June 11, 1946. D. C. ESPLEY 2,401,863

ELECTRIC SWITCH

Filed Nov. 10, 1942

Fig. 1.

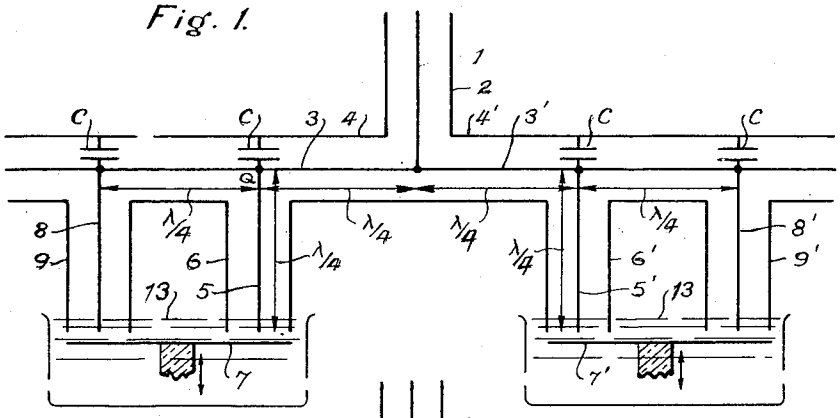



Fig. 2.

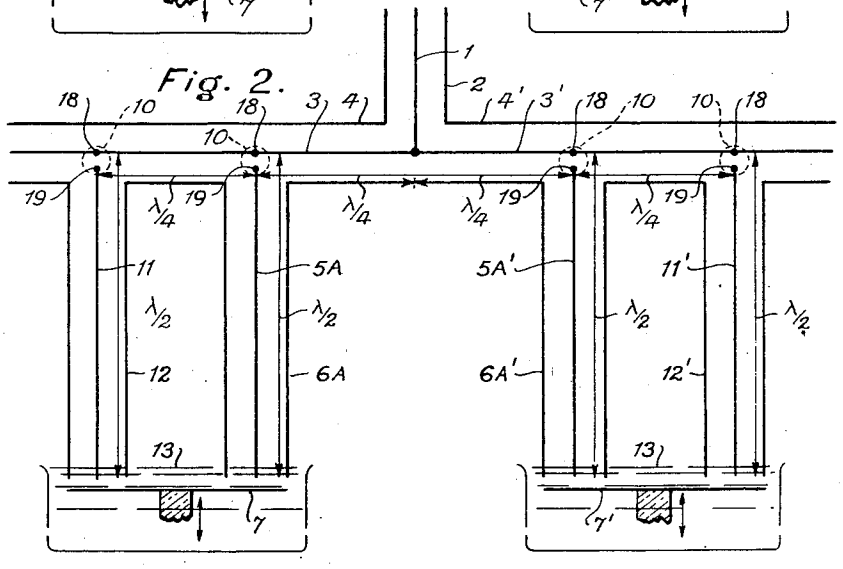



Fig. 3.

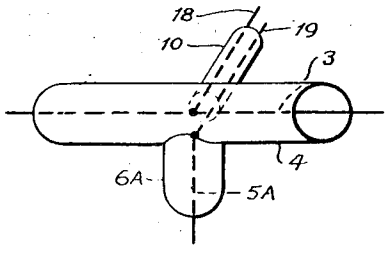
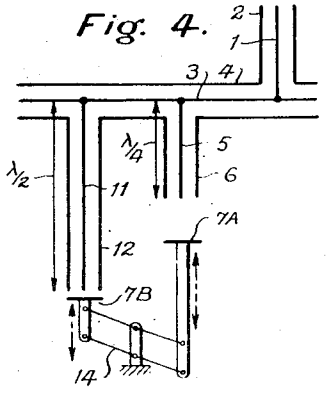



Fig. 4.




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## ELECTRIC SWITCH

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Application November 10, 1942, Serial No. 465,144
In Great Britain November 18, 1941

6 Claims. (Cl. 178—44)

1

This invention relates to electric switches for high-frequency oscillations of the type wherein a make and break is simulated by the approach of a conductor to, or its removal from, the open end of a transmission line. Switches of this type are described in the specification of my patent application Serial No. 397,017 filed June 7, 1941; but it is to be understood that the present invention is not limited to switches comprising the impedance element X mentioned in the said specification.

One problem to which the invention of the said specification is directed, and the solution of it proposed, will be described briefly with reference to the accompanying drawing, in which:

Fig. 1 shows diagrammatically a pair of switches according to the present invention combined into a two-way switch,

Fig. 2 shows a modified form of the improved two-way switch,

Fig. 3 is a detail of the switch shown in Fig. 2, and

Fig. 4 shows a further arrangement of switch according to this invention.

Referring to Fig. 1 for the explanation of my earlier invention, a concentric line is divided into two parts 3,4 and 3',4' by a T-piece 1,2. The lines 1,2, 3,4 and 3',4' have the same characteristic impedance $Z_0$. It is desired to provide a switch whereby oscillations arriving along the T-piece 1,2 can be diverted, substantially completely and without attenuation, either into the part 3,4 or into the part 3',4'. In order that the oscillations shall be so directed into the part 3,4, the input impedance of this part viewed from the T-piece must be $Z_0$ and that of the part 3',4' substantially infinite; and conversely if they are to be directed into 3',4'. I propose to achieve this by attaching to each of the parts 3,4 and 3',4', at a distance $\lambda/4$ from the T-piece, an open-ended stub 5,6 or 5',6', $\lambda/4$ long, and to provide a plate 7 which could alternatively cover (without actually touching) the open end of the stubs.

If the plate 7 actually short-circuited the end of the stub 5,6, the input impedance of the stub from 3,4 would be infinite, so that the presence of the stub would not change the properties of the line 3,4; the input impedance of the line 3,4 from the T-piece 1,2 would be $Z_0$. But if the plate 7 did not actually short circuit the end of the stub (as is desirable in practice), the said input impedance of the stub would not become infinite. In the said specification, it was proposed to make it substantially infinite by connecting across the input to the stub a suitably chosen condenser C, which might be another stub, as indicated at Q.

2

When the plate was removed from the end of the stub 5,6, the said input impedance of the stub was zero, whether the correcting condenser C was or was not present; and the input impedance from 1,2 into 3,4 was infinite.

In this account it is assumed that the length of the stub is exactly $\lambda/4$. In practice it is impossible to fulfil this condition; for no oscillations are strictly of a single frequency, and the condition can be fulfilled accurately only for a single frequency. A slight departure from $Z_0$ of the input impedance from the T-piece 1,2 into the part 3,4 when the plate 7 covers the end of the stub may often be tolerable. But a corresponding departure from infinity of this impedance when the plate is absent may have serious consequences, since it permits some of the oscillations to travel along the part 3,4 and thus, for example, to affect a sensitive receiver at the other end of the line which it is desired that the switch should isolate. It must be recognised that the switch can never provide a perfect break; at best it is an attenuator, and it may be difficult in some circumstances to obtain an attenuation greater than (say) 20 db. An object of this invention is to provide a greater attenuation in such circumstances.

This is achieved, according to this invention, by providing a plurality of switches of the said type in series. Thus, if there is provided (as shown in Fig. 1) another stub 8,9 or 8',9' farther along the branch 3,4 or 3',4' and at a distance $\lambda/4$ from the stub 5,6 or 5',6', then it will be apparent to experts that, when the ends of both stubs on the same branch are open, the switches will reinforce each other; if one stub attenuates the oscillations by $x$ db., the two stubs will attenuate them by approximately $2x$ db.

When one stub is covered by the plate 7, then the other stub on the same branch must also be covered by a similar plate, which may conveniently be another part of the same plate, as shown in Fig. 1. Further it is desirable that a correcting condenser C should be associated with the second stub as with the first. However here a subsidiary advantage of the invention arises; the imperfection of one stub that makes it necessary to provide another may act as a correcting condenser for the other. For it is known that it is possible to compensate exactly an irregularity on a transmission line by providing a similar irregularity at a suitable distance from it, in such a

manner that the two irregularities are equivalent to the absence of any irregularity. If the irregularity is small, the suitable distance is about $\lambda/4$. Now the end of a stub **5,6** imperfectly closed by the plate **7** is equivalent to an irregularity in the line **3,4** consisting of an impedance (say) X across that line at the stub. The function of the condenser C is, as explained in the said specification, to introduce an equal and opposite impedance $-X$. But the stub **8,9** also imperfectly closed by the plate is equivalent to an impedance X at the entrance to that stub. In virtue of the said fact the distance between the two stubs can be adjusted to a distance, which will be different from $\lambda/4$, at which the impedance X at the stub **8,9** will be equivalent to an impedance $-X$ at the stub **5,6** and can therefore replace the condenser C at the stub **5, 6**; if

$$X=1/j\omega C$$

and $Z_0$ is the characteristic impedance of the line, the distance between the stubs should be $l$ where $\tan 2\pi l/\lambda=2/Z_0\omega C$, $\lambda$ being the wavelength corresponding to the frequency and will therefore serve approximately at least to replace the condenser C at the stub **5,6**. Accordingly, when a plurality of switches are provided according to the present invention, it may not be necessary to add any definite element to provide the impedance element X characteristic of the invention described in the said specification, even if the advantage attendant on the presence of the element is desired.

If a compensating element X were not associated with either of the stubs **5,6** and **8,9**, or if the compensation were imperfect, the departure from $Z_0$ of the input impedance to the part **3,4** from the T-piece **1,2**, when the plate covered the end of the stub, would be somewhat greater than if only one of the stubs were present and there were a similar lack of compensation. It is therefore in general preferable that, in multiple switches according to the present invention, compensating elements should be provided. But the magnitude of the irregularity X that has to be compensated, arising from the imperfect closure of the stub by the plate **7**, can be decreased by surrounding the end of the stub and the plate by a suitable non-conducting liquid **13** having a dielectric strength much greater than that of air. The distance that must separate the plate and the stub in order that there should be no sparking is thereby reduced and, since the dielectric constant of the liquid will be greater than that of air, the capacity corresponding to a given distance will be increased.

The present invention has so far been described wholly with reference to the arrangement shown in Fig. 1 of the aforesaid specification. It will be obvious to experts how the statements made are to be modified if other variants of that earlier invention are modified according to the present invention. Thus any of the lengths heretofore called $\lambda/4$ might be $p\lambda/4$, where $p$ is any odd integer; and stubs of length $q\lambda/2$, where $q$ is an integer odd or even, might be substituted for the stubs of length $\lambda/4$ as described in the said specification. Such an arrangement is shown in Fig. 2, where the stubs **5A,6A** and **11,12** on the branch **3,4** and the stubs **5A',6A'** and **11',12'** on the branch **3'4'** differ from those in Fig. 1 by being of length $\lambda/2$ instead of $\lambda/4$, the shunt condensers C being omitted or preferably replaced by suitable series inductors. Since the input impedance of a transmission line may be a pure



inductance, the preferable form of inductor is a short length of transmission line (Fig. 3) made up of a pair of parallel wires **18,19** surrounded by a cylinder **10** and connected at right angles respectively to the conductors **3** or **3'** and **5A** or **11**, or **5A'** or **11'**, there being no conductive connection to the inner conductors of the stubs. Then, as explained in the said specification, the functions performed, when the length of the stubs is $p\lambda/4$, by approaching or removing the plate **7**, are performed respectively by removing or approaching the plate.

If in a switch according to the invention the co-operating stubs are all of the kind having length $p\lambda/4$ or all of the kind having length $q\lambda/2$, then the ends of all the stubs will be covered and uncovered together. But if, as shown in Fig. 4, some co-operating stubs were of one kind and some of the other (no advantage of this arrangement is known), then those of one kind would be covered while those of the others were uncovered. This must be remembered in interpreting the claims appended hereto. Thus it may be necessary in such circumstances to provide a plurality of conductors, instead of a single conductor, for covering the ends, these conductors may take the form of plates such as **7A** and **7B** in Fig. 4, operatively connected together by a control transmission **14** constraining them to move in opposite senses.

I claim:

1. An electric switch for high-frequency oscillations of the type specified comprising a main uniform transmission line, a plurality of stubs, each including a uniform line substantially of length $q\lambda/4$ where $q$ includes all integers of odd and even gender, the members of each of said stubs being connected at one end to said main line and spaced apart along said main line at distances substantially $p\lambda/4$ where $p$ is an odd integer, the second ends of each of said stubs being open, conductors, means to cause relative movement of said conductors and the open ends of said stubs between a first position in which said conductors and the open ends of said stubs are remotely spaced and a second position in which said conductors and the open ends of said stubs are closely spaced, whereby said conductors give rise to capacitative impedances in said second position corresponding to capacities C shunting the open ends of said stubs, and a compensating impedance element associated with the first end of at least one of said stubs, the nature of said compensating element and its connection to said first end of said stub being such with respect to the gender of $q$, and the value of said impedance element relative to the frequency of the oscillations and the impedance of the said capacity C shunting the open end of said stub in the said second position of said conductors being such that when said conductor is in one of said positions, the input impedance is substantially zero, and when said conductor is in the other of said positions, the input impedance is substantially infinite, the arrangement of said stub and said main line being such that in one position of said conductors the stubs act as attenuators in series for oscillations travelling along said main transmission line and, in the other position of said conductors, the oscillations travelling along said main line suffer little or no attenuation due to any said stub.

2. An electric switch for high-frequency oscillations of the type specified comprising a single

main transmission line, a plurality of transmission lines (stubs) each having an open end, means for causing conductors alternatively to approach closely the said open ends or to recede from them, the said stubs being spaced at distances substantially $p\lambda/4$ along said single main transmission line, where $\lambda$ is the wave-length of the oscillations along the said main line and $p$ is an odd integer, and an impedance element associated with the input end of at least one of the said stubs, the nature of the said element being such that when the conductor is in one of two positions either close to the open end of the stub or remote therefrom, the input impedance of the stub is substantially zero, and when said conductor is in the other of said positions, the input impedance of the stub is substantially infinite, and the arrangement being such that, in one position of the said conductors, the stubs act as attenuators in series for oscillations travelling along the said main transmission line and, in the other position of the said conductors, the oscillations travelling along the said line suffer little or no attenuation due to any said stub.

3. An electric switch according to claim 2 wherein the region separating the open ends of the stubs from the said conductors, when the conductors approach the said open ends closely, is occupied by a substantially non-conducting liquid having a dielectric strength greater than that of air.

4. An electric switch for high-frequency oscillations of the type specified comprising a single main transmission line, a plurality of transmission lines (stubs) each having an open end, and means for causing conductors alternatively to approach closely the said open ends or to recede from them, the said stubs being spaced at distances substantially $p\lambda/4$ along said single main transmission line, where $\lambda$ is the wave-length of the oscillations along the said main line and $p$ is an odd integer, the arrangement being such that, in one position of the said conductors, the stubs act as attenuators in series for oscillations travelling along the said main transmission line and, in the other position of the said conductors, the oscillations travelling along the said line suffer little or no attenuation due to any said stub, wherein at least one of said stubs is substantially of length $q\lambda/4$ where $q$ is an odd integer, and a capacity is connected across the input end of said one stub and has a value such as to increase the input impedance of said one stub from the main transmission line when one of said conductors is close to the open end of said one stub.



5. An electric switch for high-frequency oscillations of the type specified comprising a single main transmission line, a plurality of transmission lines (stubs) each having an open end, and means for causing conductors alternatively to approach closely the said open ends or to recede from them, the said stubs being spaced at distances substantially $p\lambda/4$ along said single main transmission line, where $\lambda$ is the wave-length of the oscillations along the said main line and $p$ is an odd integer, the arrangement being such that, in one position of the said conductors, the stubs act as attenuators in series for oscillations travelling along the said main transmission line and, in the other position of the said conductors, the oscillations travelling along the said line suffer little or no attenuation due to any said stub, wherein at least one of said stubs is substantially of length $q\lambda/4$ where $q$ is an even integer, and an inductance is connected in series between said one stub and said main transmission line, said inductance having a value such as to decrease the input impedance of said one stub from the main transmission line when one of the said conductors is close to the open end of said one stub.

6. An electric switch for high-frequency oscillations comprising a single main transmission line terminated with its characteristic impedance, two transmission line stubs each having an open end, two conductors, one associated with each said open end, means for causing said conductors alternatively to approach closely or to recede from the said open ends, the arrangement being such that in one position of the said conductors the stubs act as attenuators in series for oscillations travelling along the said main transmission line and in the other position of the said conductors the oscillations travelling along the line suffer little or no attenuation due to said stubs, and wherein the distance between the stubs is so adjusted relative to the characteristic impedance of the transmission line, the frequency of the said oscillations, and the terminating capacity at the open ends of the said stubs in the said other position of the said conductors, that the input impedances of the two said stubs mutually compensate to give effectively infinite input impedance in that position of the said conductors at which the oscillations travelling along the line suffer little or no attenuation.

DENNIS CLARK ESPLEY.