

**APPARATUS FOR COUPLING AN ANTENNA TO A WRIST CARRIED
SELECTIVE CALL RECEIVER**

Field of the Invention

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This invention relates in general to the field of wireless communication and more specifically to antenna coupling for wrist carried selective call receivers.

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Background of the Invention

Selective call receivers or pagers mounted within a wristwatch size case and having an antenna carried by a wristwatch style band are well known. Wristwatches are usually removably connected to a band or strap by a removable pin such as a conventional barrel pin or roll pin with spring loaded extensions. When connected, the strap and the wristwatch are free to pivot relative to each other. However, disadvantageously, known wristwatch sized pagers are connected to known antenna-carrying wristwatch style bands by an apparatus that is substantially different than the apparatus by which wristwatches are usually connected to wristwatch bands. The antenna carried by known wristwatch style bands is electrically coupled to the selective call receiver within known wristwatch size cases by a direct mechanical connection. As a result, the junction between the case and the band or strap is disadvantageously stiff and inflexible, and the case and band cannot pivot relative to each other. Further, antennas used with known wrist worn pagers cannot be easily replaced because they disadvantageously require breaking the antenna connection upon removal of an old band and making the antenna connection upon installation of a new band. A jeweler familiar only with conventional wristwatches and bands is not able to easily replace a band on a known prior art wristwatch style pager without special training and equipment. An example of a wristwatch sized pager having such a nonstandard connection is shown in U. S. Patent No. 5,179,733 issued January 12, 1993 to Matsui.

In some known wrist worn pagers, the mechanical connection for electrically coupling the antenna and the receiver is in addition to another mechanical connection for securing the case to the band, thereby disadvantageously requiring two separate operations to change a band.



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Examples of such wrist worn pagers are shown in U. S. Patent No. 4,754,285 issued June 28, 1988 to Robitaille and U. S. Patent No. 4,769,656 issued September 6, 1988 to Dickey.

Other known wrist worn pagers disadvantageously have a mechanical
5 connection between the antenna and a band pin for electrical coupling of the antenna to the pager. Such direct electrical connection renders the pin nonremovable or requires a special pin for attaching the band to the case. Examples of such wrist worn pagers are shown in U. S. Patent No. 3,032,651 issued May 1, 1962 to Gisiger-Stahli, et al., and U. S. Patent No. 5,159,713
10 issued October 27, 1992 to Gaskill, et al.

An example of a prior art wristwatch style pager using a spring loaded pin to mechanically secure a band to a case is shown in U. S. Patent No. 4,817,196 issued March 28, 1989 to MacNak, et al., and assigned to the assignee of the present invention. However, MacNak, et al., do not disclose
15 capacitive coupling of an antenna to a receiver. Further, MacNak, et al., do not disclose the spring loaded pin participating in the electrical coupling of the antenna to the receiver.

An example of electrically coupling a wristwatch pager to an antenna using a mechanical connection is shown in U. S. Patent No. 5,86,431 issued
20 February 23, 1993 to Marinelli and assigned to the assignee of the present invention. Marinelli provides satisfactory performance under most, but not necessarily all, operating circumstances. However, Marinelli depends upon the concave semicircular arcuate contact constantly touching the convex semicircular arcuate contact and is affected by dirt between the concave
25 contact and the convex contact. Further, a wiping action between the concave semicircular arcuate contact on the pager and the convex semicircular arcuate contact on the band produces undesirable friction.

A cordless telephone with capacitive coupling of an antenna located in a rigid hinged element to a radiotelephone located in a main body is shown in
30 U. S. Patent No. 5,170,173 issued December 8, 1992 to Krenz et al., and assigned to the assignee of the present invention. However, Krenz et al., disclose capacitors co-located with, and disposed within, the hinges.

Thus, what is needed is an apparatus for electrically coupling an antenna carried by a detachable wristwatch style band or strap to a selective call
35 receiver mounted to a wristwatch style case, while overcoming the deficiencies of the prior art noted above.

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Summary of the Invention

One aspect of the present invention is an apparatus to facilitate wearing a selective call receiver on a wrist. The selective call receiver is supported by a case. The apparatus has a strap rotatably connected to the case for securing the case to a wrist, and an antenna carried by the strap. The apparatus, comprises a capacitor having a first plate and a second plate spaced a preselected distance. The first plate is fixed on the case and electrically coupled to the selective call receiver, and the second plate is fixed to the strap and electrically coupled to the antenna. The apparatus also comprises means, separate from the first plate, for pivoting the strap with respect to the case. The apparatus further comprises means, separate from the second plate, for maintaining the preselected distance between the first plate and the second plate during pivoting of the strap with respect to the case.

Another aspect of the present invention is a selective call receiver. The selective call receiver comprises a receiver circuit and a case for holding the receiver circuit. The case has a pair of mounts, and at least one mount is electrically coupled to the receiver circuit. The selective call receiver further comprises at least one longitudinal strap for securing the case to a user having two sides with a transverse hollow cylindrical opening having a diameter and an axis and extending between the two sides. The selective call receiver also comprises an insulated metallic cylinder having a diameter larger than the diameter of the opening, and the cylinder is coaxially imbedded within the at least one strap. An antenna is carried by the at least one strap and electrically coupled to the cylinder. The selective call receiver further comprises a metallic cylindrical pin having a diameter approximately the diameter of the opening, the pin removably mounted to the pair of mounts to form an electrical connection with the at least one mount and removably positioned coaxially within the opening to capacitively interact with the cylinder.

A further aspect of the present invention is an apparatus for coupling an antenna supported by insulating material to a selective call receiver supported by a case. The insulating material is pivotally mounted to the case by two hinges. The device comprises a capacitor located intermediate the two hinges. The capacitor has a first plate located on the case and a second plate located on the insulating material. The device also comprises means for maintaining capacitance of the capacitor substantially constant during pivoting of the insulating material with respect to the case.



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Brief Description of the Drawings

FIG. 1 is a perspective, partially exploded, view of a selective call receiver and an antenna carried by a wristwatch style strap showing an apparatus for electrically coupling the antenna to the selective call receiver in accordance with the preferred embodiment of the present invention.

FIG. 2 is an enlarged side view of a portion of the apparatus shown in FIG. 1 as seen through line x - x' in FIG. 1.

FIG. 3 is a cross-sectional view of the apparatus shown in FIG. 1 showing limit of pivot of the strap in one direction.

FIG. 4 is a side view of the apparatus shown in FIG. 1 showing limit of pivot of the strap in another direction.

FIG. 5 is a perspective, partially exploded, view of another embodiment of the apparatus for electrically coupling the antenna to the selective call receiver in accordance with the preferred embodiment of the present invention.

FIG. 6 is a top view of a portion of the apparatus shown in FIG. 5.

FIG. 7 is an enlarged side view of a portion of the apparatus shown in FIGS. 5 and 6 as seen through line y - y' in FIG. 6.

FIG. 8 is simplified schematic diagram showing a capacitor of the present invention and a matching circuit between the antenna and the receiver.

Description of the Preferred Embodiment

Referring now to FIG. 1, a selective call receiver 10, such as a pager, is shown mounted in a wristwatch style case 14, preferably made of plastic. The operation of the selective call receiver 10 is well known to those skilled in the art. The selective call receiver 10 comprises a receiver circuit 12 supported by the case 14. The selective call receiver 10 is enclosed within the case 14 and a cover 16. A strap 18 having at least one end 13 is used to facilitate wearing the selective call receiver 10 on a wrist of a user. The at least one end 13 of the strap 18 is preferably similar to an end of a standard wristwatch band. Each of the at least one end 13 of the strap 18 is removably, rotatably connected to opposite sides 15 and 17 of the case 14.

The apparatus 11 for coupling an antenna to the selective call receiver 10 comprises a capacitor 50 having two capacitive plates, the two capacitive plates being a first plate 22 and a second plate 26 spaced a preselected

distance 51 (FIG. 2). The case 14 includes a substantially arcuate concave recess 20 on at least one of the opposite sides 15 and 17 adapted to receive the first plate 22. As shown in FIG. 2, the first plate 22 is an arcuate portion of a cylinder having an axis 23, a length 31, L , a radius 35, R , and an angular dimension 63, α . Referring again to FIG. 1, the first plate 22 is mounted within the substantially arcuate concave recess 20 to form a concave portion of an external surface of the case 14 at one of the opposite sides 15. Alternatively, as shown in FIG. 2, the first plate 22 is embedded a distance 55 within the case 14 at one of the opposite sides 15 by plastic molding methods well known to those skilled in the art. The first plate 22 is electrically connected by connecting conductor 28 to the receiver circuit 12.

The strap 18 is preferably flexible and made of a plastic or injection moldable, electrical insulating material. The strap 18 is longitudinal and has two sides 19 and 21. The strap 18 has a transverse hollow cylindrical opening 30 having an axis 29 and extending between the sides at the at least one end 13. An antenna 24, preferably a flexible antenna, is disposed within the strap 18. The antenna 24 is preferably a thin, flat longitudinal strip as shown in FIG. 1; alternatively, the antenna is a wire. The antenna 24 is electrically connected at one end 25 to the second plate 26. The second plate 26 is disposed entirely within the material of the strap 18 coaxially with the transverse hollow cylindrical opening 30. The operation of embedding the antenna 24 within the strap 18 and forming opening 30 by insert molding techniques is well known to those skilled in the art. A distance 49, shown in FIG. 2, is therefore obtained between the second plate 26 and the external surface 48 of the strap 18.

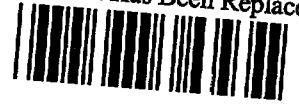
The second plate 26 is an arcuate portion of a cylinder having an axis, a length 31, L , a radius 37, r , and an angular dimension 65, β , where β is substantially larger than α , but less than 270 degrees. Alternatively, the angular dimension 65, β of the second plate 26 is substantially smaller than the angular dimension α of the first plate 22. In any event, in the preferred embodiment, the first plate 22 and the second plate 26 comprise arcuate portions 39 and 41, respectively, of cylinders (not shown, except for the arcuate portions), and each of the arcuate portions subsumes a substantially different number of degrees.

The strap 18 is attached to case 14 using a pin 32, preferably, a conventional compressible watch spring pin, snugly fitted through the opening 30 in the strap 18. Advantageously, the pin 32 is a type with which jewelers are familiar and therefore can install and remove using conventional

techniques. In fact, the strap 18 can be installed and removed as if it were a standard wristwatch band without an antenna. The material of the strap 18 insulates the second plate 26 from the pin 32. The pin 32 comprises a barrel section 34 having a diameter and having extension sections 36 and 38 with smaller diameters than the diameter of the barrel section. The extension sections 36 and 38 are spring loaded by a spring within the barrel section 34. A plain bearing is formed between each of the extension sections 36 and 38 and the barrel section 34 allowing the barrel section to roll relative to the extension sections.

Each of the opposite sides 15 and 17 of the case 14 has a pair of mounts 56 and 57, and 58 and 59, respectively, protruding from the external surface 48 of the case and preferably made from material contiguous with material of the case. The mounts 56 - 59 are separate from the first plate 22 and the second plate 26. Each of the opposite sides 15 and 17 of the case 14 is substantially similar; therefore, only one of the opposite sides 15 will be described in detail. The mounts 56 and 57 have cavities 60 and 61. One of the cavities 60 on one of the mounts 56 opposes another of the cavities 61 on another of the mounts 57. The cavities 60 and 61 are sized to snugly hold the extension sections 36 and 38 of the pin 32. The cavities 60 and 61 are within the material of the case 14; therefore, the pin 32 is insulated from the receiver circuit 12 and from all other electrical components of the selective call receiver 10. The cavities 60 and 61 are disposed on the case 14 at a predetermined distance 45 from the external surface of the case to allow for rotation of the at least one end 13 of the strap 18 about the case when the strap is mounted to the case by the pin 32. The cavities 60 and 61 on the mounts 56 and 57 cooperate with the extension sections 36 and 38 of pin 32 to form two hinges. When the strap 18 is connected to the case 14, the axis of the second plate 26 is coaxial with the axis 23 of the first plate 22. The strap 18 is capable of pivoting about the case 14. During pivoting of the strap 18, the axis of the first plate 22 and axis 23 of the second plate 26 remain coaxial. Furthermore, the strap 18 remains a fixed distance 53 from the case 14 during pivoting which advantageously allows the apparatus 11 to be relatively unaffected by friction as compared to prior art coupling apparatuses.

Capacitive engagement of the first plate 22 with the second plate 26 electrically couples the antenna 24 to the selective call receiver 10. The fixed distance 53 is chosen to allow capacitive coupling between the first plate 22 and the second plate 26 at selective call receiver operating frequencies.



Maintenance of the fixed distance 53 is required to maintain the preselected distance 51 between the first plate 22 and the second plate 26 and, therefore, a constant capacitance. Means for maintaining the preselected distance 51 between the first plate 22 and the second plate 26 during pivoting include the
5 snug fit between the barrel section 34 of the pin 32 and the strap 18, and by the snug fit between the extension sections 36 and 38 of the pin 32 and the cavities 60 and 61.

FIG. 2 shows an enlarged side view of a portion of the case 14 and a portion of the strap 18 shown in FIG. 1 except that the first plate 22 is shown
10 alternatively embedded the distance 55 within the case rather than at the external surface 44 of the case. Preferably, the distance 55 is approximately 0.5 mm. Capacitor 50 is formed by first plate 22, material of the case 14, an air gap 46, material of the strap 18, and second plate 26.

Referring to FIG. 2, the capacitance C of the capacitor 50 is described by
15 the following equation:

$$C = \frac{\epsilon_0 \epsilon_1 \epsilon_2 \epsilon_3 \alpha L}{\epsilon_1 \epsilon_2 \ln \left(\frac{(r+x)}{r} \right) + \epsilon_1 \epsilon_3 \ln \left(\frac{(r+x+y)}{(r+x)} \right) + \epsilon_2 \epsilon_3 \ln \left(\frac{R}{(r+x+y)} \right)} \quad (1)$$

wherein ϵ_0 is the permittivity of free space, ϵ_1 is the dielectric constant of the
20 material of the case 14, ϵ_2 is the dielectric constant of air, ϵ_3 is the dielectric constant of the material of the strap 18; α is, in general, the angular dimension of the angularly smaller of the first plate 22 and the second plate 26, however in the preferred embodiment α is the angular dimension of the first plate 22; L is the length of the first plate 22 and of the second plate 26; R, 35, is the
25 radius of the arc of the first plate 22; r, 37, is the radius of the arc of the second plate 26; y is the ring segment radius of the air gap 46 between the external surface 44 of the case 14 and the external surface 48 of the strap 18; and x is the ring segment radius of a portion of the material of the strap between the second plate and the external surface of the strap. The portion of the material
30 of the strap 18 between the second plate 26 and the external surface 48 of the strap acts as a dielectric. The equation (1) is used to calculate capacitance C of capacitor 50 in the preferred embodiment with three different materials between the two capacitive plates of the capacitor: material of the case 14, air gap 46, and material of the strap 18. The capacitor 50 is equivalent to three

capacitors connected in series: the capacitance C_1 contributed by the material of the case 14, the capacitance C_2 contributed by the air gap 46, and the capacitance C_3 contributed by the material of the strap 18. Therefore the total capacitance is $C = 1/C_1 + 1/C_2 + 1/C_3$. The capacitance value varies with dielectric material chosen, the plate dimensions, and the plate spacing. For example, equation (1) with dielectric constants of $\epsilon_1=5.1$, $\epsilon_2=1$, $\epsilon_3=9$, $\epsilon_0=8.85 \times 10^{-12}$ farads/meter; plate dimensions of $L=12.7$ mm, $\alpha=135$ degrees, $R=2.4$ mm, and $r=1.4$ mm; ring segment $x=0.4$ mm, and ring segment $y=0.1$ mm, results in a capacitance C of 2.1 pF. The relatively low capacitance of 2.1 pF is due to the relatively large (1.0 mm) preselected distance 51 between the first plate 22 and the second plate 26. As a result, the apparatus 11 having the foregoing dimensions is most effective at selective call receiver operating frequencies above 130 MHz.

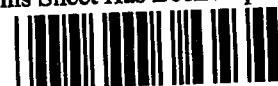
Alternatively, the first plate 22 is mounted on the external surface 44 of the case 14 and the second plate 26 is embedded within the strap 18. The capacitance C for this first alternative is calculated as follows:

$$C = \frac{\epsilon_0 \epsilon_2 \epsilon_3 \alpha L}{\epsilon_2 \ln\left(\frac{(r+x)}{r}\right) + \epsilon_3 \ln\left(\frac{R}{(r+x)}\right)} \quad (2)$$

Equation (2) for C with dielectric constants of $\epsilon_2 = 1$, $\epsilon_3 = 9$, and $\epsilon_0 = 8.85 \times 10^{-12}$ farads/meter; plate dimensions of $\alpha = 180$ degrees; $L = 14.3$ mm; $R = 1.8$ mm; $r = 1.4$ mm; and ring segment $x = 0.3$ mm and ring segment $y = 0.1$ mm, results in a capacitance of 5.1 pF. It has been found that this first alternative is effective at all frequencies presently assigned by the Federal Communication Commission (FCC) for paging systems.

In a second alternative, not shown, the first plate 22 is embedded within the case 14 and the second plate 26 is on the external surface 48 of the strap 18. In the second alternative, the second plate 26 forms a convex portion of the external surface 48 of the strap 18. The capacitance for the second alternative is calculated by equation (3) for C as follows:

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$$C = \frac{\epsilon_0 \epsilon_1 \epsilon_2 \alpha L}{\epsilon_1 \ln \left(\frac{(r+y)}{r} \right) + \epsilon_2 \ln \left(\frac{R}{(r+y)} \right)} \quad (3)$$

It has been found that the second alternative is also effective at all frequencies presently assigned by the FCC for paging systems.

In a third alternative, not shown, the first plate 22 is on the external surface 44 of the case 14 and the second plate 26 is on the external surface 48 of the strap 18. The capacitance for the third alternative is calculated by equation (4) as follows:

$$C = \frac{\epsilon_0 \epsilon_2 \alpha L}{\ln \left(\frac{R}{r} \right)} \quad (4)$$

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The lack of any dielectric, other than air, between the capacitive plates in the third alternative, limits the capacitance; therefore, the third alternative is preferably used at frequencies above 130 MHz.

Because the invention uses capacitive coupling to transfer electrical energy from the antenna 24 to the receiver circuit 12, the invention is less adversely affected by any dirt between the strap 18 and the case 14 than are prior art coupling apparatuses which use conductive coupling.

Referring now to FIG. 3, in order to further maintain a substantially constant capacitance of capacitor 50 during pivot or rotation of the strap 18 about the pin 32, the selective call receiver 10 also has means to limit pivoting of the strap relative to the case 14 to no more than a preselected number of degrees θ , where θ is equal to β minus α . The preselected number of degrees θ is equal to the substantially different number of degrees between angular dimension of the first plate 22 and the angular dimension of the second plate 26. The strap 18 is mounted to the case 14 to provide that the gap between the first plate 22 and the second plate 26 is angularly equal to α even at extreme limits of rotation. By limiting the rotation to θ degrees, the capacitance of capacitor 50 is calculated using the angular dimension of only the angularly smaller of the first plate 22 and the second plate 26. The means to limit pivoting of the strap 18 with respect to the case 14 include an edge 62 of the cover 16 and an inside corner 64 of the case 14. In FIG. 3, the strap 18 is



shown rotated about pin 32 to a maximum angular distance in one direction. Movement in the one direction is limited to a limit of pivot 87 by the edge 62 of the cover 16. Referring to FIG. 4, the strap 18 is shown rotated about pin 32 to a maximum angular distance in another direction. Movement in the other
5 direction is limited to another limit of pivot 89 by the inside corner 64 of the case 14.

Referring to FIG. 5, a selective call receiver 10 is shown in an alternate embodiment of the present invention. According to the alternate embodiment of the invention, the selective call receiver 10 comprises the receiver circuit 12
10 of conventional design enclosed within the case 70 and a smaller cover 71. The strap 18 is attached to case 70 by pin 32 that is press fit into transverse hollow cylindrical opening 30 of the strap. The strap 18 is capable of pivoting about the case 70. As a result of a tight press fit between the barrel section 34 of pin 32 and the strap 18, the barrel section and the strap rotate together
15 without relative movement during pivoting of the strap about the case. The plain bearings between the barrel section 34 and the extension sections 36 and 38 of the pin produce a constant electrical connection between each of the extension sections and the barrel section.

A top view of the alternate embodiment of present invention is shown in
20 FIG. 6 depicting the apparatus 11 with a portion of the material of the strap 18 cut away to show an insulated metallic cylinder 86 which acts as one of the two capacitive plates. The strap 18 includes preferably at least one flexible longitudinal wrist strap 43 for securing the case 70 to a user. The strap 18 has a transverse hollow cylindrical opening 30 with a diameter 83, a length 84,
25 and an axis 85. Referring now to FIG. 5 and FIG. 6, the case 70 has at least two sides and has protruding portions of contiguous case material on at least one side forming a pair of mounts 78 and 69. Mounts 78 and 69 have cavities 72 and 73, respectively, opposite each other. Tightly fitted into at least one of the cavities 72 and 73 is a metallic bracket 74 for holding an end of at least one of
30 the extension sections 36 and 38 of pin 32 and for forming an electrical connection with pin 32. The receiver circuit 12 is electrically connected to the metallic bracket 74 by bracket connecting wire 75. The extension sections 36 and 38 achieve contacting force against an arm 76 of the metallic bracket 74 from spring loading supplied internal to pin 32. Advantageously, the use of a
35 metallic bracket 74 in each of the cavities 72 and 73 also increases mechanical strength of the attachment of the strap 18 to case 70.

In the alternative embodiment, capacitor 50 is formed by the insulated metallic cylinder 86, the barrel section 34 which acts as the other of the two capacitive plates, and the material of strap 18 which acts as a dielectric. Selective call receiver signals are coupled from antenna 24 to receiver circuit 12 through capacitor 50. Referring now to FIG. 7, the insulated metallic cylinder 86 has a larger diameter 52 than diameter 83 of transverse hollow cylindrical opening 30. Pin 32 is preferably a metallic cylindrical pin such as a conventional compressible watch spring pin, having a diameter 88. The diameter 88 of pin 32 is approximately the diameter 83 of the transverse hollow cylindrical opening 30. The pin 32 fits snugly in opening 30 of strap 18 so that the air space 54 between the pin and the strap is negligible. The size of air space 54 is greatly exaggerated in FIG. 7 for clarity of illustration. Advantageously, a snug fit between pin 32 and strap 18 prevents dirt from accumulating in air space 54, while still allowing removal of the pin using conventional jeweler's techniques. Preferably, the insulated metallic cylinder 86 substantially surrounds pin 32. Alternatively, the insulated metallic cylinder 86 has an elongate opening 90 so that the insulated metallic cylinder merely partially surrounds pin 32. The extension sections 36 and 38 provide means for pivoting strap 18 with respect to case 70. Because both capacitive plates of capacitor 50 in the alternative embodiment rotate together without relative movement during pivoting of strap 18, the alternative embodiment has an advantage of not needing means to limit pivoting of the strap. Therefore, the smaller cover 71 is smaller than the cover 16 because edge 62 (FIG. 2) is not needed to limit pivoting in the one direction. Of course, there is also no need to limit pivoting in the other direction in the alternative embodiment. The equation (4) is used to calculate the capacitance for the alternative embodiment shown in FIGS. 5-7.

The value of the capacitance required for coupling is determined by the following: selective call receiver operating frequencies, antenna type, material of the case, material of the strap, and the geometry of the capacitive plates. The dependence on frequency is implicit, in that most parameters for the material of the case and the material of the strap change with frequency. At frequencies of approximately 40 MHz, the electrical properties of plastic materials are more favorable than at frequencies of approximately 900 MHz because material losses increase and the dielectric constant of many plastics decreases at higher frequencies, thereby decreasing capacitance of capacitor 50. Therefore, the third alternative of the embodiment shown in FIGS. 1 and 2

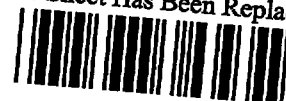


in which the capacitive plates are on external surfaces is preferably used at higher frequencies. The size and spacing of the plates is adjusted such that capacitor 50 has a negligible reactance at selective call receiver operating frequencies.

- 5 Depending on the type of antenna and the frequency of operation, the capacitance C of capacitor 50 alone is enough to resonate the antenna. The antenna used in most wrist carried selective call receivers is a loop antenna that is electrically small relative to wavelength. Since a loop antenna is inductive, capacitive tuning is used. The type of antenna greatly influences
10 the amount of capacitance needed at the apparatus 11 for antenna resonance. Alternatively, a dipole antenna is used. A dipole antenna is also electrically small; however, unlike a loop antenna, a dipole antenna is capacitive in nature. Therefore, inductive loading is used in order to employ capacitive tuning. Dipole antennas are designed to be able to use capacitance of 1 - 10 pF
15 for antenna resonance. In the lower VHF frequencies, a multiple turn loop antenna wound around a ferrite rod is typically used. Capacitance of 2 - 10 pF for capacitor 50 is acceptable for resonance, depending on antenna dimensions. The effectiveness of ferrite decreases with increasing frequency. Also, an excessive amount of turns for a multiple turn loop antenna at UHF
20 frequencies can cause excessive inductance, which in turn can make the capacitance value for resonance extremely small. So, the ferrite is not used and the number of turns of loop is decreased at UHF frequencies. At UHF frequencies, a capacitance of 1 - 10 pF is acceptable for resonance, depending on antenna dimensions. At upper UHF and low GHz frequencies, a small
25 single turn loop antenna and capacitance of 0.5 - 10 pF is used, depending on antenna dimensions.

- Antenna resonance is achieved when the reactance is zero. The reactive component of a small loop antenna is modeled as an inductor having self inductance L connected in series with capacitor 50. Therefore at resonance,
30 the capacitance of capacitor 50 is $C = 1 / \omega^2 L$. The self inductance L of a circular loop of wire is given by equation (5):

$$L \cong \mu_0 b \left(\ln \left(\frac{8b}{a} \right) - 2 \right) - \frac{\mu b}{4} \quad (5)$$



where μ is the permeability of the wire, μ_0 is the permeability of free space, a is the radius of the wire used for the loop antenna, and b is the radius of the loop. If the radius of the wire is 1.6 mm, and the radius of the loop is 3.2 cm, the self inductance L is approximately 0.1614 μH . Therefore, the capacitance C = 5.1 pF produced by the apparatus 11 shown in FIG. 1 is sufficient to achieve resonance.

FIG. 8 shows a schematic diagram of the antenna 24 with impedance matching and resonance components. The antenna 24 shown in FIG. 8 is a single turn loop antenna for simplification of illustration. As previously described, the antenna 24 in strap 18 is inductive at selective call receiver operating frequencies, and is capacitively tuned. At resonance, the impedance seen by input circuitry of the receiver circuit 12 is purely resistive and is approximately 146.04 Ω when copper wire is used. When the input circuitry of the receiver circuit 12 is slightly inductive, coupling capacitor 80 and shunt capacitor 82 are used to conjugately match the impedance of a combined antenna 24 - apparatus 11 circuit to the impedance of the input circuitry. For example, to match the impedance of the combined antenna 24 - apparatus 11 circuit (146.04 Ω) to an input circuitry impedance of $50 + j90$, coupling capacitor 80 is preferably 40.4 pF and shunt capacitor 82 is preferably 8.7 pF. The coupling capacitor 80 and the shunt capacitor 82 are used primarily for impedance matching to input circuitry of receiver circuit 12 and have minor effect on antenna resonance.

FIG. 8 shows the apparatus 11 on both of the opposite sides 15 and 17 of case 14. On one of the opposite sides 15 of the case 14, capacitor 50 acts to resonate the antenna 24 at selective call receiver operating frequencies. On another of the opposite sides 17 of the case 14, the invention couples another end of the antenna 24 to a ground within the receiver circuit 12 through a other capacitor 40. It is not required that the present invention be used on both of the opposite sides 15 and 17 of the case 14. Of course, when the antenna 24 is a dipole antenna, the invention is used on only one of the opposite sides 15 of the case 14. However, in some instances, especially when using a loop antenna at higher frequencies, such as approximately 900 MHz, a very small capacitance is needed to cancel inductive reactance of the antenna in order to bring the antenna to resonance. In these instances, the other capacitor 40 is added in series with capacitor 50 and preferably on the another of the opposite sides 17 of the case 14 to reduce capacitance to a value needed



to bring the antenna to resonance. It has been found that using larger capacitance versions of the apparatus 11 on both of the opposite sides 15 and 17 of the case 14, thereby forming a smaller capacitor from two larger series capacitors (capacitor 50 and the other capacitor 40), is economically preferable to using a smaller capacitance version of the apparatus on only one of the opposite sides 15 of the case because the same larger capacitance version of the apparatus is alternatively available for use on only one of the opposite sides 15 of the case of other selective call receivers operating at lower frequencies.

- 10 The apparatus 11 and the antenna 24 are designed so that minor dust or dirt between first plate 22 and second plate 26 will not have an adverse affect on the circuit performance. For example, at lower selective call receiver operating frequencies, a desired value of capacitor 50, which was herein above stated to be in the range of 2 - 10 pF, is closer to 10 pF than to than 2 pF.
- 15 Minor dust or dirt between first plate 22 and second plate 26 would not have a significant affect on a capacitance value that is close to 10 pF, and circuit performance is not compromised. Although FIG. 8 shows capacitors being used for impedance matching, inductors or any other type of impedance matching circuitry is alternatively used with the invention.

- 20 While a detailed description of the preferred embodiments of the invention has been given, it should be appreciated that many variations can be made thereto without departing from the scope of the invention as set forth in the appended claims. For example, while it is preferred that the angular dimension of the capacitive plate mounted on the case be smaller than the
- 25 angular dimension of the capacitive plate mounted on the strap, it is also contemplated that the angular dimension of the capacitive plate mounted on the case be larger than the angular dimension of the capacitive plate mounted on the strap. In addition, although it is preferred that the capacitive plate mounted on the case be concave and the capacitive plate mounted on the
- 30 strap be convex, it is also foreseen that the capacitive plate on the case be convex and the capacitive plate on the strap be concave. Moreover, there are many different antenna configurations that can be used with the invention. Also, although it is preferred that the apparatus be used when wearing a selective call receiver on a wrist, it is foreseen that the selective call receiver be
- 35 worn on another part of a person's body. Further, the invention is not limited to selective call receivers but can be used with other types of receivers and with transmitters and transceivers. In addition, the capacitive plates and the



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pin are not limited to metallic materials, but can be any conductive material. Furthermore, the material used for the case and the strap are not limited to plastics. It is also contemplated that ceramics be used as an alternative to plastics, especially at higher frequencies.

5 We claim:

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CLAIMS

1. An apparatus to facilitate wearing a selective call receiver on a wrist, the selective call receiver supported by a case, the apparatus having a strap for
5 securing the case to a wrist, the strap rotatably connected to the case, and a flexible antenna carried by the strap, comprising:
a capacitor having a first plate and a second plate spaced a preselected distance, the first plate fixed on the case and electrically coupled to the selective call receiver, the second plate fixed to the strap and electrically
10 coupled to the flexible antenna;
means for pivoting of the strap with respect to the case, the means for pivoting being on the case and separate from the first plate; and
means for maintaining the preselected distance between the first plate and the second plate during pivoting of the strap with respect to the case, the
15 means for maintaining being on the strap and separate from the second plate.
2. The selective call receiver of claim 1, in which the preselected distance is selected to produce a capacitance having negligible reactance at selective call receiver operating frequencies.
20
3. The selective call receiver of claim 2 in which the first plate forms an external surface of the case.
4. The selective call receiver of claim 2 in which the second plate forms an
25 external surface of the strap.
5. The selective call receiver of claim 1 in which the first plate is without the means for pivoting the strap with respect to the case.
- 30 6. The selective call receiver of claim 1 in which the second plate is without the means for maintaining the preselected distance between the first plate and the second plate during pivoting of the strap with respect to the case.
7. The selective call receiver of claim 1, including means to limit pivoting of
35 the strap with respect to the case to a preselected number of degrees.



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8. The selective call receiver of claim 7 in which the first plate and the second plate are arcuate portions of cylinders, the arcuate portions being less than 270 degrees.
- 5 9. The selective call receiver of claim 8 in which the arcuate portions are a substantially different number of degrees.
- 10 10. The selective call receiver of claim 9 in which the preselected number of degrees is equal to the substantially different number of degrees.
11. A selective call receiver, comprising:
a receiver circuit;
a case for holding the receiver circuit, the case having a pair of mounts, at least one mount electrically coupled to the receiver circuit;
15 at least one longitudinal strap for securing the case to a user having two sides with a transverse hollow cylindrical opening having a diameter and an axis and extending between the two sides;
an insulated metallic cylinder having a larger diameter than the diameter of the transverse hollow cylindrical opening, the insulated metallic cylinder coaxially imbedded within the at least one longitudinal strap;
20 an antenna carried by the at least one longitudinal strap and electrically coupled to the insulated metallic cylinder; and
a metallic cylindrical pin having a diameter approximately the diameter of the transverse hollow cylindrical opening, the metallic cylindrical pin
25 removably mounted to the pair of mounts to form an electrical connection with the at least one mount and removably positioned coaxially within the transverse hollow cylindrical opening to capacitively interact with the insulated metallic cylinder.
- 30 12. The selective call receiver of claim 11 in which the metallic cylindrical pin interacts with the insulated metallic cylinder to produce a capacitance having negligible reactance at selective call receiver operating frequencies.
- 35 13. The selective call receiver of claim 11 in which the at least one longitudinal strap is capable of pivoting about the case at the transverse hollow cylindrical opening.



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14. The selective call receiver of claim 13 in which the metallic cylindrical pin includes means for pivoting about the case at the pair of mounts.
15. The selective call receiver of claim 14 in which
5 the metallic cylindrical pin is sized to fit snugly into the transverse hollow cylindrical opening, and
the at least one longitudinal strap and the metallic cylindrical pin rotate together without relative movement.
- 10 16. The selective call receiver of claim 11 in which the insulated metallic cylinder substantially surrounds the metallic cylindrical pin.
17. The selective call receiver of claim 11 in which the case and the pair of
15 mounts are formed of contiguous material.
18. An apparatus for electrically coupling an antenna supported by insulating material to a selective call receiver supported by a case, the insulating material being pivotally mounted to the case by two hinges, comprising:
20 a capacitor disposed intermediate the two hinges, the capacitor having a first plate on the case and a second plate on the insulating material; and
means for maintaining capacitance of the capacitor substantially constant during pivoting of the insulating material with respect to the case.
- 25 19. The apparatus of claim 18 in which
each of the two hinges have a portion on the case and another portion on the insulating material, and
the case and the portion of each of the two hinges on the case are
30 formed of contiguous material.
20. The apparatus of claim 19 in which
the first plate forms a concave portion of an external surface of the case, and
the second plate forms a convex portion of an external surface of the
35 insulating material.



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