Dec. 4, 1934. W. J. POLYDOROFF 1,982,690

SELECTIVE RADIO CIRCUIT

Original Filed Aug. 26, 1929

Fig. 1.

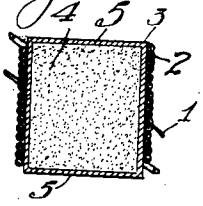


Fig. 2.

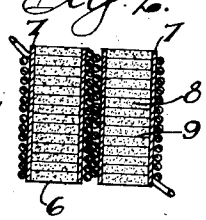


Fig. 4.

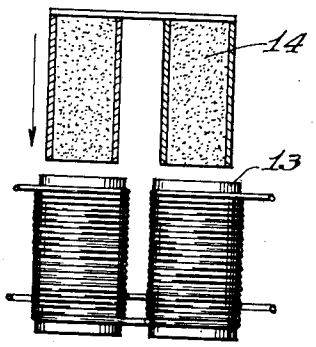
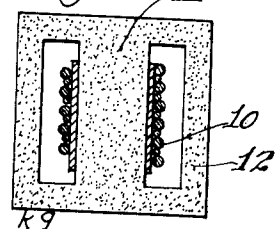


Fig. 3.



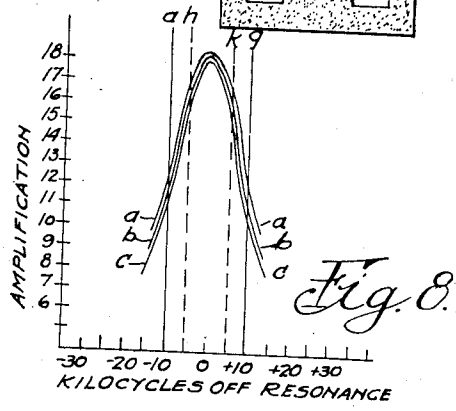
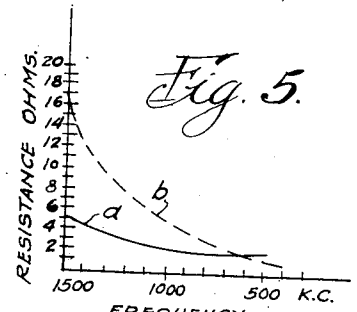


Fig. 8.

Fig. 5.



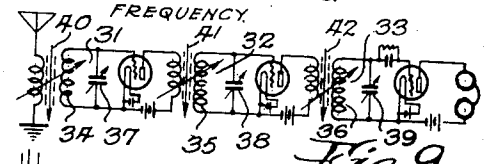


Fig. 9

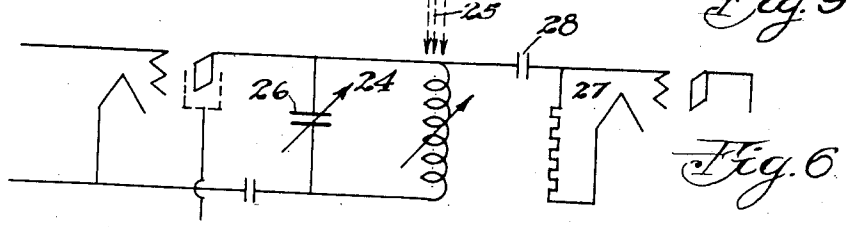
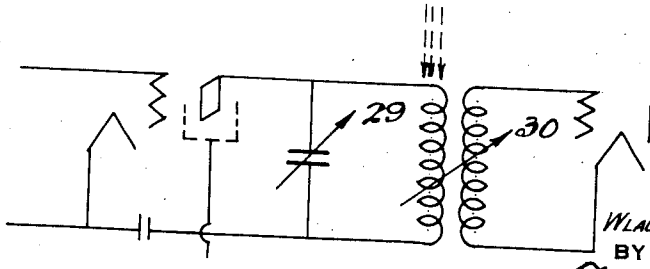


Fig. 6.

Fig. 7.



INVENTOR

WLADIMIR J. POLYDOROFF.

BY

Thomas G. Steward,

ATTORNEY.

Patented Dec. 4, 1934

1,982,690

UNITED STATES PATENT OFFICE

1,982,690

SELECTIVE RADIO CIRCUIT

Wladimir J. Polydoroff, Chicago, Ill., assignor to Johnson Laboratories, Inc., Chicago, Ill., a corporation of Illinois

Original application August 26, 1929, Serial No. 388,289, now Patent No. 1,940,228, dated December 19, 1933. Divided and this application March 8, 1933, Serial No. 660,020. In Canada July 28, 1930

REISSUED DEC 5 1939

40 Claims. (Cl. 250—40)

This application is a division of my application on which Patent No. 1,940,228 has issued, covering certain new and useful improvements in radio amplifying circuits. This division reveals and claims certain new and useful improvements in selective circuits.

Hitherto, many attempts were made to employ iron cores in the transformers used in radio-frequency apparatus, but owing to great losses produced by the iron as then employed, efficiency was impaired, generally to such extent that circuits in which said transformers were used became aperiodic.

Circuits employed in the radio art are usually called "aperiodic" when their damping is so great that free oscillations are entirely suppressed, and they are called "periodic" or "free-oscillatory" when they are capable of sustaining oscillations of a single periodicity or frequency.

Periodic circuits, when employed in a receiving system, have inherent selective properties, that is, they have the ability to sharply respond to an incoming frequency corresponding to their natural period. Aperiodic circuits, on the other hand, respond to a very wide band of frequencies.

The mathematical criterion of a periodic circuit is $CR<4L$. When this condition is fulfilled, free electrical oscillations of a single frequency are possible in the circuit.

The iron used in devices embodying the present invention is applied to periodic circuits as above defined, that is, circuits having inherent selective properties.

The invention will be better understood if reference is made to the accompanying drawing wherein—

Figures 1, 2, 3 and 4, partly in section, show various modifications of the present invention;

Figure 5 is a diagram showing the resistance variations of various transformers and coils;

Figures 6, 7 and 9 show applications of the present invention in selective circuits, and

Figure 8 shows the selectivity curves of a selective circuit employing the present invention.

Actual measurements of the resistance of an air coil or transformer show that the resistance changes with frequency. Curve *a* of Figure 5 shows the resistance for a certain air coil, measured at different frequencies, while curve *b* shows how the resistance would have to change if it were to remain proportional to the square of frequency. The attainment of this result is one of the objects of this invention. It is evident that when the resistance of a coil varies in accordance with curve *b*, Figure 5, such a coil, in conjunction with a condenser, may form a parallel resonant circuit whose resonant impedance or dynamic resistance may be maintained constant when the circuit is tuned by the condenser throughout a given range of frequencies. This dynamic resistance is usually expressed as

$$R_d=\frac{L^2\omega^2}{R},$$

where L and R are the inductance and the resistance of the coil respectively, and ω is the angular velocity corresponding to the frequency. As ω is changed by tuning and R varies as the square of frequency, the resultant R_d may be maintained constant.

It is shown in the parent specification that in an inductively-coupled circuit, maintenance of optimum coupling in a transformer is also a function of the resistance of the coil, and that when R varies as the square of frequency, the coupling remains at its optimum value.

In the measurements which form the basis of Figure 5, a low-loss coil was used, and its inductance was materially augmented by powdered iron disposed within said coil. The resistance as actually measured throughout the range of frequencies utilized is shown by the curve *b*, Figure 5. The curve indicates that the resistance changed approximately nine times while the frequency changed approximately three times. Numerous measurements have verified the fact that the resistance of a low-loss coil with a powdered-iron core may be made to vary substantially proportionally to the square of the frequency. Applicant's invention, therefore, comprehends, among other things, a circuit, which may be inductively related to the source, containing a low-loss coil, a powdered-iron core and a tuning condenser, the condenser being used to vary the frequency of the circuit, and the core being employed to vary the resistance of the coil so as to maintain the dynamic resistance of the complete circuit substantially constant.

The resistance of transformers having powdered-iron cores, is extremely small at the lower frequencies; such, for example, as 550 k. c. It is possible, therefore, to design transformers and coils for those low frequencies that will have an L/R ratio much higher than is possible in any practical design using air coils. Furthermore, when powdered-iron cores are used, it is possible to decrease the size of the windings and thereby minimize the size of the radio-frequency transformer itself, thus effectuating a saving in cost and space.

There may be several embodiments of my iron-core transformers and inductances, one embodiment being shown in Figure 1 wherein primary and secondary coils, 1, 2, are wound on an insulated tube 3, powdered iron 4 is packed inside the tube 3, and the ends 5 of the tube are sealed.

Figure 2 shows schematically a binocular coil 6 wound on insulated tubes 7, portions 8 of the powdered iron being separated by thin paper discs 9, to prevent readjustment of the particles and consequent packing, which would produce slight changes in inductance.

To obtain the maximum increase in inductance, due to the powdered-iron cores, the length of the coil should be preferably about twice its diameter, and the wire should be space-wound. In the arrangement shown in Figure 3, 10 indicates a space-wound wire, and 11 indicates the powdered-iron core. A still further inductance increase will be secured if the iron core extends around the outside of the coil. Such an arrangement of the iron completely closes the magnetic lines around the coil, forming an astatic coil. When iron cores are employed in coils of the closed or semi-closed magnetic field type, the original astatic properties of such coils are greatly enhanced. If, for instance, the powdered-iron core doubles the individual primary and secondary inductances, it may increase the mutual inductance between the windings four or five times.

Iron cores consisting of powdered iron alone are very useful, but cores can also be made by mixing various adhesive and insulating compounds with the powdered iron, and giving these cores the desired shape, with or without use of pressure. The insulators, preferably of elastic nature such as rubber, natural and synthetic gums and certain varnishes, mixed with iron and pressed together, will maintain insulating films between the iron particles and will, therefore, reduce resultant radio-frequency losses.

The word "iron" as used in this specification should be taken as including any other metal or alloy having magnetic properties, such for example, as silicon-iron, permalloy and nickel-iron. Various powdered metals have been tested for radio-frequency transformers and inductances. It has been found that for the most satisfactory results iron reduced by hydrogen, and having particles which fall freely through a screen of 300 meshes to the inch, should be used for frequencies between 1500 and 1000 k. c. Coarser particles of magnetic material, however, may be used for frequencies below 1000 k. c. The fineness, and also the degree of compression, determine the radio-frequency resistance of the coil and core combination.

There is usually present on the surfaces of iron particles an insulating coat of oxide and this helps to reduce the eddy-current losses. When silicon-iron powder is used, it is practical to chemically treat the powder with a phosphoric acid solution to create such an insulating film.

When, in this specification, the term "powdered iron" is used, it should be taken to mean either incoherent masses of finely-divided iron, or masses of finely-divided iron compressed into bodies in which the individual particles are held together by an insulating binder. The degree of compression, however, should not be so great as to cause the particles of powdered iron to touch each other and thus displace the insulating material which should separate them.

Another object of the present invention is to tune a radio-frequency circuit in a new, simple and efficient manner, a movable powdered-iron core disposed in the field of a coil being employed for tuning purposes. Depending on the amount of the iron powder inserted in the form of a core, the self-inductance of a coil may be increased four and even six times with a resulting increase in radio-frequency resistance. Figure 4 shows such a device in a form of binocular transformer 13, having a core 14 which can be moved in and out to obtain variations of self-inductance and mutual inductance.

When the selection of a desired signal accompanies amplification, as in the radio-frequency amplifiers shown in Figures 6 and 7, the ability to discriminate between frequencies is called the "selectivity" of the system. In an ordinary air-core transformer, one winding of which forms a portion of a resonant circuit, the selectivity varies with frequency. The present invention, however, provides means for maintaining the selectivity constant. These means include a low-loss low-inductance coil and a movable powdered-iron core as shown in the circuits of Figures 6 and 7. This circuit, when tuned to a high-frequency signal, such as 1500 k. c., and with the core entirely withdrawn, develops the selective characteristics of the curve *a* of Figure 8. To tune the circuit to lower frequencies between 1500 and 1500 k. c., the core is gradually moved into the coil. Due to the simultaneous increases of self and mutual inductance and of radio-frequency resistance, new curves such as *b* and *c* are obtained. Curves *a*, *b* and *c*, in fact, were measured at three different frequencies, and show substantially the same selectivity and fidelity through the entire range of frequencies.

It is customary to state the selective properties of a circuit in terms of band width in kilocycles at half amplitude, and I have called this quantity the "selectance". As determined in Figure 8, it is of the order of 30 k. c., varying slightly at the three investigated frequencies. Theoretical analysis of a resonant circuit indicates that selectance expressed in band width is directly proportional to

$$\frac{R}{L},$$

where R and L are, respectively, resistance and inductance of the circuit. The selectance is somewhat impaired by the effects of the plate electrode of an associated thermionic relay in an amplifying stage. The fact that the selectances are substantially equal at three investigated frequencies, indicates that

$$\frac{R}{L}$$

is kept substantially constant. Another expression, showing that the dynamic resistance

$$R_d = \frac{L}{RC},$$

is especially suitable for a circuit with variable inductance L and fixed capacity C. As above deduced,

$$\frac{R}{L}$$

or its reciprocal

$$\frac{L}{R},$$

may be maintained constant when the circuit is tuned by an iron core of suitable design. It is

evident, from this expression, that the dynamic resistance R_d may also be maintained constant if the capacity C is of fixed value.

When movable iron cores are used for tuning purposes in conjunction with other variable devices, such as variable condensers, variable inductances, variometers and the like, the movement of the iron core should be correlated with the movement of the other variable devices. It is preferable to so adjust the core that, at the higher frequencies, the iron is kept away from the coil. As the frequency decreases, the iron core should be gradually inserted into the coil, with a constant or an increasing speed, depending on the design of other tuning devices employed.

Figure 9 diagrammatically shows the invention embodied in a system for the reception of radio signals and the like. This system includes a plurality of selective resonant circuits 31, 32, 33, arranged in cascade with amplifying relay devices. Each circuit is provided with an inductance coil 34, 35 or 36, an external capacitance 37, 38 or 39, across said coil and a magnetic body 40, 41 or 42 disposed in the field of said coil which is movable relatively to the coil in which it is included, to thereby inductively affect more or less of its winding, and simultaneously and in the same proportion vary the inductance and the radio-frequency resistance of each selective circuit and thus maintain its desired characteristics.

Having thus described my invention, what I claim is:

1. A resonant circuit including a tuning condenser, a coil and a magnetic body in the field of said coil, said body having insulated magnetic particles and being of such characteristics that the effective radio-frequency resistance of said circuit is substantially proportional to the square of the frequency to which the circuit is tuned.

2. A resonant circuit inductively related to a source of oscillations, including a tuning condenser, a coil and a magnetic core in the field of said coil, said core having insulated magnetic particles and being of such characteristics that the effective radio-frequency resistance of said coil is substantially proportional to the square of the frequency to which the circuit is tuned.

3. A resonant circuit including a condenser, a coil and tuning means comprising a magnetic body having insulated magnetic particles and being movable relatively to said coil, said tuning means being characterized by the fact that the said circuit has substantially the same resonant response at at least two materially different frequencies.

4. A resonant circuit including a condenser, a coil and tuning means comprising a magnetic body having insulated magnetic particles and being movable relatively to said coil, said tuning means being characterized by the fact that the said circuit has substantially the same selective properties at at least two materially different frequencies.

5. A resonant circuit including a condenser, a coil and means for varying the effective magnetic permeability of the space surrounding said coil, said means comprising a magnetic body having insulated magnetic particles and being characterized by the fact that the said circuit has substantially the same resonant response at at least two materially different frequencies.

6. A resonant circuit including a condenser, a coil and means for varying the effective magnetic permeability of the space surrounding said coil, said means comprising a magnetic body having insulated magnetic particles and being characterized by the fact that the said circuit has substantially the same selective properties at at least two materially different frequencies.

7. A resonant circuit including a condenser, a coil and magnetic means for varying the effective value of the inductance of the coil, said means comprising a magnetic body having insulated magnetic particles and being characterized by the fact that the said circuit has substantially the same resonant response at at least two materially different frequencies.

8. A resonant circuit including a condenser, a coil and magnetic means for varying the effective value of the inductance of the coil, said means comprising a magnetic body having insulated magnetic particles and being characterized by the fact that the said circuit has substantially the same selective properties at at least two materially different frequencies.

9. A resonant circuit including a condenser, a coil and tuning means comprising a magnetic body having insulated magnetic particles and being movable relatively to said coil, said tuning means being characterized by the fact that the circuit may be tuned over a substantial range of frequencies and will have substantially the same resonant response throughout the said tuning range.

10. A resonant circuit having a condenser, a coil and tuning means including a magnetic body having insulated magnetic particles and being movable relatively to said coil, said tuning means being characterized by the fact that the circuit may be tuned over a substantial range of frequencies and will have substantially the same selective properties throughout the said tuning range.

11. A resonant circuit including a condenser, a coil and tuning means comprising a magnetic body having insulated magnetic particles and being movable relatively to said coil, said coil and said condenser being chosen to give a desired resonant response at a particular frequency and said magnetic body having such characteristics that the circuit maintains substantially the same resonant response when tuned by said body to a materially lower frequency.

12. A resonant circuit including a condenser, a coil and tuning means comprising a magnetic body having insulated magnetic particles and being movable relatively to said coil, said coil and said condenser being such as to give desired selective properties at a particular frequency, said magnetic body having such characteristics that the circuit maintains substantially the same selective properties when tuned by said body to a materially lower frequency.

13. A resonant circuit including a condenser, a coil and tuning means comprising a magnetic body having insulated magnetic particles and being movable relatively to said coil, said coil and said condenser being such as to give a desired ratio of inductance to resistance at a particular frequency, said magnetic body having such characteristics that the ratio of inductance to resistance is substantially maintained when the circuit is tuned by said body to a materially lower frequency.

14. That method of tuning a selective circuit having inductance, capacity and resistance and having desired characteristics at a given frequency, which consists in simultaneously varying said inductance and said resistance of said

selective circuit by magnetic means comprising a magnetic body having insulated magnetic particles so as to resonate the circuit to a substantially different frequency while maintaining said desired characteristics.

15. That method of tuning a selective system, having a plurality of resonant circuits each including inductance, capacity and resistance, which consists in simultaneously varying said inductance and said resistance in said resonant circuits, by magnetic means comprising a magnetic body having insulated magnetic particles, to thereby tune said system from an upper frequency to a lower frequency while maintaining the resonant response of the system substantially the same at both of said frequencies.

16. A resonant circuit including a tuning condenser, a coil and a magnetic body having insulated magnetic particles in the field of said coil, said magnetic body being of such characteristic that the said circuit may be tuned over a substantial range of frequencies and will have substantially the same resonant response throughout said tuning range.

17. A resonant circuit including a tuning condenser, a coil and a magnetic body having insulated magnetic particles in the field of said coil, said magnetic body being of such characteristic that the said circuit may be tuned over a substantial range of frequencies and will have substantially the same resonant response at at least two materially different frequencies.

18. A resonant circuit inductively related to a source of oscillation, including a tuning condenser, a coil and a magnetic body having insulated magnetic particles in the field of said coil, said magnetic body being of such characteristic that the said circuit may be tuned over a substantial range of frequencies and will have substantially the same resonant response throughout said tuning range.

19. A resonant circuit inductively related to a source of oscillation, including a tuning condenser, a coil and a magnetic body having insulated magnetic particles in the field of said coil, said magnetic body being of such characteristic that the said circuit may be tuned over a substantial range of frequencies and will have substantially the same resonant response at at least two materially different frequencies.

20. A resonant circuit including a tuning condenser, a coil and a magnetic body having insulated magnetic particles in the field of said coil, said magnetic body being of a closed type and having such characteristics that the effective radio-frequency resistance of the circuit is substantially proportional to the square of the frequency to which the circuit is tuned.

21. A resonant circuit inductively related to a source of oscillations, including a tuning condenser, a coil and a magnetic body having insulated magnetic particles in the field of said coil, said magnetic body being of a closed type and having such characteristics that the effective radio-frequency resistance of the circuit is substantially proportional to the square of the frequency to which the circuit is tuned.

22. A resonant circuit including a condenser, a coil and tuning means comprising a magnetic core having insulated magnetic particles and being movable relatively to said coil, said core being of a substantially closed type and having such characteristics that the said circuit may be tuned over a substantial range of frequencies and will have substantially the same resonant response at at least two materially different frequencies.

23. A resonant circuit including a condenser, a coil and tuning means comprising a magnetic core having insulated magnetic particles and being movable relatively to said coil, said core being of a substantially closed type and having such characteristics that the said circuit may be tuned over a substantial range of frequencies and will have substantially the same selective properties at at least two materially different frequencies.

24. A high-frequency transformer having a primary winding and a secondary winding and a compressed core having insulated magnetic particles capable of passing through a screen of 300 meshes to the inch.

25. A transformer having a primary winding and a secondary winding, and a compressed magnetic core within said windings, said core having insulated magnetic particles small enough to pass through a screen of 300 meshes to the inch.

26. A transformer including primary and secondary windings and a compressed magnetic core having insulated magnetic particles small enough to pass through a screen of 300 meshes to the inch and having an effective permeability of the order or from four to six.

27. A high-frequency open-core transformer including primary and secondary windings and a compressed magnetic core having insulated magnetic particles and having an effective permeability of from four to six.

28. A closed-core high frequency transformer having primary and secondary windings and a compressed core member having insulated magnetic particles small enough to pass through a screen of 300 meshes to the inch.

29. A high-frequency transformer having a plurality of insulated windings and a compressed magnetic body having insulated magnetic particles for providing a relatively low-reluctance flux path for the flux created by at least one of said windings.

30. A high-frequency inductance device for use in resonant circuits including at least one low-loss winding and a compressed comminuted magnetic core having insulated magnetic particles small enough to pass through a screen having 300 meshes to the inch.

31. A high-frequency inductance device for use in resonant circuits including at least one low-loss winding and a compressed comminuted magnetic core having insulated magnetic particles small enough to pass through a screen having 300 meshes to the inch, the losses in said core being such that the effective radio-frequency resistance of said winding varies approximately in proportion to the square of the frequency.

32. A high-frequency inductance device for use in resonant circuits including at least one low-loss spaced-turn winding and a compressed comminuted magnetic core having insulated magnetic particles small enough to pass through a screen having 300 meshes to the inch.

33. A high-frequency inductance device for use in resonant circuits including at least one low-loss winding and a compressed comminuted magnetic core of such form as to provide a substantially complete return path for the flux created by said winding, said core having insulated magnetic particles small enough to pass through a screen having 300 meshes to the inch.

34. A high-frequency inductance device for use in resonant circuits including at least one low-

loss winding and a compressed comminuted magnetic core of such form as to provide a substantially complete return path for the flux created by said winding, said core having insulated magnetic particles small enough to pass through a screen having 300 meshes to the inch, the effective inductance of said winding being increased from 4 to 6 times by said core.

35. A high-frequency inductance device for use in resonant circuits including at least one winding of a transformer, said winding being of low-loss character, and a compressed comminuted magnetic core having insulated magnetic particles small enough to pass through a screen having 300 meshes to the inch.

36. A high-frequency inductance device for use in resonant circuits including at least one winding whose length is approximately twice its diameter and a compressed comminuted magnetic core having insulated magnetic particles small enough to pass through a screen having 300 meshes to the inch.

37. A high-frequency inductance device for use in resonant circuits including at least one low-loss winding and a compressed comminuted magnetic core having particles insulated with an elastic substance and small enough to pass through a screen having 300 meshes to the inch.

38. A high-frequency inductance device for use in resonant circuits including at least one low-loss winding and a compressed comminuted magnetic core having insulated particles small enough to pass through a screen having 300 meshes to the inch, the increase in the effective inductance of said winding due to said core being substantially greater than the increase in the effective resistance of said winding due to said core.

39. A high-frequency inductance device for use in resonant circuits including at least one low-loss winding and a compressed comminuted magnetic core of such form as to provide a substantially complete return path for the flux created by said winding and having insulated magnetic particles small enough to pass through a screen having 300 meshes to the inch, the increase in effective inductance of said winding due to said core being substantially greater than the increase in the effective resistance of said winding due to said core.

40. A high-frequency inductance device for use in resonant circuits including at least one low-loss winding and a compressed comminuted magnetic core having a length at least twice its diameter and having insulated magnetic particles small enough to pass through a screen having 300 meshes to the inch.

WLADIMIR J. POLYDOROFF.

CERTIFICATE OF CORRECTION.

Patent No. 1,982,690. December 4, 1934.

WLADIMIR J. POLYDOROFF.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 2, line 104, for "1500" read 500; and page 4, line 103, claim 26, for "or" read of; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 28th day of May, A. D. 1935.

Leslie Frazer

(Seal) Acting Commissioner of Patents.