding slug 73, has slotted spring fingers at its extremities to clutch or engage anode connection 39 and the conductor 78, thus forming the inner conductor assembly of the coaxial coupling circuit.

Slug member 73 is so proportioned as to be a quarter wavelength long at the frequency of the desired sideband, 3970 megacycles. The tubular central member 74 is slightly longer than slug member 73 so that notwithstanding its movement longitudinally on anode connection 39 and conductor 78 by means presently to be described, it continues to form with member 73 a quarter-wave resonant section of coaxial line which serves as an impedance transformer.

The lower surfaces of the elements 73 and 74 of the impedance transformer are radial and form a boundary of the resonant pill-box plate circuit cavity 59. The output or plate circuit cavity 59 is defined by the grid 40, anode 37 and anode connection 39 of the microwave triode, by the radial faces of the elements of the impedance transformer and by a portion of the interior wall of block 28 forming the outer conductor 77. The plate impedance of the tube is transformed by the plate circuit cavity to a very low resistance in the order of a fraction of an ohm (0.5-0.7 ohm approximately) on the plate connection 39 just outside the seal 43 of the tube. The quarter-wave transformer matches this low impedance to the surge impedance (45 ohms approximately) of the coaxial line above the impedance transformer. The relative diameters of the elements 73 and 74 of the quarter-wave transformer are proportioned so as to present a characteristic impedance equal to the geometric mean of the impedance of the plate circuit cavity and

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the surge impedance of the coaxial line. In a particular instance the inner diameter of slug member 73 was 0.478 inch. Excluding the contact fingers, which are one-eighth inch in length, the solid section of 73 corresponding to the quarter-wave dimension of the transformer measured 0.727 inch. The outer diameter of tubular member 74 measured 0.438 inch and its overall length was 1.00 inch. Figs. 2 and 3 are drawn approximately to scale to indicate the relative proportions of the modulator components.

A limited adjustment of the band width of the modulator may be obtained by introducing external loading resistances into the plate cavity 50 through a small square aperture located on each side of plate 27 of the housing assembly. A simple screw mechanism 80 (see Fig. 3) adjusts the penetration of the loading resistive strips 81 into the plate cavity so as to vary the "Q" of the plate circuit cavity to match the "Q" of the output filter section 93 described below.

The inner conductor 78 of the coaxial line above the impedance transformer is supported by a dielectric washer 82 secured in a recessed entry in the upper surface of block 28. Conductor 78 is undercut where it passes through dielectric washer 82 in order to compensate for the discontinuity introduced in the path of the waves by the dielectric thus assuring an electrically smooth system. The upper portion of conductor 78 extending into the rectangular cavity 30 is threaded to take the coaxial-to-waveguide transducer 83 which is an internally threaded hollow probe antenna screwed securely on conductor 78 and against dielectric washer 82.

A hollow stud 84 and lock nut 85 located at the top of the housing assembly is screwed down into the rectangular cavity 30 forming a variable capacitance with antenna probe 83 and is used to adjust the impedance match between cavity 30 and output wave guide 70.

The impedance match looking back into the modulator from the output wave guide 70 is broadened by adding the elements of a maximally-flat filter 93 in the output wave guide. This filter should not only provide a broad impedance match at the desired sideband frequencies but it should also provide discrimination against the other frequency components present in the output circuit of the modulator. The filter employed for this purpose incorporates the impedance of the plate circuit cavity and may, like the beating oscillator filter 60 in the input wave guide, be of the type whose design and theory are set forth in the aforementioned article entitled "Maximally-flat Filter in Wave Guide."

The application of plate voltage to a modulator of the present design raises the problem of providing efficient means to prevent the escape of the modulated energy through the B+ plate supply line. For this purpose a radio-frequency trap is provided in the output circuit of the modulator as shown in Fig. 3. The trap comprises a high impedance quarter-wave wire 86 which is electrically essentially a quarter wavelength at the modulated sideband frequency and functions as a quarter-wave stub across a transmission line presenting a high impedance thereto. The B+ plate supply line 88 is brought through a metallic bushing 90 surrounded by a hard rubber insulating bushing 91 in a side wall of top block 31 and attaches to the termination of the quarter-wave wire 86 in bushing 90. The other end of wire 86 is soldered to antenna probe 83 which

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makes connection with the anode of the triode through the inner conductor assembly of the coaxial coupling circuit. A button capacitor 89, such as the Erie type 370 button silvered mica condenser, mounted in bushing 90 serves as an insulating support for wire 86 passing centrally therethrough and also as a by-pass to ground for any radio-frequency signal energy that appears on wire 86.

Fig. 3 is a front elevation sectional view of the modulator of Fig. 2 excluding the modulating element 35 and it further illustrates the tuning mechanism that is used to adjust the size of the plate circuit cavity.

The size of the plate circuit cavity may be adjusted by varying the position of either the central member 74 or the slug contact member 73 of the coaxial transformer bounding the plate circuit cavity. Fine tuning is accomplished by sliding the central member 74 up and down on the anode connection 39 while a coarse tuning process may be effectuated by varying the axial position of slug member 73.

In the present case the driving mechanism employed to accomplish a fine tuning process is contained within the central member 74 of the coaxial transformer thus effectively isolating the mechanical from the electrical design problem.

The tubular central member 74 of the quarter-wave coaxial transformer is composed of two parts, a lower sleeve member 95 and an upper shell member 96 each of which have conductive contact fingers at one of their ends to engage anode connection 39 and inner coaxial conductor 78, respectively. Upper shell member 96 is cup-shaped, its base having an internally threaded hole axially disposed therein to accommodate the threaded end of a rod 98 passing centrally through 78. The lower portion of the periphery of shell 96 is undercut or slightly recessed, and sleeve member 95 is securely fastened and soldered thereon. The spherical head 99 of rod 98 is retained within antenna probe 83 to prevent longitudinal movement of 98 relative to 78 while allowing rotational movement. Conductor 78 is stationary, being secured between dielectric washer 82 and probe 83. Guide pin 100, fixed in the lower end of stationary conductor 78, passes loosely through a small hole in the base of upper shell member 96 and prevents circular motion of the coaxial transformer central section 74. An actuating tool in the form of an insulated screw-driver 94 or the like is inserted through the hollow stud 84 in cover plate 32 and engages a recessed socket in the head 99 of rod 98. The screw-driver is made of a low-loss plastic material having a dielectric constant slightly greater than unity and is permanently maintained in position. The length of hollow stud 84 through which the screw-driver is inserted provides a length of wave guide beyond cut-off which keeps the microwave energy from leaking out through the screw-driver. Thus by turning the screw-driver 94 the circular motion imparted to rod 98 is translated into a longitudinal axial movement of the central member 74 of the coaxial transformer on inner conductor 78 and anode connection 39 and the fine tuning process is accomplished.

By means of the fine tuning process the plate cavity resonance frequency can be adjusted to any desired value within a fairly wide frequency band such as, for example, over a 600-megacycle band, from 3650 megacycles to 4250 megacycles. The position of the coarse tuning slug 73 determines the central frequency of the desired oper-

ating range of frequencies, and this position is adjusted and fixed at the time when the circuit is assembled so that the desired tuning range is covered by the fine tuning control. For this purpose slug 73 is provided with two tapped holes 76 in its upper face to allow for the insertion of threaded screws (not shown) into it through holes 87 provided in the dielectric supporting washer 82. To facilitate the insertion of these screws, the top plate 32 of the cavity 30 is removable from the block 31 thus making it unnecessary to disassemble completely the circuit to make the coarse adjustment.

Where the desired operating range of frequencies exceeds the 600-megacycle band which can be covered by the fine tuning process the following method of moving the slug 73 can be adopted. A mechanism for sliding the slug can be inserted through the walls of block 28 without affecting the electrical performance of the circuit since the outside of the slug 73 and the inside of block 28 adjacent thereto are not a part of the radio-frequency circuit. This mechanism might include a pin which engages a slot in slug 73, the pin being mounted eccentrically on the end of a cylinder which is free to rotate in block 28. A screw-driver or wrench may be used to rotate the cylinder from outside of block 28, so that as the cylinder rotates the eccentric pin moves up or down thereby shifting the relative position of the slug.

Fig. 4 is a sectional side elevation of another embodiment of the invention structurally related to the modulator of Figs. 2 and 3 and illustrates the use of different types of radio-frequency input and output trap circuits.

Briefly the modulator of Fig. 4 comprises a rectangular enclosure block 28 having a cylindrically bored interior separated into a lower and upper chamber, 49 and 50, respectively, by the grounded grid 38 of the microwave triode electron tube 35. Beating oscillations from a microwave frequency source 64 are impressed upon the input wave guide 57 coupled to the input chamber 49 by means of constricted rectangular passageway 56 between the chamber and the face of the enclosure block. Tuning screw 58 centrally located near the entrance 55 to passageway 56 adjusts the impedance match between the input wave guide and chamber 49. A reflection-type filter 60 is positioned in the input wave guide as set forth hereinabove. Signal energy is impressed on the cathode of the tube as shown in Fig. 2.

The input circuit of the Fig. 4 modulator is thus seen to be similar to that of Figs. 2 and 3, the principal difference as described below residing in the form of radio-frequency trap employed to isolate the beating oscillator energy from the signal input circuit. In the foregoing description it will be recalled that the intercapacitance between the cathode 40 and the shell 44 of the tube was utilized to effectively ground the cathode at radio frequency. In the present case the same effect is obtained with a simple quarter-wave shorted line 105 circumferentially disposed about the bottom of the input cavity. Line 105 presents a very high impedance to the microwave energy at its open end as at 106 and a very low impedance at the top of the shell 44, thereby isolating the microwave energy from the signal circuit. It has been noted that where the radial dimensions of the quarter-wave trap 105 become relatively great undesirable higher order transmission modes may be supported. The form

of radio-frequency input trap characterized by condenser 45 inside the tube in Fig. 2 should be more effective at higher frequencies than the trap of Fig. 4 since the radial dimensions of the former are less.

The output chamber 50 of the Fig. 4 modulator is bounded by the grid 38 and anode 37 of the microwave triode, by the inner wall of the enclosing block 28 and by the radial face of the transformer element 74 formed by expanding the diameter of the inner conductor 78 of the coaxial coupling circuit. Transformer element 74 may be constructed so as to be slidably mountable on the inner conductor 78 and the cylindrical extension 39 of the anode electrode for purposes of adjusting the size of the output chamber. The outer conductor of the coaxial coupling circuit is formed by a tubular conductive shield 77 of the same internal diameter as the cylindrical bore of enclosure block 28 and extends between the enclosure block and the conductively bounded rectangular enclosure 108 connected to the output wave guide 70. The length, diameter and position of element 74 are correlated so as to form with a portion of the interior of shield 77 a quarter-wave transformer which serves to match the impedance of the output cavity to the surge impedance of the coaxial coupling circuit.

The size of the output cavity 50 of Fig. 4 is varied by moving the quarter-wave transformer 74 along the coaxial line 78 by means of an actuating tool passing through the holes 87 provided in dielectric washer 82 and extending down into the interior of block 28 to engage transformer 74. This movement is equivalent to moving both the slug 73 and member 74 of Fig. 2 together. It is readily apparent that the tuning arrangement employed in the Figs. 2 and 3 structures affords a much finer and smoother control of the output cavity.

A radio-frequency trap circuit of the type employed in the Fig. 4 modulator to prevent the escape of the modulated microwave energy through the B+ plate supply line 88 is illustrated at Figs. 12 and 16, pages 1189 and 1191 of the aforementioned article entitled "Microwave Converters" by C. F. Edwards. The trap circuit is connected to the coaxial line near the anode of the tube in order to keep the plate load impedance low at the 65-megacycle signal frequency. Structurally, the trap circuit is characterized by a quarter-wave stub 110 connected across the outer conductor 77 of the coaxial coupling circuit and a quarter-wave coaxial line designated by 111 and 112 followed by a cylindrical polystyrene-filled resonant cavity 113 in the form of a disk transmission line shorted at its outer edge 114. The short circuit at the outer edge of the cavity is transferred to the gap 115 at the open end of the quarter-wave stub thus effectively isolating the microwave output energy from the B+ plate supply line.

Placing the radio-frequency output trap in the coaxial line between the quarter-wave transformer 74 and the coaxial-to-wave-guide transducer 83 as is done in Fig. 4 tends to extend the length of the coaxial line 78. The output trap shown in Fig. 3 in the form of a quarter-wave wire 86 placed in the output wave guide is not only a simpler structure than the trap of Fig. 4, but it also affords a saving of space and permits a compact unit since the length of the coaxial line 78 can be made shorter.

Although the present invention has been de-

scribed with reference to microwave modulating apparatus, it is apparent that various of the structural features are applicable to other forms of microwave apparatus such, for example, as microwave amplifiers. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination, a space discharge device having a grid septum and cathode and anode electrodes on opposite sides of the grid septum, a pair of conductively bounded space resonators having the said grid septum in a common boundary portion thereof and each enclosing one of said electrodes, a coaxial coupling circuit comprising a tubular outer conductor one end of which forms a part of the boundary of one of said space resonators and an inner conductor coupled to said one resonator, the separation between said coaxial conductors being constricted adjacent said one resonator over a length of substantially a quarter wavelength or odd multiple thereof at the resonance frequency of said one space resonator.

2. In combination, a space discharge device having a grid septum and cathode and anode electrodes on opposite sides of the grid septum, a pair of conductively bounded space resonators having the said grid septum in a common boundary portion thereof and each enclosing one of said electrodes, a coaxial coupling circuit comprising a tubular outer conductor one end of which forms a part of the boundary of one of said space resonators and an inner conductor coupled to said one resonator, a quarter-wave impedance transformer in said coupling circuit adjacent said one resonator and comprising an axially-movable section of one of said coaxial conductors whereby axial movement of said section adjusts the resonance frequency of said one space resonator.

3. In combination, a space discharge device having a grid septum and cathode and anode electrodes on opposite sides of the grid septum, a pair of conductively bounded space resonators having the said grid septum in a common boundary portion thereof and each enclosing one of said electrodes, a coaxial coupling circuit comprising a tubular outer conductor one end of which forms a part of the boundary of one of said space resonators and an inner conductor coupled to said one resonator, an impedance transformer in said coupling circuit adjacent said one resonator, said impedance transformer comprising a section of one of said coaxial conductors that is axially-movable and has a length of an odd number of quarter wavelengths at the resonance frequency of said one space resonator and a juxtaposed section of the other of said coaxial conductors that is axially-movable and has a length substantially greater than that of said first-mentioned section whereby axial movement of either of said sections affects the tuning of said one space resonator.

4. In combination, a conductively bounded enclosure adapted to support microwaves, a hollow stationary coupling probe entering through said enclosure, a tubular conductive shield around the portion of said probe external to said enclosure, a member within said shield adapted for movement axially of said probe, and an actuating tool passing through said enclosure and centrally through said hollow probe to engage said movable member and vary its position axially of said probe.

5. In combination, a conductively bounded enclosure adapted to support microwaves, a hollow stationary coupling probe one end of which enters through said enclosure, a tubular conductive shield around the portion of said probe external to said enclosure, an internally threaded tubular sleeve axially aligned with the other end of said hollow probe and constrained to be movable axially thereon and an actuating tool comprising a screw-driver or the like passing through said enclosure and centrally through said hollow probe to engage said threaded tubular sleeve and vary its position axially of said probe.

6. In combination, a conductively bounded enclosure adapted to support microwaves, a hollow stationary coupling probe one end of which enters through said enclosure, a cylindrical conductive shield around the portion of said probe external to said enclosure, a tubular sleeve axially aligned with the other end of said hollow probe and adapted for movement axially thereon, a member fixed within said tubular sleeve, said member having a threaded central section, a circularly-movable rod retained within said hollow probe, said rod having a threaded end to engage said threaded section of said member within said sleeve, a guide pin attached to the said other end of said probe and passing freely through a section of said member within said sleeve to prevent circular motion thereof, and an actuating tool comprising a screw-driver or the like passing through said enclosure and centrally through said hollow probe to engage said threaded rod and vary the position of said tubular sleeve axially of said probe.

7. In combination, an ultra-high frequency space discharge tube having a grid septum and a cathode and anode electrodes on opposite sides of the grid septum, a pair of conductively bounded resonant chambers having the said grid septum in a common boundary portion thereof and each enclosing one of said electrodes, a coaxial coupling circuit comprising a tubular outer conductor one end of which forms a part of the boundary of the one of said chambers that encloses said anode electrode and a hollow inner conductor, said coaxial coupling circuit including a quarter-wave impedance transformer adjacent said one chamber and comprising an axially-movable tubular conductor slidable on said hollow inner conductor and electrically connected to said anode electrode whereby an actuating tool may be inserted centrally through said hollow inner conductor to vary the position of said slidable tubular conductor axially to adjust the resonance frequency of said one chamber.

8. In combination, an ultra-high frequency space discharge tube having a grounded grid septum and a cathode and anode electrodes on opposite sides of the grid septum, a pair of conductively bounded resonant chambers having the said grid septum in a common boundary portion thereof, a first one of said resonant chambers enclosing the said cathode electrode of said space discharge tube and the second enclosing the said anode electrode thereof, a source of microwaves coupled to said first resonant chamber for impressing waves of ultra-high frequency thereon, a coaxial coupling circuit comprising a tubular outer conductor one end of which forms a part of the boundary of said second resonant chamber and an inner conductor one end of which is connected to said anode electrode, and an axially-movable quarter-wave coaxial impedance transformer in said coupling circuit adjacent said sec-

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ond resonant chamber for adjusting the resonance frequency of said chamber.

9. A grounded grid microwave modulator comprising in combination, an ultra-high frequency space discharge tube having a grounded grid septum and a cathode and anode electrodes on opposite sides of the grid septum, a pair of conductively bounded resonant chambers having the said grid septum in a common boundary portion thereof, a first one of said resonant chambers enclosing the said cathode electrode of said space discharge tube and the second enclosing said anode electrode thereof, an input wave guide connected to said first resonant chamber, means for impressing carrier waves of microwave frequency on said first resonant chamber through said input wave guide, means for impressing signal waves on said cathode electrode for intermodulation with said carrier waves, filter means in said input wave guide to reflect the modulated sideband energy appearing in said first resonant

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chamber into said second resonant chamber in phase with the modulated sideband energy appearing in said second chamber, a coaxial coupling circuit comprising a tubular outer conductor one end of which forms a part of the boundary of said second resonant chamber and an inner conductor one end of which is connected to said anode electrode, and an axially-movable quarter-wave coaxial impedance transformer in said coupling circuit adjacent said second resonant chamber for adjusting the resonance frequency of said second resonant chamber.

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REFERENCES CITED

The following references are of record in the file of this patent:

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Number	Name	Date
2,424,089	Gethmann	July 15, 1947