July 30, 1946. **D. C. ESPLEY** **2,404,832**

SWITCH FOR HIGH-FREQUENCY ELECTRICAL OSCILLATIONS

Filed June 7, 1941

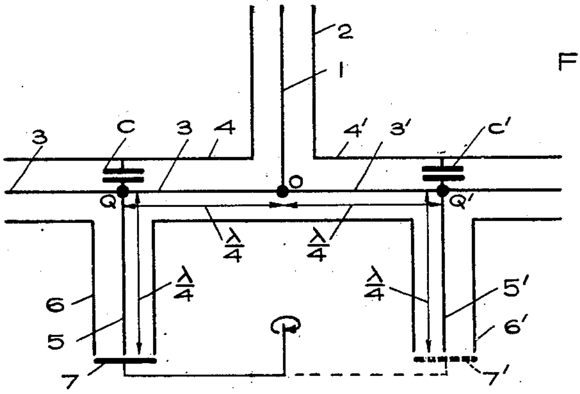

FIG. 1

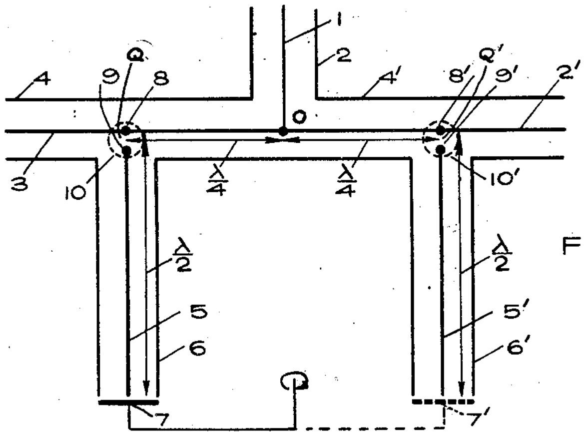

FIG. 2

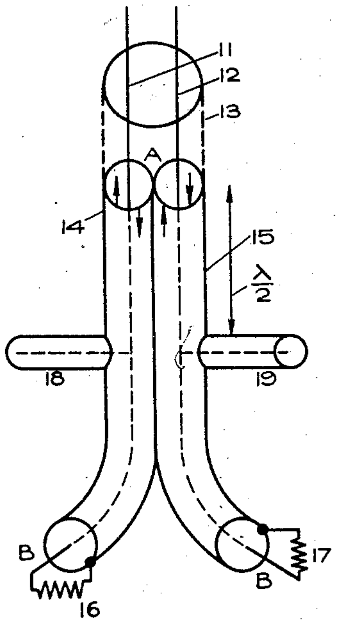

FIG. 4

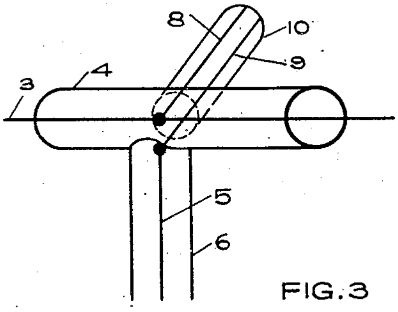

FIG. 3

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SWITCH FOR HIGH-FREQUENCY ELECTRICAL OSCILLATIONS

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20 Claims. (Cl. 178—44)

This invention relates to switches for high-frequency electrical oscillations of frequency *f*. A switch means a device which renders the impedance between a pair of terminals alternatively very large and very small.

It has been proposed to provide switches for high frequency oscillations by the use of a known proposition concerning uniform transmission lines with distributed inductance and capacity and with zero attenuation constant. For brevity such lines will be called hereafter simply "uniform lines." Uniform lines have a characteristic impedance Z_0, independent of frequency, and, corresponding to any frequency f, a characteristic wave-length λ, which, if the dielectric constant is everywhere that of a vacuum, will be equal to c/f, where c is the velocity of light. The said proposition may then be stated thus.

Let Z_0 be the characteristic impedance of a uniform line, and let its length be $p\lambda/4$, where p is an odd integer. Let Z_1 be the input impedance to one end of the line, denoted by 1; let Z_2 be the impedance of a two-terminal network connected across the other end of the line, denoted by 2. Then $Z_1 Z_2=Z_0^2$.

If $Z_2=0$ and end 2 is short circuited, $Z_1=\infty$; if $Z_2=\infty$ and the end 2 is open, $Z_1=0$. Accordingly if the end 1 of such a line is connected across the said pair of terminals, and if means (e. g. a make and break switch of conventional type) are provided for alternatively short-circuiting and open-circuiting end 2, a switch, as defined, will be provided.

But contacts, such as are involved in a conventional switch, are often undesirable in high-frequency apparatus, especially receiving apparatus. It is possible to make Z_2 small, but not zero, by bringing up to the end 2 a conductor which does not actually touch it; Z_2 is then the impedance of the capacity which is the resultant of the capacities of the outer and inner members with the conductor, these capacities being in series. The primary object of my invention is to modify the arrangement just described so that, in spite of Z_2 never being zero, the impedance of the switch can be made either substantially zero or substantially infinite.

Let C be the said resultant capacity. Then, when the conductor is in place, $Z_2=1/j\omega C$, where $\omega=2\pi f$. Since Z_0^2 is real, positive and independent of frequency, Z_1 will be of the form $j\pi L$, where $L=Z_0^2C$. Let there now be connected permanently across the said pair of terminals a capacity $C'=1\omega^2L$. If Z_1' is now the total impedance across the pair of terminals,

$$\frac{1}{Z_1'}=\frac{1}{Z_1}+j\omega C'=\frac{1}{j\omega L}-\frac{1}{j\omega L}=0,$$

and $Z_1'=\infty$. On the other hand, if the conductor is absent, $Z_2=\infty$, $Z_1=0$ and

$$\frac{1}{Z_1'}=\frac{1}{0}+j\omega C'$$

so that $Z_1'=0$. The said object of my invention is attained.

According to my invention in its simplest aspect a switch for high-frequency oscillations of frequency f comprises a uniform line of characteristic impedance Z_0 and substantially of length $p\lambda/4$, where p is an odd integer, having the outer and inner members at one end connected to the said pair of terminals, means for approaching a conductor to the other (open) end of the said line so as to provide a capacity C shunting the said open end, and a condenser of capacity C′ connected permanently across the said pair of terminals, where C′ is substantially

$$\frac{1}{4\pi^2 f^2 Z_0^2 C}$$

p is preferably 1.

Another object of my invention is to provide a switch alternative to that according to the first aspect of my invention, using the same general principles and with the same advantage over known switches.

This alternative switch is based on the following well known proposition. Let Z_1 be input impedance to one end, denoted by 1, of a uniform line or length $q\lambda/2$, where q is an integer, odd or even. Let Z_2 be the impedance of a two-terminal network connected across the other end of the line, denoted by 2. Then $Z_1=Z_2$. If $Z_2=\infty$ and end 2 is open, $Z_1=\infty$; if $Z_2=0$, and end 2 is short-circuited, $Z_1=0$. As before, Z_2 may be made nearly but not quite zero by bringing up to end 2 a conductor that does not actually touch it. The resulting value of Z_1 will also be Z_2. In order that the aforesaid advantage may be obtained, some other impedance X must be added at end 1, so that Z_1', the resultant of Z_1 and X, is zero. In order to achieve this, X cannot now be an impedance in parallel with Z_1, unless $X=0$. If X is to be finite, it must be in series with the line and have the value $-Z_2$. Thus, since Z_2 is of the form $1/j\omega C$, where C is capacitative, X must be of the form $j\omega L$, where L is inductive and equal to

$$\frac{1}{4\pi^2 f^2 Z_0^2 C}$$

When the conductor is removed and Z_2 becomes ∞, $Z_1'=\infty+j\omega L=\infty$. Consequently, if the series impedance X is always in place, Z_1 will be substantially zero or infinity according as the conductor is or is not in place. The preferred way in which the series impedance X may be introduced will be described hereinafter.

According to my invention in its more general aspect a switch for high-frequency oscillations of frequency f comprises a uniform line substantially of length $q\lambda/4$, where q is an integer, having its members connected at one end to the said pair of terminals, means for approaching a conductor to the other (open) end of the line so as to provide an impedance shunting the said open end which is the impedance of a capacity C, and an impedance element X of such a nature and value and constantly associated with the said pair of terminals in such a manner that, when the said conductor is near the said open end, the impedance between the said pair of terminals assumes substantially one of the values zero and infinity and, when the said conductor is far from the said open end, the impedance between the said pair of terminals approaches the other of the said values.

Certain applications of switches according to my invention will now be described by way of example with reference to the accompanying drawing in which Figures 1 and 2 and 3 show a pair of switches according to my invention combined into a two-way switch and Figure 4 shows the use of a pair of switches according to my invention to short-circuit alternately one or other of two paths in series.

In the first application (Figures 1 and 2) a pair of switches according to my invention are combined into a two-way switch, so as to permit oscillations to be directed into either of two alternative parallel paths. It will be clear to experts that if n switches were provided, the oscillations might be directed into n alternative parallel paths; and further that, though the arrangement is described as a transmitter, sending energy into the alternative paths, it could be converted without essential modification into a receiver, receiving energy from alternative paths.

In Figure 1 a concentric line (which is a uniform line as above defined) with inner member **1** and outer member **2** leads from an oscillator (not shown) to a T junction **0**, where the inner member branches into inner members **3**, **3'** and the outer member into branches **4**, **4'**. Each branch leads to consuming apparatus (not shown). A concentric line with an open end (often known as a "stub") is inserted as a T into each of the branches at a distance $\lambda/4$ from **0**. These stubs have respectively inner members **5**, **5'** and outer members **6**, **6'**; each is of length $\lambda/4$. Q, Q' are the junctions of the stubs with the branches. A conducting plate can be made to assume the position **7** close to the open end of the stub (**5**, **6**) or alternatively the position **7'** close to the end of stub (**5'**, **6'**). The capacity between **5** and **7** in series with the capacity between **6** and **7** constitutes a capacity C. Small condensers, each of capacity C', related as described above to C, to ω and to Z_0 the characteristic impedance of the stub, are connected between Q and the member **4** and between Q' and the member **4'**.

It is well known that, if the length of a transmission line, not necessarily concentric, is appropriately chosen in relation to the frequency of the oscillations applied to its open end, its input impedance is a pure capacity. Accordingly the said small condensers may be transmission lines of appropriate length.

In accordance with the principles set forth, when the plate is in the position **7**, the input impedance to the stub (**5**, **6**) from the junction Q is infinite; the presence of the stub makes no difference to the propagation of oscillations down the branch (**3**, **4**). On the other hand, since the end of the stub (**5'**, **6'**) is open, the input impedance into it from the junction Q' is zero; the line between O and Q' is short-circuited at Q'. But the length of this line is $\lambda/4$; consequently the input impedance into it from **0** is infinite. No energy will pass down the line **3'**, **4'**; all will pass down **3**, **4**. When the plate is moved to **7'**, the converse position will obtain; all the energy will pass down (**3'**, **4'**) and none down (**3**, **4**). The plate, moving between **7** to **7'**, thus switches the oscillations from one branch to the other.

Experts will realise that, owing to the finite diameter of the members of the concentric lines, the distances that should be $\lambda/4$ may not be exactly those so indicated in the figure. Again, if the frequency of the oscillations were completely determinate, there would be no reason why these distances should be $\lambda/4$ rather than $p\lambda/4$, where p is any odd integer; but experts will realise that in practice it will be nearly always desirable that p should be 1.

Of the applications of the invention considered, that shown in Figure 1 is likely to be the most useful. But as has been indicated above, the quarter wave-length stubs may be replaced by half-wave-length stubs, the shunt condenser C' being replaced by a suitable series inductor L or its equivalent. Since the input impedance of a transmission line may be a pure inductance, as well as a pure capacity, the preferable form of inductor is a short length of transmission line inserted so as to separate one of the members of the stub (preferably the inner for practical reasons) from the junction Q or Q'. This modification is shown in Figure 2.

The members and points denoted by **1**, **2**, **3**, **4**, **7**, **0**, Q, Q' are the same as in Figure 1; the stubs (**5**, **6**) and (**5'**, **6'**) differ from those in Figure 1 only in being of length $\lambda/2$ and not $\lambda/4$. Each inductor introduced in series with each stub is made up of a pair of parallel wires (**8**, **9**) or (**8'**, **9'**) surrounded by a cylinder **10** or **10'**; **8** branches at right angles to **3** and **9** at right angles to **5**, and there is no longer conductive connection between **3** and **5**.

The arrangement of the parts **3**, **4**, **5**, **6**, **8**, **9**, **10** is shown in perspective and on an enlarged scale in Figure 3. Experts will know how to adjust the dimensions of these wires (**8**, **9**), (**8'**, **9'**) and cylinders **10**, **10'** so that the input impedance to the arrangement from the end Q (or Q') is $j\omega L$, where $L=1/\omega^2C$.

The relation of the direction of the oscillations to the position of the plate **7** is now reversed. When the plate is at **7**, the input impedance to stub (**5**, **6**) is zero; the input impedance to the line **0**Q is infinite; the oscillations pass down the branch **3'**, **4'**, not the branch **3**, **4**. It should be observed that when the length of the stubs is increased to $\lambda/2$, the length of the lines **0**Q, **0**Q' must remain $\lambda/4$ or some odd multiple thereof.

In the second application, to which Figure 4 refers, a pair of switches according to my invention is used to short-circuit one or other of two paths in series, each containing a consuming device, so that either of these devices can be made operative and the other inoperative.

A pair of straight wires 11, 12, preferably surrounded by the shield 13, lead from an oscillator. In a plane transverse to those wires they enter tubes 14, 15 (which may be made by merely dividing the shield 13), so that the wires 11, 12 then each become the inner member of a concentric uniform line of which the outer member is 14 or 15. Later the tubes diverge, and there is connected across the end B of each, between the inner and outer member, a consuming device 16 or 17. The two concentric lines and the consuming devices are all in series, as is indicated by the short arrows which show, in one phase, the currents flowing in 11, 12, 14, 15 near the end A where 11, 12 enter 14, 15.

A stub 18 or 19 with its associated condenser (not shown), similar to that described with reference to Figure 1, is attached to each concentric line (11, 14) or (12, 15) at a distance $q\lambda/2$ from the end A. If a conducting plate (not shown) is brought up to the open end of stub 18 and the input impedance to that stub from the line (11, 14) to which it is attached is thus made infinite, the stub has no effect on transmission along that line. But when the plate is removed the input impedance to the stub becomes zero; the line (11,14) is short-circuited at the stub; since the distance of the stub from the end A is $q\lambda/2$, the input impedance to the line (11, 14) at A also becomes zero. Consequently no energy therefore passes down the line (11, 14) to the consuming device 16; but energy can travel across the short-circuited entrance to (11, 14) to the line (12, 15) and thus to the consuming device 17.

Similarly, where the conducting plate is brought up to (or removed from) the open end of the stub 19, the energy is directed into the consuming device 17 (or 16). Accordingly the device 16 or 17 will receive energy according as the plate is opposite the end of 18 or 19.

Of course the quarter-wavelength stubs 18, 19 could be replaced by half-wavelength stubs as described with reference to Figure 2. Then 16 or 17 would receive energy according as the plate is opposite 19 or 18. The distance from the stub to the end A must be $q\lambda/2$ subject, as aforesaid, to considerations arising from the finite diameter of the concentric lines) whether quarter-wavelength of half-wavelength stubs are used.

It must be understood that my invention is not limited to the examples hereinbefore described but is defined in scope by the following claims.

I claim:

1. A switch for high-frequency oscillations of frequency f comprising a stub including a concentric uniform line substantially of length $q\lambda/4$ where q includes all integers of odd and even gender, the members of said stub being adapted to be connected at one end of the stub to another uniform line which the switch is to control, the second end of said stub being open, a conductor, means to cause relative movement of said conductor and the open end of said stub between a first position in which said conductor and the open end of said stub are remotely spaced and a second position in which said conductor and the open end of said stub are closely spaced, whereby said conductor gives rise to a capacitative impedance of value C in said second position shunting the open end of said stub, and a compensating impedance element permanently electrically connected to said first end of the stub, the type of impedance element and its connection to said first end of the stub being such with respect to the gender of q and the value of said impedance element relative to the frequency f and impedance C being such that when said conductor is in one of said positions the impedance across said first end of the stub is substantially zero and when said conductor is in the other of said positions the impedance across said first end of the stub is substantially infinity.

2. A switch for high-frequency oscillations of frequency f comprising a stub including a concentric uniform line substantially of length $q\lambda/4$ where q is an odd integer, the members of said stub being adapted to be connected at one end of the stub to another uniform line which the switch is to control, the second end of said stub being open, a conductor, means to cause relative movement of said conductor and the open end of said stub between a first position in which said conductor and the open end of said stub are remotely spaced and a second position in which said conductor and the open end of said stub are closely spaced, whereby said conductor gives rise to a capacitative impedance of value C in said second position shunting the open end of said stub, and a compensating capacity in shunt across said first end of the stub, the value of said capacity being such relative to the frequency f and impedance C that when said conductor is in the second position the impedance across said first end of the stub is substantially infinity and when said conductor is in the first position the impedance across said first end of the stub is substantially zero.

3. A switch for high-frequency oscillations of frequency f comprising a stub including a concentric uniform line substantially of length $q\lambda/4$ where q is an even integer, the members of said stub being adapted to be connected at one end of the stub to another uniform line which the switch is to control, the second end of said stub being open, a conductor, means to cause relative movement of said conductor and the open end of said stub between a first position in which said conductor and the open end of said stub are remotely spaced and a second position in which said conductor and the open end of said stub are closely spaced, whereby said conductor gives rise to a capacitative impedance of value C in said second position shunting the open end of said stub, and a compensating inductance connected in series with said first end of the stub, the value of said inductance being such relative to the frequency f and impedance C that when said conductor is in the first position the impedance across said first end of the stub is substantially infinity and when said conductor is in the second position the impedance across said first end of the stub is substantially zero.

4. An electric system comprising a uniform transmission line connected at one end to a source of high-frequency energy and at the other end to a current consuming device, said system including a switch as set forth in claim 1 for controlling the supply of energy from said source to the current consuming device, the stub of said switch being connected to said uniform transmission line at an integral number of quarter wave lengths from that end of the transmission line which is connected to the source of high-frequency energy.

5. An electric system comprising a uniform transmission line connected at one end to a source of high-frequency energy and at the other end to a current consuming device, said system including a switch as set forth in claim 2 for controlling the supply of energy from said source

to the current consuming device, the stub of said switch being connected to said uniform transmission line at an integral number of quarter wave lengths from that end of the transmission line which is connected to the source of high-frequency energy.

6. An electric system comprising a uniform transmission line connected at one end to a source of high-frequency energy and at the other end to a current consuming device, said system including a switch as set forth in claim 3 for controlling the supply of energy from said source to the current consuming device, the stub of said switch being connected to said uniform transmission line at an integral number of quarter wave lengths from that end of the transmission line which is connected to the source of high-frequency energy.

7. An electric system comprising a plurality of uniform transmission lines each electrically connected at one end to a common source of high-frequency energy and at the other end to a current consuming device, each of said transmission lines having a switch as set forth in claim 1 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an integral number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy.

8. An electric system comprising a plurality of uniform transmission lines each electrically connected at one end to a common source of high-frequency energy and at the other end to a current consuming device, each of said transmission lines having a switch as set forth in claim 2 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an integral number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy.

9. An electric system comprising a plurality of uniform transmission lines each electrically connected at one end to a common source of high-frequency energy and at the other end to a current consuming device, each of said transmission lines having a switch as set forth in claim 3 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an integral number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy.

10. An electric system comprising a plurality of uniform transmission lines electrically connected in parallel, each electrically connected at one end to a common source of high-frequency energy and at the other end to a current consuming device, each of said transmission lines having a switch as set forth in claim 1 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an odd number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy.

11. An electric system comprising a plurality of uniform transmission lines electrically connected in parallel, each electrically connected at

one end to a common source of high-frequency energy and at the other end to a current consuming device, each of said transmission lines having a switch as set forth in claim 2 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an odd number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy.

12. An electric system comprising a plurality of uniform transmission lines electrically connected in parallel, each electrically connected at one end to a common source of high-frequency energy and at the other end to a current consuming device, each of said transmission lines having a switch as set forth in claim 3 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an odd number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy.

13. An electric system comprising a plurality of uniform transmission lines electrically connected in series with each other and with a common source of high-frequency energy at one set of ends, each of said transmission lines being electrically connected to a current consuming device at its other end, and each of said transmission lines having a switch as set forth in claim 1 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an even number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy.

14. An electric system comprising a plurality of uniform transmission lines electrically connected in series with each other and with a common source of high-frequency energy at one set of ends, each of said transmission lines being electrically connected to a current consuming device at its other end, and each of said transmission lines having a switch as set forth in claim 2 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an even number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy.

15. An electric system comprising a plurality of uniform transmission lines electrically connected in series with each other and with a common source of high-frequency energy at one set of ends, each of said transmission lines being electrically connected to a current consuming device at its other end, and each of said transmission lines having a switch as set forth in claim 3 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an even number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy.

16. An electric system comprising two uniform transmission lines electrically connected in parallel, each electrically connected at one end to a common source of high-frequency energy and at the other end to a current consuming device,

each of said transmission lines having a switch as set for in claim 1 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an odd number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy, the moving conductors of the two switches being ganged so that energy is switched alternatively from one current consuming device to the other.

17. An electric system comprising two uniform transmission lines electrically connected in parallel, each electrically connected at one end to a common source of high-frequency energy and at the other end to a current consuming device, each of said transmission lines having a switch as set forth in claim 2 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an odd number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy, the moving conductors of the two switches being ganged so that energy is switched alternatively from one current consuming device to the other.

18. An electric system comprising two uniform transmission lines electrically connected in parallel, each electrically connected at one end to a common source of high-frequency energy and at the other end to a current consuming device, each of said transmission lines having a switch as set forth in claim 3 for alternatively diverting energy from or passing energy to the current consuming device connected to the other end of said line, said switch having a switch stub connected across said transmission line at an odd number of quarter wave lengths from that end of said line which is connected to the source of high-frequency energy, the moving conductors of the two switches being ganged so that energy is switched alternatively from one current consuming device to the other.

19. A switch for high-frequency oscillations of frequency f comprising a stub including a concentric uniform line substantially of length $q\lambda/4$ where q is an even integer, the members of said stub being adapted to be connected at one end of the stub to another uniform line which the switch is to control, the second end of said stub being open, means for introducing at the open end of said stub a capacity variable between two values and shunting said open end, and a compensating inductance connected in series with said first end of the stub, the value of said inductance relative to the frequency f and said variable capacity being such that when said variable capacity is at its highest value the impedance across said first end of the stub is substantially zero and when said variable capacity is at its minimum value the impedance across said first end of the stub is substantially infinity.

20. A switch for high-frequency oscillations of frequency f comprising a stub including a concentric uniform line of length $q\lambda/4$ where q is an integer, the members of said stub being adapted to be connected at one end of the stub to another uniform line which the switch is to control, the second end of said stub being open, a conductor, and means to cause relative movement of said conductor and the open end of said stub between a first position in which said conductor and the open end of said stub are remotely spaced and a second position in which said conductor and the open end of said stub are closely spaced but not touching.

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