March 13, 1951 J. L. LAWSON 2,544,842

OVERLOAD PROTECTION OF HIGH-FREQUENCY RECEIVERS

Filed June 23, 1943 2 Sheets-Sheet 1

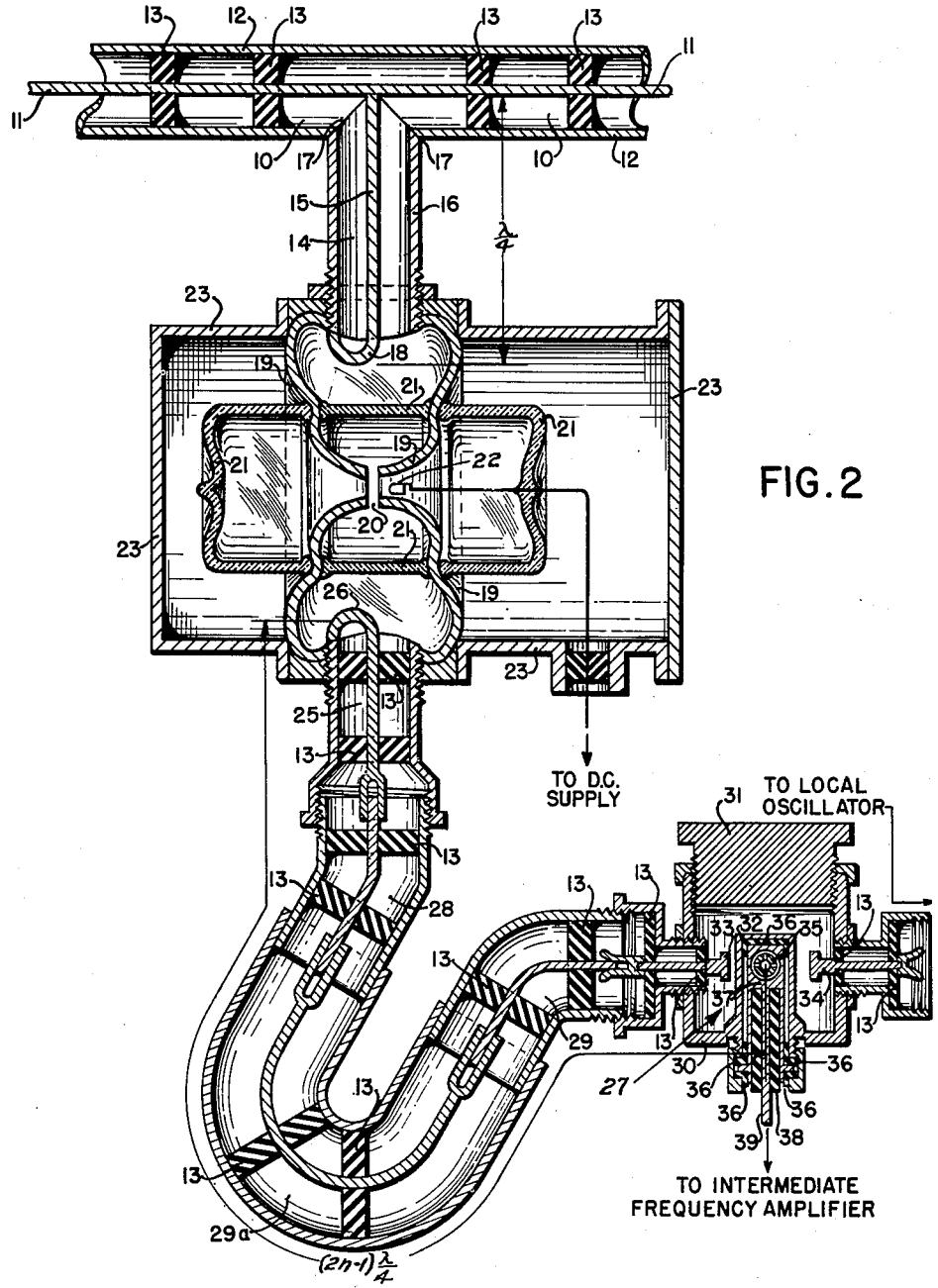


FIG. 2

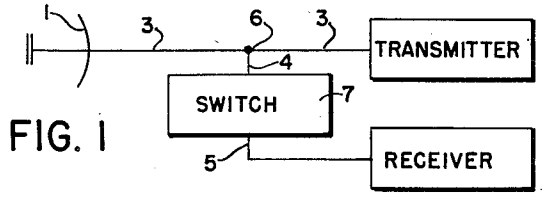


FIG. 1

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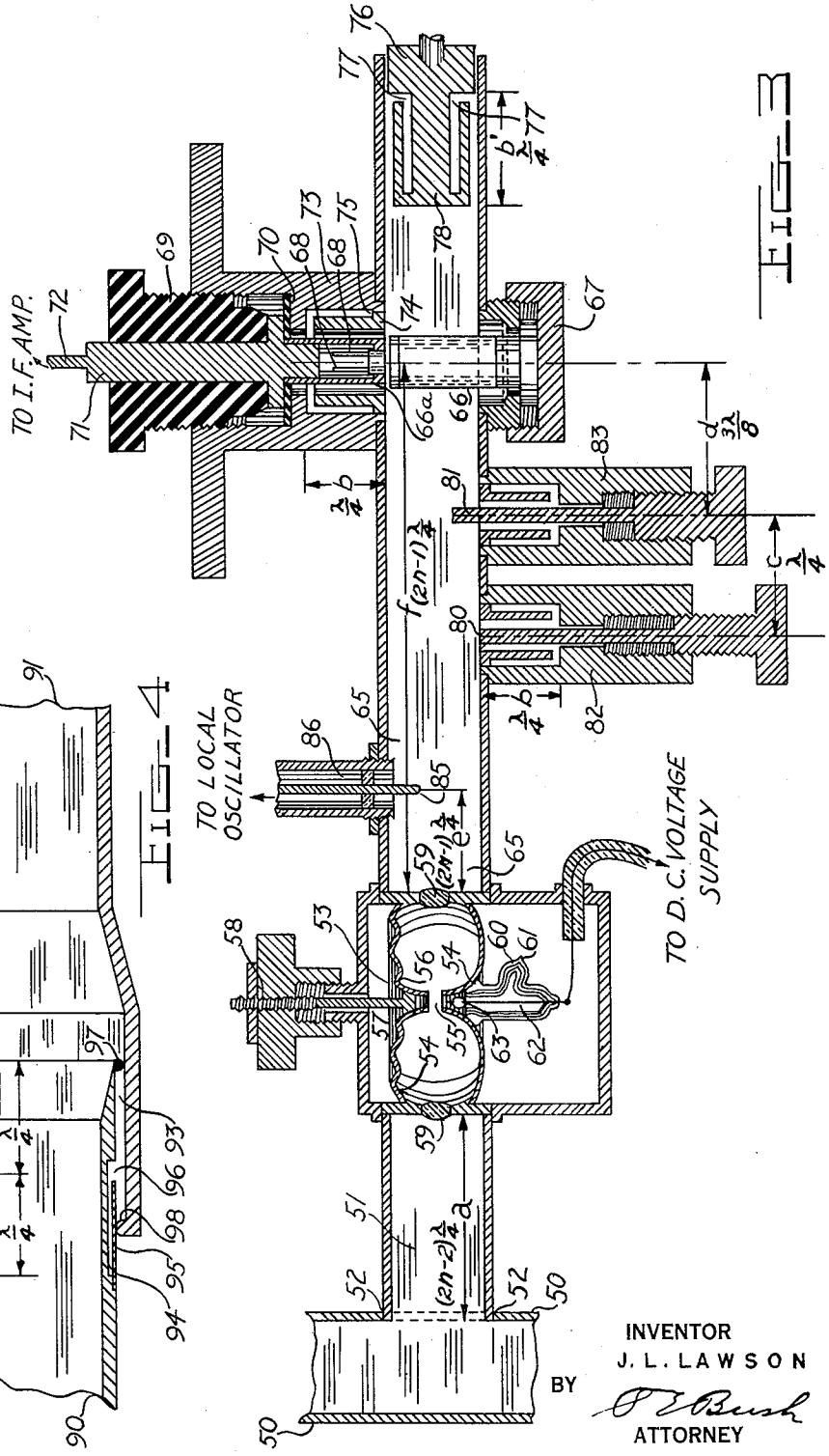


FIG. 3

FIG. 4

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OVERLOAD PROTECTION OF HIGH-FREQUENCY RECEIVERS

James L. Lawson, Cambridge, Mass., assignor, by mesne assignments, to the United States of America as represented by the Secretary of the Navy

Application June 23, 1943, Serial No. 491,988

10 Claims. (Cl. 250—13)

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This invention relates to radio transmitting and receiving systems in which a transmitter and a receiver are operated in connection with a common antenna system, and particularly to such systems in which an electrical breakdown discharge switching apparatus, such as those described in my copending applications, Serial 479,662 filed March 18, 1943 and entitled, "Protection of Receiver Against Overload," and Serial No. 492,062 filed June 24, 1943 and entitled, "Radio Transmit-Receiving System and Method of Adjusting the Same," is used for short circuiting the receiver input during periods of transmission.

The protection afforded to the receiver in such a system by an electric breakdown discharge device placed across its input is not complete because the electrical breakdown does not result in an absolute short circuit at the breakdown gap, but instead there is a definite voltage across the gap. Since the practical type of electrical breakdown switches employed utilize a resonator which acts as a transformer, as explained in one of the said copending applications, the voltage appearing across the receiver input is not as high as that across the gap. Nevertheless, the voltage of the disturbance appearing in the receiver input line as a result of the breakdown discharge, even though considerably downwardly transformed by the resonator of the discharge apparatus, may be sufficiently appreciable to make additional protection of the receiver input desirable.

I have found that the degree of protection afforded by electrical breakdown switches in transmission and reception systems employing a single antenna system for transmission and reception varies a great deal with the electrical line length between the electrical breakdown switch and the receiver input. Not only is it possible, according to this invention, to increase the degree of protection greatly by a proper adjustment of this electrical line length, as hereinafter described, but it is also to be noted that ignorance or disregard of the principles of this invention may result in an apparatus with an unfavorable line length between the electrical breakdown discharge device and the receiver input which greatly reduces the protective effect which would normally be expected from the electrical breakdown device. It is an object of this invention to improve the degree of protection against overload which can be provided for a receiver employed in a radio transmitting and receiving system employing a common antenna for transmitting and receiving, thereby increasing the service life of sensitive receiver components and making possible the use of more sensitive receiving apparatus. It is a further object of this invention to provide means for obtaining a maximum protection against overload for a receiver of given

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input characteristics provided with an electrical breakdown device of given characteristics.

Some of the possible arrangements for carrying out this invention are illustrated in the drawing, in which

Fig. 1 is a block diagram showing a type of system in which the invention finds its chief utility;

Fig. 2 shows in cross section an arrangement of apparatus for the realization of the advantages of this invention;

Fig. 3 shows, also in cross section, another possible arrangement of apparatus which embodies the invention, and

Fig. 4 is a cross section of an adjusting device which may be used in a modified form of apparatus of the general type shown in Fig. 3.

The block diagram, Fig. 1, shows the general location of the chief components in a typical system for transmitting and receiving with an antenna system which is common to the transmitter and receiver. Such systems are particularly useful in high-frequency radio echo detection and location service where highly directive antenna systems are usually employed and the antenna systems are usually movable for exploring in different directions, so that great economy of equipment and saving of space and weight can be effected by using a single antenna system for transmission and reception.

In Fig. 1 the transmitter and receiver are shown in a general way by large rectangles. The antenna system is shown at 1, the curved line 2 being representative of the usual parabolic reflector used in a directive antenna system operating at very high frequencies. The wave guide 3 is a linear transmission means, such as a coaxial transmission line or a hollow pipe of conducting material, for transferring high-frequency electromagnetic energy along its length. The lines 4 and 5 are likewise linear transmission means of the same character for transmitting energy from the antenna towards the receiver. The line 4 at one of its extremities forms a junction 6 with the line 3 so that the antenna 1 is effectively connected for interchange of high-frequency electromagnetic oscillatory energy with both the transmitter and the receiver. Between the lines 4 and 5 is inserted an electrical breakdown switch 7 which is designed to effect, to a large extent, an interruption of the transmission line connection between the receiver and the line 3 during periods when the transmitter is in operation by permitting an electrical breakdown discharge to be set up by the oscillations transmitted by the transmitter, as more fully described in my aforesaid copending applications.

It is the transmission line 5, between the electrical breakdown switch 7 and the receiver, the length of which I have now found to have an

important effect upon the mount of oscillatory energy which reaches the receiver while the transmitter is in operation and the switch 7 is functioning normally. The reason for this effect of the length of the transmission line 5 appears to lie in the fact that the input of the receiver, particularly if the input circuit includes a crystal detector, such as a silicon crystal, exhibits an impedance which varies non-linearly with the current therethrough. Thus when the receiver input circuit is properly matched to the impedance of the line 5 under low current conditions such as usually prevail during reception, the occurrence of larger currents during periods of transmitter operations on account of energy leaking through the electrical breakdown switch 7 will cause the receiver input to be appreciably mismatched to the line 5. Such mismatch will result in the formation of standing waves in the line 5, and the acceptance of energy by the system comprising the line 5 and the receiver input circuit will be largely determined by the phase of the standing waves at the end of the line 5 where it is connected to the electrical breakdown switch 7. For certain line lengths of the line 5 the phase of the standing wave will be such that increasing mismatch at the receiver input will result in an increased tendency to accept energy from the breakdown switch 7, thus increasing the possibilties of damage to the receiver from energy passing through the electrical breakdown switch 7. This will greatly reduce the effectiveness of the electrical breakdown switch. In electrical breakdown switches there will always be some energy passing on to the receiver because of the voltage occurring across the breakdown gap, and indeed, for low and medium power transmitters, at least, the voltage passed on to the receiver is almost independent of the transmitter power but depends instead upon the characteristics of the electrical breakdown switch 7 and in particular upon the nature of the discharge gap. The discharge device may be regarded as a constant voltage generator (that is, a generator with a low internal impedance); consequently, the power it delivers to the load depends chiefly on the impedance of the load, being great when a low impedance is presented across the output of the breakdown device. If now the length of the standing wave upon the line 5 is such that a relatively large energy will be accepted for a given voltage appearing at the switch 7, then more energy will be taken from the line 4 and the apparatus 7 and passed on to the receiver than would be passed if the length of the standing waves on the line 5 were such as to inhibit the acceptance of energy by the line 5 and receiver input, although the voltage at the electrical breakdown gap in these two cases might not be very different.

When the input stage of the receiver is a crystal mixer circuit or, in general, a crystal detector circuit, increased current through the crystal will reduce the impedance of that element. Thus if the crystal circuit is matched to the line under receiving conditions, a rise of crystal current during periods of transmitter operation will result in the receiver input having an impedance lower than the characteristic impedance of the line, so that the standing waves set up in the line will be those of the type set up by a short circuit in the line (that is, there will be a voltage node of the standing wave pattern at the crystal). Therefore, if the line 5 is coupled to the electrical breakdown switch 7 at a low impedance point of a resonator associated with the electrical breakdown switch, which is usually done in order that the gap voltage may be downwardly transformed between the electrical discharge gap and the line 5, a minimum of energy acceptance by the system comprising the line 5 and the receiver input can be obtained by making the electrical length of the line 5 from the non-linear element of the receiver input to the coupling arrangement between the line 5 and the electrical breakdown switch 7 very nearly equal to an odd number of quarter wave lengths of the oscillations in question. The theoretically prescribed electrical length for the effect sought in accordance with the invention, however, refers to the length from the sensitive point of the crystal. The electrical length in the crystal cartridge and in the mixer resonator, if one is used, may be difficult to calculate or measure. There is also some "end effect" at the other end of the line 5 on account of loading (usually inductive) inherent in the coupling between the line 5 and the device 7, though this effect is not usually large. Consequently, the desired adjustment of the line 5 is most conveniently made by standing wave measurements or by other measurements determinative of the phase of the standing waves in the line 5 where the line 5 is connected with the device 7, as hereinafter more particularly described.

If a receiver input should be used the impedance of which increases with overload, then upon overload the standing wave in the line 5 would exhibit a voltage antinode at the receiver end and consequently the desirable length of the line 5 from such a receiver input to a low impedance output end of the breakdown device 7 would be approximately an integral number of half-wave lengths of the oscillations in question instead of an odd number of quarter-wave lengths. This is chiefly a matter of academic interest, however, for the receiver inputs used in practice almost universally exhibit a decrease of impedance upon overload, when they exhibit any non-linear effect at all.

Two illustrative arrangements of apparatus forming part of systems of the general type shown in Fig. 1 and adapted for the application of this invention are shown respectively in Fig. 2 and Fig. 3. The arrangement of Fig. 2 illustrates the use of the invention in a system employing transmission lines of the coaxial conductor type for transferring energy from one component of the system to another. The arrangement of Fig. 3 illustrates the application of the invention to a system in which metallic hollow pipes are used for guiding the oscillatory energy from one part of the system to another.

Referring to Fig. 2, the transmission line between the transmitter and the antenna system, corresponding to the transmission line 3 in Fig. 1, is shown at 10, with an inner conductor 11 and an outer conductor 12 in the usual coaxial form. The elements 13 appearing at various parts of the system are spacing discs made of insulating material. Another transmission line 14 having an inner conductor 15 and an outer conductor 16 forms a junction with the transmission line 10 at the point 17. At its other end the transmission line 14 is coupled by means of a loop 18 to a resonator 19 forming part of an electrical breakdown device and provided with a gap 20 adapted to permit an electrical breakdown discharge to

take place while the transmitter (not shown on Fig. 2) is in operation. As pointed out in my said copending application, the electrical length of the coaxial transmission line 14 should approximate an odd number of quarter wave lengths of the transmitted oscillations, in order to mitigate interference with transmission of power to the antenna.

The resonator 19 is of generally toroidal shape and may be provided with a tuning adjustment (not shown) located on its outer surface at some point conveniently spaced from coaxial line couplings and other obstructions. The electrical breakdown device of which the resonator 19 forms a part is provided with a glass envelope 21 sealed to the metal wall of the resonator 19 for the purpose of maintaining a partial vacuum in and around the electrical discharge gap 20. An electrode 22 is also provided within the glass envelope 21 and near the discharge gap 20, although not within the oscillating field of the resonator 19, upon which electrode a steady electrical potential may be impressed with respect to the resonator 19 and its associated structure, in order to maintain a low but constant degree of ionization in the neighborhood of the gap 20 so that prompt breakdown is promoted in the gap 20 upon the commencement of transmitter operations. A housing 23 is also provided for convenience of support and installation and for protection of the resonator 19 and the glass envelope 21 from mechanical shock. This housing is preferably made of metal in order that it may also act as an electrical shield about the discharge taking place at the gap 20. An output transmission line 25, which like the transmission line 14 has a coaxial configuration, is coupled to the resonator 19 by means of a loop 26. The transmission line 25 leads oscillatory energy from the loop 26 to a receiver input stage, here shown as a crystal mixer apparatus 27. Between the loop 26 and the crystal mixer apparatus 27 two bent sections of line 28 and 29 are inserted in order to accommodate a U-shaped section of line 29*a* provided with extremities adapted to form sliding joints with the sections of line 28 and 29. The U-shaped section of line 29 may be descriptively termed a "trombone section" or "line-stretcher." By sliding the trombone section 29 axially with respect to the extremities of the section 28 and 29 engaged therewith, the electrical line length between the loop 26 and the mixer apparatus 27 may be varied in order that the optimum length for protection of the crystal element of the mixer apparatus 27 may be obtained as described in connection with Fig. 1.

The crystal mixer apparatus 27 comprises a resonator which includes a cylindrical shell 30, a cover plug 31 which is adjustable for tuning purposes and a central cylindrical post 32. This resonator may be regarded or analyzed either as a resonant cavity or as a capacity loaded resonant section of coaxial conductor transmission line. The outer conductor of the line 25 is connected with the cylindrical shell 30 and the inner conductor of the line 25 is brought into the cavity of the resonator and is terminated by a disc 33 which is positioned quite close to the post 32, whereby a coupling condenser is constituted. Oscillatory energy transmitted by the transmission line 25 is able to excite the resonator of the crystal mixer apparatus 27. In a similar manner the output of a local oscillator (not shown) is coupled to the resonator of the crystal mixer apparatus 27 by means of a disc shown at 34. It is usually desirable to couple the local oscillator more loosely to the apparatus 27 than the corresponding coupling between the line 25 and the apparatus 27, since the signal voltage is usually lower than the local oscillator voltage and it is desired to inhibit the transfer of signal energy from the line 25 to the local oscillator, which might result in undesired losses.

In the crystal mixer apparatus 27 the crystal (not shown) is supported at one end in a clip 35 and at its other end by a suitable arrangement to the outer wall of the cylindrical shell 30 (not shown). The particular form of mixer apparatus shown at 27 has the central post 32 of the resonator constructed in a composite form with an outer conducting shell separated by insulation 36 from an inner post 37, also of conducting material, upon which the clip 35 is supported. The inner and outer conducting parts of the post 32 are, because of the narrow clearances between them, capacitively coupled, so that a resultant oscillatory voltage induced by the discs 34 and 33 and appearing in the resonator circuit which includes the post 32 will be impressed across the crystal. Part of the inner conducting post 37 is cut away and a cylinder of insulating material 38 inserted therein in order that the element 37 might embody a choke which would prevent radio frequency energy from going into the intermediate amplifier. The ungrounded end of the intermediate frequency amplifier is connected to the extremity 39 of the element 37. Other forms of mixer apparatus could of course be used in a system such as that of Fig. 2.

If a crystal mixer is used in an input stage of the receiver, as for example in Fig. 2, the crystal should be so located (e. g. by adjusting input line length) that when the crystal current rises and approaches the assumed safe limit for reasonable crystal life, the impedance presented to the resonator 19 at the loop 26 should be high, so that the line 28 tends to accept less energy. It is therefore desirable that the crystal be either matched to the line or mismatched in such a fashion that overload will increase the mismatch, the direction of mismatch desired being the "short-circuited termination" type in the case of crystals which reduce their impedance upon overload. Exact matching of the crystal to the resonator and line system is to be desired for obtaining maximum response to an incoming signal during reception, but for purposes for insuring adequate protection of the crystal during periods of transmission it may be advisable to provide a slight amount of mismatch in the above-mentioned sense. In the crystal mixer of Fig. 2 the matching of the crystal may be varied by varying the location of the clip 35 longitudinally of the post 32. In the apparatus of Fig. 3, which is about to be described in detail, adjustments are provided for matching the particular crystal employed to the input circuit or for introducing any desired degree of mismatch for additional crystal protection at the expense of a small amount of receiver sensitivity.

In Fig. 3 is shown an arrangement of apparatus for carrying out the present invention which is particularly adapted for transmitting and receiving systems in which hollow pipe wave guides are used for the transfer of oscillatory energy from one part of the system to another. Such an arrangement is consequently of particular utility at the shorter wave lengths and in apparatus where high transmitter power is employed. The hollow pipe wave guide leading from the

transmitter to the antenna system is shown at 50. This and the other wave guides of the system are usually provided in rectangular form, although cylindrical wave guides could also be used, because the rectangular form of wave guide gives good control over the polarization of the transmitted waves. A branch wave guide 51 forms a junction with the wave guide 50 at 52. The various wave guides in Fig. 3 are shown in a section parallel to the direction of the electric vector, which is to say, in accordance with wave guide design practice, they are shown in a longitudinal section parallel to the shorter wall of the wave guide. The junction 52 is therefore one of the type known as an "electric plane" junction. It is to be understood that a "magnetic plane" junction could also be used, in which case the axis of the wave guide 50 would have a direction perpendicular to the plane of Fig. 3 and the junction 52 would open into a narrower wall of the wave guide 50 instead of into one of its broader walls.

The wave guide 51 leads to an automatic electric breakdown discharge device 53 provided with a resonator 54 having a discharge gap 55. This device has the same function as the apparatus inside the housing 23 of Fig. 2. In this particular form of device the resonator 54 is provided with a flexible wall 56 which permits adjustment of the dimensions of the gap 55 and consequently of the resonant frequency of the device by means of a rod 57 and a screw thread adjustment 58. Coupling between the input and output wave guide and the resonator 54 is provided simply by holes in the resonator walls which close off the respective wave guides, which coupling holes are provided with sealed-in glass windows 59 for the purpose of maintaining a partial vacuum in the resonator 54. The partial vacuum is originally established through an exhaust tube 60, which is sealed off, as at 61, after the evacuation. The exhaust tube also serves for the support of a "keep alive" electrode 62 having the same function as the electrode 22 of Fig. 2. A small glass bead 63 is mounted on the electrode 62 to prevent accidental short-circuiting of the electrode voltage and to assist in centering the electrode in the structure.

In order to reduce dissipation of transmitter power of the gap 55 the length of the wave guide 51 should be properly adjusted. As pointed out in my said copending application the length of the wave guide 51 indicated on Fig. 3 by the dimension a should closely approximate an even number of half-wave lengths for best results, with a small adjustment (usually shortening the length slightly from that just prescribed) on account of the loading effect of the coupling aperture between the wave guide 51 and the resonator 54. It will be noted that the proper length of a hollow pipe wave guide between a wave guide junction and an electrical breakdown switch differs from the desirable length between a coaxial conductor line junction and an automatic electrical breakdown switch, as is pointed out more fully in my above referred-to companion application.

The resonator 54 is coupled through the other of the windows 59 to a wave guide 65 leading towards the receiver input. In the apparatus of Fig. 3 the function of the resonator apparatus 27 of Fig. 2 is performed by the end portion of the wave guide 65 in the neighborhood of the crystal 66, which portion is caused to act as a resonant section of wave guide, the characteristic impedance of the non-resonant part of the wave guide 65 being matched to the resonant section of wave guide which includes the crystal, by means of a suitably located loading capacitance as hereinafter described. Such apparatus may be said to function as a resonant transformer between the crystal and a non-resonant transmission means. This view is only accurately descriptive when the impedances of the system are fairly well matched by the arrangement, for otherwise the transmission means connected to the "transformer" will have standing waves and will not act as a non-resonant line.

The crystal 66 which operates as a first or heterodyne detector is located between a clip 66a and an adjustable screwcapped recess 67, thus being essentially across the wave guide 65. The crystal 66 is shown in the form of a cartridge of the type commonly used for mounting microwave detector crystals, which contains the usual silicon crystal, "cat's whisker" wire and electrical connections, the structure being sealed in wax and enclosed in an insulating structure having terminal contact caps. This form of structure is adapted to preserve the crystal contact adjustment against disturbance from shock. The clip 66a is hollow in order to receive the crystal and is provided with slots such as those shown at 68 in order to provide spring action for better contact with the crystal. The clip 66a is insulated from the wave guide structure by a large insulating plug 69 and a thin insulating washer 70. A direct connection is made from the clip 66a to the ungrounded side of the input of the intermediate frequency amplier of the receiver (not shown), the electrical connection being effected by means of the rod 71 and the wire 72. Although for purposes of clearer illustration the washer 70 appears on the drawing as having a substantial thickness, in fact this washer in practice is extremely thin and may for instance be made by stamping out of polystyrene tape of a thickness of only five thousandths (.005) of an inch.

The close approach of the structure 71 to the structure 73 across the thin polystyrene washer 70 provides a by-pass condenser across the intermediate frequency amplifier input which by its filtering action tends to prevent any signal or local oscillator frequency currents which may reach the neighborhood of the washer 70 from going on toward the intermediate frequency circuits. The by-pass capacitance so provided is too small to have any appreciable effect upon the intermediate frequency output of the mixer stage.

Although the by-pass capacitance just described can serve to filter the intermediate frequency output of the mixer it is too far from the crystal to provide the short and direct signal frequency connection desired between the end of the crystal cartridge engaged in the clip 66a and the wave guide wall. The latter effect is obtained by surrounding the clip 66a by a resonator such that a short circuit for such frequency appears by "reflection" at the crystal end of the clip, which is to say that the resonator presents an extremely low impedance between the clip and the wave guide wall for its resonant frequency. Such a resonator may be designated as a "by-pass resonator." The special form of resonator used for radio frequency by-passing is formed by providing a circumferential space about the clip 66 and dividing that space by a flanged cylinder 74, the flanged end of which forms part of the wave

guide wall 65 and is in good electrical contact with the structure 73. As shown on Fig. 3 this results in providing a cylindrical space which at a certain distance from the point where it opens up into the wave guide is folded back on itself and terminates in a closed end at 75. The point where this space or cavity is folded back on itself is made to approximate very closely a quarter-wave length of the oscillations of microwave frequency upon which the device is to operate, which is to say that the dimensions shown at *b* on Fig. 3 should approximate a quarter-wave length of such oscillations. The closed end of the cavity at 75 will then "appear" at the mouth of the cavities which surround the extremity of the clip 66*a* as a very low impedance, practically a short circuit, since the mouth is spaced electrically a half-wave length away from the closed end 75. In addition the configuration of this by-pass resonator is such that the nature of the electrical insulation between the rod 71 and the structure 73 at points beyond the folded end of the resonator becomes quite immaterial to the radio frequency operation of the crystal circuit. As a result of the operation of the by-pass resonator the crystal is effectively, for the microwave frequencies in question, connected directly across the wave guide 65.

The end of the wave guide 65 beyond the crystal location is closed off by a conducting plug or plunger 76. This plunger 76 is provided on its upper and lower faces with by-pass resonators such as those just described in connection with the clip 66*a*. Since the configuration of the wave guide is, as in the usual case, rectangular, and since the by-pass resonators are in such a case useful only between the plunger and the broader sides of the wave guide (the electric vector being perpendicular to the broader side), the by-pass resonators are rectangular in configuration in the case of the plunger 76 instead of cylindrical as shown in connection with the clip 66*a* and the structure 73. The by-pass resonators are shown in the plunger 76 at 77. As in the case of the by-pass resonator in the structure 73 surrounding the clip 66, the dimension marked *b'* on Fig. 3 should closely approximate one quarter of the wave length of the oscillations in question. When constructed as described the plunger 76 acts to close off the wave guide 65 at the plane of its front surface 78 with the practical effect of a perfectly conducting terminating wall, irrespective of the quality of the contact between the plunger 76 and the wave guide 65 rearwardly of the by-pass resonator 77.

Motion of the plunger 76 in or out of the wave guide 65 will change the pattern of the standing waves produced as a result of reflection of oscillations from the termination of the wave guide at the surface 78, so that by adjustment of the position of the plunger 76 the impedance of the oscillating system at the point where the crystal is connected across it may be made to match the impedance of the crystal or to correspond to some slightly higher value, providing the factor of safety against overload as previously described in the discussion of the system of Fig. 2.

In order that the resonant end portion of the wave guide 65 which includes the crystal and its associated structure may be coupled to the signal input for maximum energy transfer of the received signal during periods when the transmitter is not operating, which requirement usually corresponds to the requirement that there shall be no standing waves in the portion of the wave guide 65 immediately adjacent to the electrical discharge device 53, two adjustable capacitance loading devices 80 and 81 are provided in the wave guide 65 at particular locations between the crystal position and the electrical discharge device 53. Because crystals usually differ quite widely from each other in radio frequency impedance, a sufficiently wide range matching adjustment for practical use cannot be made with a single adjustable capacitance at a fixed location. A single adjustable matching capacitance such as the structure 81, 83 could be mounted in a fashion permitting it to be slid longitudinally along the wave guide 65, which could be suitably slotted for the purpose. I prefer, however, to provide two adjustable matching capacitances, separated by a distance equal to a quarter wave length of the oscillations in the guide (as indicated by the dimension *c* on Fig. 3), so that if a suitable match cannot be obtained with any adjustment of one of the capacitances, it is practically certain to be obtainable with some adjustment of the other adjustable capacitance. One of the adjustable capacitances is thus preferably kept flush with the wave guide as shown by the position of the capacitance screw 80.

The capacitance loads 80 and 81 are essentially screws protruding into the wave guide 65 at suitably selected points. The structures 82 and 83 in which the screws 80 and 81 are respectively threaded and which are in electrical contact with the wall of the wave guide 65 are provided with by-pass resonators similar to those previously described in connection with the structure 73 and in connection with the plunger 76, which here serves the function of establishing an effective radio frequency connection directly between the screws 80 and 81 and the immediately adjacent portion of the wall of the wave guide 65. Thus a good radio frequency electrical contact is maintained at the desired point between the capacitance load and the wave guide wall, irrespective of the quality of electrical contact occurring at the screw threads associated with the capacitance loading devices. This is a great advantage since the electrical contacts at such screw threads are often uncertain and sparking might otherwise occur. The by-pass resonators in this case have a cylindrical configuration, similar to that of the by-pass resonator associated with the structure 73 surrounding the crystal clip 66. As before, the dimension of these resonators marked on Fig. 3 as *b* should closely approximate one quarter of the wave length of the oscillations in question.

The distance between the axis of the crystal 66 and the nearer matching screw 81, shown on Fig. 3 by the dimension *d*, is not critical within wide limits, since variations therein can usually be compensated by adjustment of the particular matching screw which is used. Distances less than one-half wave length are to be preferred in order to minimize frequency sensitivity. It is to be noted that the continuation of the wave guide 65 beyond the crystal 66 and the adjustable termination 78 in effect constitute a variable admittance across the wave guide 65 at the crystal position. The tuning screws 80 and 81 likewise constitute variable admittances across the wave guide 65. The adjustment of the terminating wall 78 and of one of the screws 80, 81 may be performed in accordance with the practice relating to "double stub" tuners for the purpose of matching the impedance of the crystal to the characteristic impedance of the wave guide

65. Also in accordance with the practice in connection with double stub tuners, a spacing between the variable admittances of approximately three-eighths wave length is preferred, so that the distance *d* indicated on Fig. 3 between the crystal axis and the axis of the tuning screw 81 is preferably made approximately three-eighths or one-third wave length. This dimension may be varied rather widely, however, the only limitation being that a spacing between the crystal axis and one of the tuning screws equal to a half wave length would make the tuning screw in question useless, since a double stub tuner with one-half wave spacing between stubs would require stubs capable of adding infinite susceptance in order to fulfill its purpose, a condition which cannot generally be met in practice.

The matching arrangement comprising the adjustable closure 78 and the adjustable capacitive loads 80 and 81 is somewhat different from the conventional double stub tuner to which an analogy has just been drawn for the purpose of illustration and explanation, one of the tuning stubs being replaced in this case by two tuning elements, the screws 80 and 81. It is desirable to provide two matching screws 80 and 81 as shown because the variable admittance provided by a capacitive load has a range corresponding only to a 90° variation in the electrical length of a tuning stub of a double stub tuner. In order that the other 90° variation may be provided in order to complete the 180° of variation necessary for full control over the matching of reactances it is desirable to provide a second capacitive load a quarter-wave length distant from the first capacitive load. Ordinarily the matching adjustment is made by adjusting the plunger 76 and one of the screws 80, 81, the other screw being left in a retracted position such as that of the screw 80 in Fig. 3.

In order that the crystal may function as a heterodyne detector or mixer it is necessary to feed to the crystal a locally generated oscillation as well as the signal picked up by the antenna system. In the apparatus of Fig. 3 the local oscillator output is coupled to the wave guide 65 by extending the central conductor 85 of the coaxial output line 86 of the local oscillator so that the conductor 85 protrudes into the wave guide 65 and is thereby adapted to excite oscillations in the wave guide 65 which will be transmitted along the wave guide to the crystal. In order to mitigate transfer of energy from the local oscillator to the resonator 54 and then to the antenna system and out into space, the location of the central conductor 85 where it protrudes into the wave guide 65 is so arranged that the distance between it and the apparatus 53 which distance is shown on Fig. 3 by dimension *e*, is approximately an odd number of quarter-wave lengths of the oscillations in question, thus mismatching the oscillator output for transfer of energy toward the antenna and mitigating undesired radiation.

For the application of the present invention to the arrangement of apparatus shown in Fig. 3 the apparatus should be so constituted that the distance between the crystal and the output side of the apparatus 53, which distance is shown on Fig. 3 by the dimension *f*, will approximate an odd number of quarter-wave lengths of the oscillations in question, subject to allowances for terminal effects discussed below. In the apparatus of Fig. 3 no arrangement is shown for adjusting the dimension *f* and it is expected that the frequency of operation will be sufficiently well known in advance of manufacture that the proper dimension *f* can be incorporated into the design of the apparatus. If the frequency of operation is not known to a sufficient degree of accuracy for the obtaining of a dimension *f* suitable to achieve the advantages of this invention in the fullest degree, mechanical arrangements could be provided in the portion of the wave guide 65 adjacent to the apparatus 53 for varying the wave guide length. Such an arrangement could be a sliding joint, preferably one provided with a by-pass resonator as shown in Fig. 4 and hereinafter described, which would eliminate the necessity for extremely good electrical contacts. As in similar cases previously described, the exact magnitude of the dimension *f* is subject to a slight correction which in the case of the apparatus of Fig. 3 would be a slight decrease in the length *f*, on account of the loading effect of the coupling aperture between the wave guide 65 and the resonator 54. This correction is relatively slight and it may be estimated by known methods either through calculation or experimental determination. A more important factor modifying the actual dimension *f* used in practice lies in the fact that the crystal cartridge 66 has an appreciable electrical length, which should be taken into account in any calculation of the dimension *f*. The calculation of these terminal effects can be avoided if the dimension *f* is determined by direct experiment, such as by measurement of the standing waves in the wave guide 65 for different amounts of crystal current.

It is to be noted that the dimensions which have heretofore been described in terms of wave lengths are not to be referred to the free space wave lengths of the oscillations in question, but rather to the wave lengths of the oscillations in the structure in question. Where the structure in question is a wave guide of known cross section, the wave length of the oscillations within the wave guide may readily be calculated by known formulae and of course it may also be experimentally determined. The wave length in two conductor lines is affected by such factors as the number and kind of spacing insulators. Formulae for the wave length in various types of line are well known. The wave length to which the dimension shown on Fig. 3 as small *b* refers is related to a somewhat more complicated structure, namely, the by-pass resonators above described. These resonators operate in the "coaxial" mode and the wave length is substantially the free space wave length, it being desirable, however, to make a small allowance for the "end effect" at the mouth of the resonator in calculating the length of the resonator. The by-pass resonators 77 operate in the rectangular wave guide mode and the electrical quarter-wave length dimension *b'* should consequently be physically somewhat longer than the electrical quarter-wave length dimension *b*, being almost one quarter of the wave length in the guide 65 (but not quite that great, because of the lesser width of the resonators 77).

As shown in Fig. 3, the spacing of the electrical line length according to this invention between the protective breakdown switch and the receiver input may be provided for in the design of the apparatus when the apparatus is intended to be used at a single frequency, without incorporating means for adjusting the said spacing. If it is desired to incorporate into apparatus of the general configuration shown

in Fig. 3 some means for adjusting the said spacing in accordance with changes in operating frequency, this may be done by providing a sliding joint in the pipe wave guide 65, as above suggested. A preferred type of sliding joint for the provision of such an adjustment is illustrated in Fig. 4.

In Fig. 4 the two portions of rectangular pipe wave guide between which the sliding joint is arranged are shown at 90 and 91 in a cross section parallel to the electric vector of the oscillations intended to be transmitted. The pipe 91 is provided with a widened extremity 92 adapted to fit over the pipe 90 leaving a small clearance 93 between the upper and between the lower walls. Shallow cavities 94 are formed in the upper and lower sides of the pipe 90 (i. e., its broader sides) which are covered by conducting partitions 95 except for a narrow slot 96 along the forward end of each cavity 94, where the said cavities communicate with the clearance space 93. The center lines of slots 96 are spaced an electrical quarter-wave length from both the end of the pipe 90 and from the rear wall of the associated cavity 94. Such electrical quarter-wave length corresponds approximately to the dimension *b'* on Fig. 3.

The cavities 94 are closed off at the sides by the lateral walls of the pipe 90 which also provide support for the cover plates 95. The plates 95 are preferably soldered onto the pipe wave guide 90. Beads 97 and 98 are provided on the wave guide extremities to maintain the clearance 93 between the upper walls and between the lower walls of the wave guide pipes and to assure the absence of electrical contact at points located between the slots 96 and the immediate neighborhood of the end of the wave guide 90. The beads 97 need not be continuous ridges and may be replaced by simple guide studs near the corners of the wave guides or at intervals across the guide walls along a line perpendicular to the wave guide axis.

The cavities 94 cooperate with the clearance space 93 to constitute by-pass resonators and to produce the equivalent of a very good electrical contact between the end of the pipe 90 and the wall of the pipe 91 for electric oscillations of frequencies approximately equal to the frequency of operation.

In an apparatus in which the length of the line between the receiver input and the electric breakdown device is adjustable, as for instance in the apparatus shown in Fig. 2, the line length best adapted to protection of the receiver against overload in accordance with this invention may readily be obtained in accordance with the following method. First a signal is tuned in on the receiver which, although not strong enough to cause a breakdown in the protective electrical breakdown device, is sufficiently strong so that some mismatch occurs at the receiver input. If the receiver input is purposely mismatched for additional protection as above mentioned, any signal sufficiently strong to be distinguished can be used for this adjustment. The signal in question might be provided by a signal generator associated with the transmission line 10 or with the transmission line 14 or it might be provided by a suitable operation of the transmitter to produce an echo signal at repeated intervals which is of sufficient strength for convenient performance of the adjustment in question. When a signal has been tuned in on the receiver under conditions producing some mismatch at the receiver input, the line length should be varied (which in the case of the apparatus of Fig. 2 would be performed by moving the trombone section 29*a*) until a minimum signal strength is observed (at the same time varying the local oscillator coupling, if necessary, to maintain a substantially constant crystal current). In cases where the adjustment in question is an important part of the receiver protection provided in the apparatus, it is of course desirable to perform this test with a signal generator rather than in connection with the operation of the transmitter of the system, to avoid overloading the receiver during transmitter operation at moments when the line between the protective device and the receiver is at an unfavorable adjustment.

In practical apparatus of the type in question, such, for instance, as the apparatus shown in Fig. 2, one of the coupling loops of the automatic electrical breakdown device is usually made adjustable, which adjustment may be coordinated with the foregoing adjustment as follows. After the length of line between the receiver input and the protective electrical discharge device has been adjusted for minimum received signal, the adjustable coupling in the electrical discharge device is then readjusted for maximum received signal. Since this adjustment of the coupling may have disturbed the previous adjustment of the line length, slight readjustment of the line length, again for minimum signal, might well be made. If the latter adjustment appears to be of substantial proportions, the coupling may again be readjusted for minimum signal. In this fashion the adjustment for maximum energy transfer upon reception through the resonator of the electrical discharge device is coordinated with the adjustment of the line length between such device and the receiver input for maximum receiver protection against overload during transmission.

It has been experimentally found in connection with this invention that the difference in power absorption at the crystal during periods of transmission under conditions of optimum adjustment of the distance between the crystal and the electrical breakdown device in accordance with this invention and the most undesirable adjustment of the aforesaid distance may amount to as much as ten decibels in the case of systems of the general type which have been heretofore manufactured. The adjustment of the electrical line length between the receiver input and the electrical breakdown device is therefore of great importance in obtaining the full benefit of the capabilities of the electrical breakdown device in question.

What I desire to claim and secure by Letters Patent is:

1. In a high-frequency radio circuit including a sensitive detecting device which has a nonlinear impedance characteristic with respect to the current therethrough and a protective electrical breakdown device having low internal impedance and an inductively coupled output, transmission means connecting said output and said sensitive detecting device of a length closely approximating an odd number of quarter wave lengths at the frequency of operation of said circuit whereby when the current in said sensitive detecting device increases beyond a predetermined amount at a desired frequency of operation, the input impedance of said linear transmission means at the end thereof connected with

said output changes so as to inhibit acceptance of energy by said transmission means and said sensitive device.

2. In a high-frequency radio circuit including a sensitive detecting device which exhibits a radio frequency impedance decreasing as current through said device increases and, coupled to said device, a protective breakdown device having characteristics of a generator with a low internal impedance, the provision of transmission means and associated coupling means, interposed between said breakdown device and said sensitive device, of a length such that the total electrical length of said transmission means, including said coupling means, closely approximates an odd number of quarter-wave lengths at the frequency of operation of said circuit.

3. In a high-frequency radio receiving circuit including a crystal detector and a protective resonant electrical breakdown device having an inductively coupled output, a linear transmission means connecting said output and said crystal detector of a length approximately equal to an odd number of quarter-wave lengths in said transmission means of oscillations of the frequency of operation of said circuit.

4. In a high-frequency radio receiving circuit including a detector element which exhibits a radio frequency impedance decreasing as current through said element increases and a protective resonant electrical breakdown device, a transmission means connecting said device and said detector element of an electrical length between said device and the sensitive point of said detector element approximately equal to an odd number of quarter-wave lengths for the means frequency of operation of said circuit.

5. In a high-frequency radio receiving circuit including a crystal detector element which exhibits a radio frequency impedance decreasing as current through said device increases above a predetermined normal value and a protective resonant electrical breakdown device having an output coupling, transmission means of adjustable length connecting said output coupling of said device and said detector element and adjusted to a length such that standing waves occurring in said transmission means between the sensitive point of said detector element and said output coupling when current in said element exceeds said predetermined normal value exhibit a pattern of an odd number of quarter waves.

6. In a high-frequency radio system for transmitting and receiving over a common antenna, the combination which includes a protective resonant electrical breakdown device having inductive output coupling means, a detecting element which exhibits radio frequency impedance decreasing as current through said element increases and a transmission means connecting said output coupling means and said detecting element having an electrical length closely approximating an odd number of quarter-wave lengths at the frequency of operation of said system.

7. The method of protecting against overload a sensitive detector element having a non-linear radio frequency impedance characteristic in a high frequency radio receiving system which includes in addition to said element a protective resonant electrical breakdown device and an adjustable coupling therethrough and also a linear transmission means of adjustable length connecting said electrical breakdown device and said sensitive element, which method consists of alternately adjusting the length of said linear transmission means for minimum reception of a strong signal and adjusting said adjustable coupling for maximum reception of said signal until said minimum and maximum adjustments substantially coincide.

8. The method of protecting against overload a sensitive detector element having a non-linear radio frequency impedance characteristic in a high frequency radio receiving system which includes in addition to said element a protective resonant electrical breakdown device having an adjustable coupling therethrough and also a linear transmission means of adjustable length connecting said electrical breakdown device and said sensitive element, which method consists of adjusting the length of such linear transmission means for a minimum received signal when a signal of sufficient strength to cause a mismatch between said element and said transmission means in the same direction as the mismatch occurring upon overload is impressed upon said system and said detector element.

9. A high-frequency radio circuit including a sensitive detecting device which exhibits a radio frequency impedance decreasing as current through said device increases, a protective electrical breakdown device having when broken down, a low internal impedance, a resonator associated with said sensitive detecting device, transmission means connecting said breakdown device and said sensitive detecting device of a total electrical length approximately equal to an odd number of quarter-wave lengths for the frequency of operation in said circuit, said sensitive element being located in said resonator at a point where the reflected surge impedance of said transmission means is higher than the radio frequency impedance of said sensitive detecting device under conditions of reception of signals of moderate amplitude, whereby substantial impedance mismatch on occurrence of overloading signals is assured.

10. In an electrical circuit having a sensitive element characterized by a non-linear impedance function of current therethrough and a protective device having an output coupling for said element, transmission means interconnecting said element and the output coupling of said device, said transmission means having an electrical length between said coupling and said sensitive element substantially equal to an odd number of quarter wavelengths for the frequency of circuit operation.

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REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,129,712	Southworth	Sept. 13, 1938
2,142,159	Southworth	Jan. 3, 1939
2,253,589	Southworth	Aug. 26, 1941
2,400,796	Watts et al.	May 21, 1946
2,401,717	Wolff et al.	June 4, 1946
2,402,839	Ohl	June 25, 1946
2,403,302	Richmond	July 2, 1946
2,409,608	Anderson	Oct. 22, 1946
2,412,161	Patterson	Dec. 3, 1946
2,419,561	Jones et al.	Apr. 29, 1947
2,424,156	Espley	July 15, 1947
2,438,367	Keister	Mar. 23, 1948
2,439,656	Hausz	Apr. 13, 1948