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**DYNAMIC CONTROL OF TRANSMITTING POWER AT A TRANSMITTER AND
ATTENUATION AT A RECEIVER****BACKGROUND**

Applicants' invention relates to communications systems
5 including transmitters and receivers, and more particularly
to a communications system that optimizes performance by
dynamically adjusting transmitter power and receiver at-
tenuation.

In a typical telecommunications system, such as in a cellular
10 telephone system, a receiver is designed to function with
signals in a given signal strength range. This signal
strength range is referred to as the dynamic range of the
receiver. The lowest acceptable signal strength that can be
received is called the receiver sensitivity. The highest
15 acceptable signal strength that can be received is called the
blocking limit.

In a cellular telephone system, the distance between a base
station (BS) and a mobile station (MS) varies as the mobile
station moves around within a cell. Consequently, in large
20 cells, the variations in received signal strength can be very
large. Sometimes, these variations are so large that they
cannot be compensated by varying the mobile station's transmit
power. In such cells, it would be useful for the receiver
dynamic range, that is, the signal level range defined by the
25 highest and lowest acceptable received signal levels, to be
changed/transposed in relation to the distance between the
base station and the mobile station.

The receiver dynamic range may be transposed by placing an
attenuator between the antenna and the receiver. As at-
30 tenuation increases, both the lowest and highest acceptable
received signal strengths increase. Similarly, the receiver



dynamic range is transposed downward as attenuation decreases. This influence of attenuation on dynamic range is illustrated in Figure 1. When attenuation is set at 0 decibels (dB), the receiver dynamic range 101 is defined by
5 the sensitivity 102 and the blocking limit 103 of the receiver (not shown).

If attenuation is increased to 3 dB, the receiver dynamic range shifts to a new dynamic range 104, defined by sensitivity 105 and blocking limit 106, both of which are
10 substantially 3 dB higher than the respective sensitivity 102 and blocking limit 103 that existed when attenuation is only 0 dB. Similarly, if attenuation is increased to 6 dB, the sensitivity 108 and blocking limit 109 are again increased, yielding a new receiver dynamic range 107.

15 In small cells, the distance between a mobile station and a base station can be very small. This can lead to disturbances in the receive band if there are large cells in the same area as the small cell. These large cells may belong to the same network as the small cell, or they may belong to another
20 network operating in the same or an adjacent frequency band. The measure of these disturbances can be a bit error rate in digital communications systems. In analog systems, other signal quality measures can be used, such as total distortion of a modulated pilot tone.

25 The situation just described is illustrated in Figure 2, in which a base station B 201 is associated with a cell 202, and a base station A 203 is associated with a cell 204. It will be observed that cell 204 is smaller than cell 202, and defines a geographical area that is located inside or near cell 202.
30 Thus, because of the difference in the cells' relative sizes with respect to one another, cell 202 may be called a "macrocell" and cell 204 may be called a "microcell". When a mobile station B 205, associated with the "macrocell" 202 comes near

base station A 203, the base station A 203 receiver may experience disturbances from mobile station B 205. This may be so even if the radio frequencies used by base station A 203 are widely separated from those used by base station B 201 and
5 mobile station B 205.

If base station A 203 is equipped with a dynamically adjustable attenuator interposed between the antenna and receiver as described above, the attenuation can be increased until the disturbance experienced by the receiver is acceptably low.
10 This is because the disturbances in the receive band are attenuated with at least the value of the attenuator. However, the desired signal from mobile station A 206, which is transmitting to base station A 203, is also attenuated with the value of the attenuator. This may cause the signal from
15 mobile station A 206 to be unacceptably low for reception by base station A 203.

SUMMARY

The above-described problem, and others, are solved in accordance with the Applicants' invention by dynamically
20 controlling both the attenuation at the base station A 203 receiver, and the transmit power of the mobile station A 206.

In one aspect, Applicants' invention provides a receiver that receives a communications signal from a transmitter, the received communications signal being attenuated at the
25 receiver. The signal strength of the signal is then measured. This measured signal strength is then applied to a means for controlling the attenuation and to a means for controlling the transmission power. The attenuation control means dynamically controls the amount by which the received signal is
30 attenuated.



The transmission power control means generates a power control signal to be communicated to the transmitter. The transmitter uses the received power control signal to adjust the power level at which it transmits the communications signal to the receiver. Both the attenuation control means and the transmission control means control, respectively, receiver attenuation and transmission power level so as to optimize system performance.

In another aspect of the invention, receiver attenuation and transmission power level are adjusted to keep the attenuated signal within the dynamic range of the receiver. This feature is useful, for example, for designing a less expensive receiver having a reduced dynamic range which is compensated for by appropriate adjustment of receiver attenuation and transmission power level.

In still another aspect of the invention, receiver attenuation is adjusted so that the receiver sensitivity level is relatively high compared to a disturbance signal level, while at the same time transmission power level is adjusted so that the communications signal coming through the attenuator is still within the dynamic range of the receiver.

In yet another aspect of the invention, the attenuator may include an antenna having a dynamically adjustable gain.

In still another aspect of the invention, dynamic adjustment of receiver attenuation and transmission power level are applied to a system in which a plurality of receivers are coupled to a common antenna through a multicoupler. In one embodiment, a common attenuator is interposed between the common antenna and the multicoupler. In another embodiment, each receiver is also capable of further attenuating its received communications signal.



BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will become apparent from the following description read in conjunction with the accompanying drawings in which:

- 5 Figure 1 is a graph showing the dynamic range of a receiver as a function of attenuation;

Figure 2 illustrates the situation of having a small mobile communications cell at least partly located within a large mobile communications cell;

- 10 Figure 3 is a block diagram of an apparatus in accordance with the present invention for dynamically controlling receiver attenuation and transmitter power;

- 15 Figure 4 is a block diagram of several receivers coupled to one antenna in accordance with another embodiment of the invention;

Figure 5 is a block diagram of another embodiment of the invention which uses partitioned attenuation in a system having multiple receivers coupled to a common antenna by means of a multicoupler; and

- 20 Figure 6 is a block diagram of an alternative embodiment of the invention in which an antenna and a variable attenuator have been combined in a common element.





DETAILED DESCRIPTION

Referring now to Figure 3, a mobile telecommunications system incorporating the present invention is illustrated. Blocks to the right of the dotted line 301 are located in a mobile station. Blocks to the left of the dotted line 301 are located in a base station.

Signals received at the base station by means of an antenna (not shown) are input to a dynamically adjustable attenuator 302. The signal that is output from the attenuator 302 is input to a signal strength measurement circuit 303. The output of the signal strength measurement circuit 303 is coupled to the inputs of an attenuation control circuit 304, and to a mobile station power control circuit 305. The attenuation control circuit 304 is coupled to the attenuator 302 in order to control the amount of signal attenuation that occurs. The mobile station power control circuit 305 uses the output of the signal strength measurement circuit 303 in order to generate a signal that is communicated to a mobile station power circuit 306, where it controls the transmit power level of the mobile station. In one preferred embodiment of the invention, the signal strength measurements and power control functions are made in accordance with the European Telecommunications Standards Institute's (ETSI) Global System for Mobile Communications (GSM) standards, which are herein incorporated by reference. In particular, GSM recommendation 05.08 describes signal strength measurement in Sections 8.1.2 and 8.1.3. Sections 3.2-4.7, in conjunction with GSM recommendation 05.05 Section 4.1, describe RF power control. The control functions of the attenuation control circuit 304 and the mobile station power control circuit 305 are described in more detail below.

One use of the dynamic control system depicted in Figure 3 is to compensate for the varying signal strength received by a

base station B 201 (see Figure 2) that occurs when a mobile station B 205 travels within a large cell 202. If the transmit power of the mobile station B 205 is constant, the signal strength received by the base station B 201 decreases
5 as the distance between the mobile station B 205 and the base station B 201 increases. Conversely, as the mobile station B 205 comes closer to the base station B 201, the received signal strength increases, assuming again that the transmit power of the mobile station 205 is constant.

10 The present invention compensates for this as follows. When the mobile station B 205 is situated near the border of the cell 202, the mobile station power control circuit 305 detects the diminution in received signal strength, and transmits a signal ordering the mobile station B 205 to transmit at a high
15 power level. Due to the large path loss that occurs over this distance, the received signal strength in the base station B 201 may still be weak, and may be close to the receiver sensitivity level.

When the mobile station B 205 moves towards the base station
20 B 201, the received signal strength in the base station B 201 increases. This is detected by the mobile station power control circuit 305, which responds by transmitting a signal to the mobile station B 205 which causes it to reduce its transmit power to a level that keeps the received signal
25 strength within the receiver dynamic range. At some point, as the mobile station B 205 travels towards the base station B 201, the mobile station B 205 is transmitting at its lowest possible power level. As the mobile station B 205 continues towards the base station B 201, the received signal strength
30 will increase, and after some time may be higher than is acceptable. In other words, despite the fact that the mobile station B 205 is transmitting at its lowest possible power level, its proximity to the base station B 201 causes the



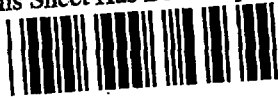


received signal strength to exceed the blocking limit of the receiver.

This problem is solved in the present invention by the attenuation control circuit 304, which detects the unacceptably high received signal strength, and orders the attenuator 302 to increase the amount of attenuation. The upper limit of the acceptable signal strength (i.e., the blocking limit) will then increase, thereby eliminating the problem with the high received signal strength.

- 10 Another problem that is solved by the present invention is the above-described situation that can occur when a small cell 204 is located inside, or near, a large cell 202. As explained above, the disturbance in a base station A 203 caused by a mobile station B 205 that is attempting to transmit to a base station B 201 may be high, relative to the wanted signal being transmitted by the mobile station A 206.

In accordance with the present invention, the mobile station power control circuit 305 detects the high level of disturbance, recognizable in digital communications systems, for example, as an increase in the bit error rate for the channel, and causes actions as follows. The attenuation control circuit 304 causes the attenuator 302 to increase its attenuation until the signal strength of the disturbance 110 (see Figure 1) is considerably reduced, possibly below the receiver sensitivity level 105. However, the desired carrier signal is also attenuated by this action. To compensate for this, the mobile station power control circuit 305 transmits a signal to the power control circuit 306 of mobile station A 206, causing it to increase its transmit power level until the received signal strength of the carrier signal 111 (see Figure 1) is above the receiver sensitivity level 105. Thus, the received signal strength of the desired signal is kept



constant above the sensitivity level while the disturbance is suppressed.

It will be recognized by those skilled in the art that, in the above scenario, the mobile station power control 305 could
5 have been the first to act by ordering the mobile station A 206 to increase its transmit power level in order to increase the received signal strength accordingly, and thereby reduce the bit error rate. The attenuation control circuit 304 could
10 then respond to this occurrence by increasing attenuation of the received signal to bring the received signal strength back down to a desired level.

In another feature of the invention, dynamic attenuation under the control of the attenuation control circuit 304 is combined with a mobile station power control process, carried out by
15 the mobile station power control circuit 305, in which signal quality of the received signal is used to determine the transmit power. By combining dynamic attenuation control with this kind of power control, unnecessary attenuation of the wanted signal is prevented when the disturbance is low. This
20 has the advantage of keeping the mobile transmit power to a minimum, which is of great importance for many mobile applications. In one preferred embodiment, the mobile station power control process, in which signal quality of the received signal is used to determine the transmit power, is that which
25 is described in copending U.S. Patent Application Serial No. _____ entitled METHOD AND APPARATUS FOR TRANSMISSION POWER REGULATION IN A RADIO SYSTEM, filed in the name of Almgren et al. on May 14, 1993 and assigned to the assignee of this invention, the entire disclosure of which is hereby
30 incorporated by reference.

Frequently, a base station has several receivers coupled to the same receiver antenna. In such situations, the attenuation must be partitioned accordingly. Another embodiment



of the invention that solves this problem will now be described with reference to Figures 4 and 5.

In Figure 4, a number of receivers 403 are shown coupled to a single antenna 401 by means of a receiver multicoupler 402.

5 The receiver multicoupler 402 is a wideband amplifier that receives a broad band signal and has a plurality of narrow band signal outputs. Each receiver 403 may include the invention as described above with reference to Figure 3. However, the receiver multicoupler 402 may, itself, suffer

10 blocking by strong signals that are input from the antenna 401. In that case, it is apparent that any attenuation that occurs within individual receivers 403 will be unable to eliminate this blocking. To avoid this problem, the receiver multicoupler 402 may be designed to have a higher blocking

15 limit than any of the individual receivers 403.

Another solution to the problem of blocking in the receiver multicoupler 402 is shown in Figure 5. Here, attenuation is partitioned in order to achieve an optimum selection of attenuation before and after the receiver multicoupler 402.

20 One of a number N of receivers 503 is shown in Figure 5. Although the following description makes reference only to a single receiver 503, it should be understood that the description is applicable to each of the N receivers 503. Each receiver 503 has the control circuitry as described above with

25 reference to Figure 3. In addition, the output of the signal strength measurement circuit 303 from each receiver 503 is coupled to an input of a base station front end attenuation control circuit 504.

A signal representing the amount of attenuation being utilized

30 by the respective receiver 503 is also output from the receiver's base station attenuation control circuit 505 and coupled to an input of the base station front end attenuation



control circuit 504. The base station front end attenuation control circuit 504 combines these inputs with corresponding inputs from the other receivers 503 to determine the true signal strength of the signal that is being output from the front end attenuator 506. For example, these input signals to the base station front end attenuation control circuit 504 may simply be averaged. Other methods of determining the true signal strength of the signal that is being output from the front end attenuator 506 may also be used.

- 10 The base station front end attenuation control circuit 504 then adjusts, by means of an output signal that is coupled to the front end attenuator 506, the strength of the signal that is input to the receiver multicoupler 502. The adjustment is such that the front end attenuation is kept as low as possible
- 15 while still preventing blocking in the receiver multicoupler 502. It will be recognized that in order to make this adjustment, the base station front end attenuation control circuit 504 must also have information regarding the dynamic range of the receiver multicoupler 502. The information
- 20 pertaining to the dynamic range of the receiver multicoupler 502 should preferably be preprogrammed in the base station front end attenuation control circuit 504.

The rest of the regulation is accomplished as described above with reference to Figure 3. That is, each individual base

25 station-mobile station link is regulated so as to produce an optimum balance of transmitted power and received signal quality.

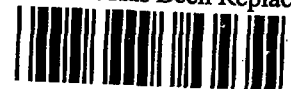
Referring now to Figure 6, an alternative embodiment of the invention is shown. This embodiment is very much like the one

30 shown in Figure 3. The difference between the two embodiments is that, in Figure 6, the variable attenuator has been replaced by the antenna/attenuator 602, which is an antenna having adjustable antenna gain, such as an electronically

adjustable phased array antenna. The remaining elements in Figure 6 operate the same as the corresponding elements described above with respect to Figure 3, and need not be described in further detail.

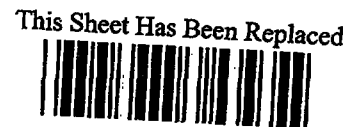
- 5 The advantage of incorporating the adjustable attenuation directly in the antenna element is that intermodulation (IM) products generated in the antenna itself are attenuated by an amount that is approximately equal to the set attenuation raised to the n^{th} power, where n is the order of the inter-
- 10 modulation product. This makes it possible to implement a receiver/antenna configuration having an extreme robustness against radio environments having the kinds of disturbances discussed above, including high signal strength (causing blocking), and intermodulation products. In addition, by
- 15 designing a receiver which can compensate for high signal strength and intermodulation products, system margins can be widened to improve performance in the presences of other types of disturbances, such as cochannel interference and propagation channel distortion.
- 20 The invention has been described with reference to several specific embodiments. It will be recognized by those skilled in the art, however, that the invention may be practiced in ways not illustrated here. Thus, the scope of the invention is not limited by this description, but is, instead, defined
- 25 by the following claims.

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WHAT IS CLAIMED IS:

1. In a communications system having a receiver that receives a communications signal transmitted by a transmitter, the transmitter including transmitter power control
5 means, responsive to a received power control signal, for controlling a power level at which the transmitter transmits the transmitted communications signal, a receiver apparatus comprising:
 measurement means for generating a signal strength
10 measurement signal based on the received communications signal;
 means for attenuating the received communications signal by an amount dynamically determined by a control signal;
 attenuation control means, coupled to the measurement
15 means and the attenuating means, for supplying a control signal thereto; and
 first power control means, coupled to the measurement means, for generating a power control signal to be communicated to the transmitter;
20 wherein the attenuation control means and the first power control means dynamically control, respectively, receiver attenuation amount and transmitter power level so as to substantially optimize communications system performance.
2. A receiver apparatus according to claim 1, wherein
25 optimizing communications system performance includes keeping the attenuated signal within a dynamic range of the receiver.
3. A receiver apparatus according to claim 2, wherein the attenuating means includes an antenna having a dynamically adjustable antenna gain.
- 30 4. A receiver apparatus according to claim 1, wherein optimizing communications system performance includes dynamically adjusting receiver attenuation to produce an



effective dynamic range for receiving only signals having a signal strength level that is higher than a disturbance signal strength level, while at the same time adjusting transmitter power level so that the transmitter will produce an adjusted
5 communications signal that is within the effective dynamic range of the receiver.

5. A receiver apparatus according to claim 4, wherein optimizing communications system performance is performed by the attenuation control means and the first power control
10 means in response to a bit error rate of the received communications signal being higher than a predetermined amount, the higher bit error rate indicating the presence of a disturbance signal.

6. A receiver apparatus according to claim 4, wherein the
15 attenuating means includes an antenna having a dynamically adjustable antenna gain.

7. A receiver apparatus according to claim 1, wherein the attenuating means includes an antenna having a dynamically adjustable antenna gain.

20 8. In a communications system having a plurality of receivers coupled to a common antenna through a receiver multicoupler, the multicoupler having a signal input and a plurality of signal outputs each corresponding to one of the plurality of receivers, each of the receivers receiving a
25 communications signal transmitted by a corresponding one of a plurality of transmitters, each transmitter including transmitter power control means, responsive to a received power control signal, for controlling a power level at which the transmitter transmits the transmitted communications
30 signal, a receiver apparatus comprising:





a plurality of first measurement means, each generating a first signal strength measurement signal based on a corresponding received communication signal;

front end attenuating means for attenuating the plurality of received communications signals by an amount dynamically determined by a first control signal, the front end attenuation means having an output for supplying the attenuated plurality of received communications signals to the receiver multicoupler;

front end attenuation control means coupled to the plurality of first signal strength measurement means and to the front end attenuating means for supplying a first control signal thereto; and

a plurality of first power control means, each coupled to a corresponding one of the plurality of first signal strength measurement means, each for generating one of the plurality of power control signals to be communicated to a corresponding one of the plurality of transmitters;

wherein the front end attenuation control means and the plurality of first power control means dynamically control, respectively, receiver first attenuation amount and transmitter power level of the plurality of transmitters so as to substantially optimize communications system performance.

9. A receiver apparatus according to claim 8, wherein optimizing communications system performance includes keeping the attenuated signal within a dynamic range of each of the plurality of receivers.

10. A receiver apparatus according to claim 8, wherein optimizing communications system performance includes dynamically adjusting receiver front end attenuation to produce an effective dynamic range for receiving only signals having a signal strength level that is higher than a disturbance signal strength level, while at the same time adjusting a power level of each of the plurality of transmitters so that



each transmitter will produce an adjusted communications signal that is within the effective dynamic range of a corresponding receiver.

11. A receiver apparatus according to claim 10, wherein
5 optimizing communications system performance is performed by the front end attenuation control means and the plurality of first power control means in response to a bit error rate of the received communications signals being higher than a predetermined amount, the higher bit error rate indicating the
10 presence of a disturbance signal.

12. A receiver apparatus according to claim 8, wherein the front end attenuating means includes an antenna having a dynamically adjustable antenna gain.

13. In a communications system having a plurality of receivers coupled to a common antenna through a receiver multicoupler, the multicoupler having a signal input and a plurality of signal outputs each corresponding to one of the plurality of receivers, each of the receivers receiving a communications signal transmitted by a corresponding one of
20 a plurality of transmitters, each transmitter including transmitter power control means, responsive to a received power control signal, for controlling a power level at which the transmitter transmits the transmitted communications signal, a receiver apparatus comprising:

25 front end attenuating means for attenuating the plurality of received communications signals by an amount dynamically determined by a first control signal, the front end attenuation means having an output for supplying the attenuated plurality of received communications signals to the
30 receiver multicoupler;

a plurality of second attenuating means, each for further attenuating a corresponding one of the attenuated plurality





of received communications signals by an amount dynamically determined by a corresponding second control signal;

a plurality of first measurement means, each for generating a first signal strength measurement signal based on the
5 corresponding received communications signal;

front end attenuation control means coupled to the plurality of first signal strength measurement means and to the front end attenuating means for supplying a first control signal thereto;

10 a plurality of first power control means, each coupled to a corresponding one of the plurality of first signal strength measurement means, each for generating one of the plurality of power control signals to be communicated to a corresponding one of the plurality of transmitters; and

15 a plurality of second attenuation control means, each coupled to a corresponding one of the plurality of first signal strength measurement means and to a corresponding one of the plurality of second attenuating means, for supplying the corresponding second control signal thereto;

20 wherein the front end attenuation control means, the plurality of first power control means, and the plurality of second attenuation control means dynamically control, respectively, receiver front end attenuation amount, transmitter power level of the plurality of transmitters, and
25 receiver further attenuation amount so as to substantially optimize communications system performance.

14. A receiver apparatus according to claim 13, wherein optimizing communications system performance includes keeping each of the plurality of further attenuated signals within a
30 dynamic range of a corresponding receiver.

15. A receiver apparatus according to claim 13, wherein optimizing communications system performance includes dynamically adjusting receiver front end attenuation and respective receiver further attenuation to produce, for each



of the plurality of receivers, an effective dynamic range for receiving only signals having a signal strength level that is higher than a disturbance signal strength level, while at the same time adjusting a corresponding transmitter power level
5 so that a corresponding transmitter will produce a corresponding adjusted communications signal that is within the effective dynamic range of the respective receiver.

16. A receiver apparatus according to claim 15, wherein optimizing communications system performance is performed by
10 the front end attenuation control means, the plurality of second attenuation control means, and the plurality of first power control means in response to a bit error rate of the received communications signals being higher than a predetermined amount, the higher bit error rate indicating the
15 presence of a disturbance signal.

17. A receiver apparatus according to claim 13, wherein the front end attenuating means comprises an antenna having a dynamically adjustable antenna gain.

18. In a communications system having a receiver that
20 receives a communications signal transmitted by a transmitter, the transmitter including transmitter power control means responsive to a received power control signal for controlling a power level at which the transmitter transmits the communications signal, the receiver including attenuating
25 means for attenuating the received communications signal by an amount dynamically determined by a control signal, a method for dynamically optimizing communications system performance comprising the steps of:

measuring a signal strength of the received communications signal;
30

dynamically adjusting the attenuation amount, based on the measured signal strength; and





generating a power control signal to be transmitted to the transmitter based on the measured signal strength.

19. A method according to claim 18, wherein the steps of dynamically adjusting the attenuation amount and generating
5 a power control signal are further based on keeping the attenuated signal within a dynamic range of the receiver.

20. A method according to claim 18, wherein the steps of dynamically adjusting the attenuation amount and generating
a power control signal are further based on dynamically
10 adjusting receiver attenuation to produce an effective dynamic range for receiving only signals having a signal strength level that is higher than a disturbance signal strength level, while at the same time adjusting transmitter
power level so that it will produce an adjusted communications
15 signal that is within the effective dynamic range of the receiver.

