

TEMPERATURE COMPENSATED AUTOMATIC GAIN CONTROL

BACKGROUND OF THE INVENTION

5 I. FIELD OF THE INVENTION

The present invention relates to automatic gain control. More particularly, the present invention relates to adjusting the transmit power in a portable radio in response to temperature.

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II. DESCRIPTION OF THE RELATED ART

The Federal Communications Commission (FCC) governs the use of the radio frequency (RF) spectrum. The FCC allocates certain bandwidths within the RF spectrum for specific uses. A user of an allocated bandwidth of the RF spectrum must take measures to ensure that the radiated emissions inside and outside of that bandwidth are maintained within acceptable levels to avoid interfering with other users operating in the same and or other bandwidths. These levels are governed by both the FCC and the particular user groups of said bandwidth.

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The 800 MHz cellular telephone system operates its forward link, the cell to radiotelephone transmission, in the bandwidth of 869.01 MHz to 893.97 MHz and the reverse link, the radiotelephone to cell transmission, in the bandwidth of 824.01 MHz to 848.97 MHz. The forward and reverse link bandwidths are split up into channels each of which occupies a 30 kHz bandwidth. A particular user of the cellular system may operate on one or several of these channels at a time. All users of the system must ensure that they are compliant with the level of radiated emissions allowable inside and outside of the channel or channels that they have been assigned.

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There are several different techniques of modulation that can be used in the cellular radiotelephone system. Two examples of modulation techniques are frequency division multiple access (FDMA) and code division multiple access (CDMA). The FDMA technique is used in the advanced mobile phone system (AMPS) that is described in greater detail in the standards document IS-54. The requirements of the CDMA radiotelephone system are described in greater detail in the standards document IS-95.

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The FDMA modulation technique generates signals that occupy one channel at a time while the CDMA modulation technique generates signals that occupy several channels. Both of these techniques must control their return link

radiated emissions to within acceptable limits inside and outside of the assigned channel or channels. For maximum system performance, users of the CDMA technique must carefully control the level of radiated power inside the channels in which they are operating.

- 5 Two methods of controlling the radiated power are open and closed loop power control. Together, these two methods of power control determine the return link transmit energy, as disclosed in U.S. Patent No. 5,056,109 to Gilhousen et al. and assigned to QUALCOMM, Incorporated.

FIG. 1 shows a typical cellular radiotelephone. In both an FDMA and a
10 CDMA based radiotelephone, there exists the possibility of driving the power amplifier (101) in the transmitter beyond a point where acceptable out of channel radiated emissions are maintained. This is primarily due to the increased distortion output levels of the power amplifier (101) at high output powers. Also, driving the power amplifier (101) beyond a certain point can cause interference
15 internal to the radio. For example, PA puncturing in CDMA affects synthesizer phase noise due to large current transitions. Both of these issues cause unacceptable radio performance.

Maintaining the proper on-channel output power can be difficult due to several undesirable effects in the radiotelephone hardware. For example, the
20 CDMA based radio must implement a power control system that operates over a very wide dynamic range, 80 dB to 90 dB, such that the transmitted output power is linearly related to the received input power.

The linear and nonlinear errors produced in both the receiver (103) and transmitter (102) RF sections can cause unacceptable power control performance. Also, both the FDMA and CDMA based radios must operate on different
25 channels while maintaining acceptable output power levels. Variation in output power level and input power detection versus frequency can cause an unacceptable amount of error in the amount of return link transmitted energy.

Another power control problem in radios is the heat generated by
30 power amplifiers and supporting circuitry. The heat dissipation of these parts is directly related to the RF output power of the power amplifier.

This heat dissipation can be handled by large heat sinks, fans, and other mechanical fixtures that remove heat. In each case, however, extra weight and cost is added to the radio. In the case of a portable radio, adding a fan or large
35 heat sink is not feasible due to the need to reduce the size, weight, and cost of the radios.

These issues present significant problems to the designer of both FDMA and CDMA based radios. There is a resulting need to reduce the operating temperature of a radio without adding substantial weight and cost.

SUMMARY OF THE INVENTION

5 The temperature compensated automatic gain control of the present invention encompasses a temperature compensated power amplifier apparatus. This apparatus is comprised of a variable gain amplifier that has a control input for adjusting the gain of the amplifier. A power detector is coupled to the variable gain amplifier and generates a power value of the transmitted signal. A temperature sensor is used to generate a temperature signal for predetermined
10 heat generating components. A power control circuit has a first input coupled to the power detector, a second input coupled to the temperature sensor, and an output coupled to the control input of the variable gain amplifier. The power control circuitry adjusts the variable gain amplifier in response to the power value and the temperature signals.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a block diagram of a typical prior art radiotelephone frequency section for use in a radiotelephone system.

20 FIG. 2 shows a block diagram of the power control correction implementation of the present invention.

FIG. 3 shows a block diagram of the power limiting control section as related to FIG. 2.

25 FIG. 4 shows a block diagram of the closed loop power control section as related to FIG. 2.

FIG. 5 shows a block diagram of the PA limit threshold control section as related to FIG. 2.

30 FIG. 6 shows an alternate embodiment of the present invention that employs a power limiting control system based on accumulator feedback control.

FIG. 7 shows an alternate embodiment of the present invention that employs a power limiting control system based on the closed loop power control accumulator.

35 FIG. 8 shows an alternate embodiment of the present invention that employs a power limiting control system based on integral feedback control.

FIG. 9 shows an alternate embodiment of the present invention that employs a power limiting control system based on a measure of receive power and the closed loop power control setting to estimate output power.

FIG. 10 shows a block diagram of the temperature compensated automatic gain control of the present invention.

FIG. 11 shows a graph indicating the benefits of the embodiment of FIG. 10.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The process of the present invention provides power control correction for a mobile radio as well as maintaining acceptable in and out of band maximum emission levels. This is accomplished by real-time compensation utilizing a set of correction tables that are generated during the production testing of each radio.

FIG. 2 shows a block diagram of a CDMA radio with the power control correction implementation of the present invention. FIGs. 3, 4, and 5 detail specific blocks of FIG. 2. The radio is comprised of a receive linearization section, transmit linearization section, power amplifier bias control section, and power limiting control section.

The receive linearization section includes an automatic gain control (AGC) section. The signal input to the AGC section is received on the forward link and amplified by a low noise amplifier (LNA) (211). The output of the LNA (211) is input to a variable gain amplifier (212). The variable gain amplifier (212) produces a signal that is converted to a digital signal using an analog to digital converter (ADC) (213).

The power of the digitized received signal is next computed by a digital power detector (214). The power detector (214) includes an integrator that integrates the detected power with respect to a reference voltage. In the preferred embodiment, this reference voltage is provided by the radio's demodulator to indicate the nominal value at which the demodulator requires the loop to lock in order to hold the power level constant. The demodulator requires this value for optimum performance since a power level too far out of the optimum range will degrade the performance of the demodulator. The power detector (214) performs the integration, thus generating an AGC setpoint. The setpoint and a receive frequency index are input to a receiver linearizing table (216).

The AGC setpoint and the frequency index are used to address the linearizer (216), thus accessing the proper calibration value. This calibration value is then output to a digital to analog converter (215) that generates the analog representation of the receive AGC setting.

The analog value adjusts the biasing of the variable gain amplifier (212). The control of the variable gain amplifier (212) forces the receive AGC loop to close such that the input to the receiver linearizing table (216) follows a predetermined straight line with respect to RF input power. This linearization removes the undesired linear and non-linear errors in addition to variations versus frequency that would otherwise be apparent at the input to the receiver linearizing table (216) in the receiver. These errors and variations would contribute to errors in the transmitter.

In order to reduce the error in the receive and transmit chains versus frequency, the receive and transmit linearizers utilize the frequency index that specifies the current center frequency on which the receive and transmit chains are operating. During factory calibration of the radio, the linearizers are loaded with values, in addition to the previously mentioned calibration values, that are indexed by frequency to correct the errors related to operating center frequency.

The AGC setpoint is the open loop power control signal for the radio. In the preferred embodiment, this is the power control performed by the radio by itself without control input from the cells. As the power of the signal received from the cell increases, the radio decreases its transmit power. This output power control is accomplished by the AGC setpoint that is filtered by a low pass filter (217).

The transmit section includes a digital summer (210) that combines the AGC setpoint and a closed loop power control setting (206). The output of the summer (210) is fed into a power control limiting section (205). The operation of the power control limiting section (205) and the closed loop power control section (206), illustrated in FIGs. 3 and 4 respectively, will be discussed subsequently in greater detail.

The output of the power control limiting section (205), along with the transmit frequency index, are used to address values stored in a transmitter linearizing table (204). The transmitter linearizing table (204) contains values determined from production testing of the radio. The selected value is input to a digital to analog converter (203) whose output, an analog representation of the digital value input, controls a variable gain amplifier (202).

The biasing of the variable gain amplifier (202) is adjusted by the analog calibration value to a point such that the input to the transmitter linearizing table (204) follows a predetermined straight line with respect to transmitted RF output power. This linearization removes the undesired linear and non-linear errors along with variations versus frequency in the transmitter. This, combined with the previously mentioned receive linearization, greatly reduces the

open and closed loop power control errors due to RF performance imperfections.

The power amplifier (PA) bias control section (218) controls the bias point of the transmit PA (201) based on the transmit gain setting such that the
5 transmit sidebands for the given gain setting are optimized versus PA (201) current consumption. This allows a battery powered telephone to maximize talk time by reducing PA (201) current consumption at lower output powers while still maintaining acceptable sideband levels at higher output power levels.

The power control limiting section (205) is illustrated in FIG. 3. The
10 power control limiting section (205) controls the closed loop power control and transmit gain settings when the output of the transmit gain summer (210) corresponds to a transmit output power level which is equal to or greater than the intended maximum output power. The maximum gain setting is determined by the PA limit threshold control section (209).

15 The threshold control section (209) determines the maximum gain setting based on a nominal value that is modified by a real-time measurement of the transmitted output power. The measurement is accomplished by an analog power detector (207) whose output is transformed into a digital signal by an analog to digital converter (208). The digitized power value is then input to the
20 threshold control section (209).

The threshold control section, detailed in FIG. 5, operates by the high power detector (HDET) linearizer (501) scaling the input digitized power value in order to match the numerology of the digital transmit gain control section. The scaled output from the linearizer (501) is subtracted (502) from the nominal
25 maximum gain setting. This maximum gain setting can be hard coded into the radio during assembly or input during manufacturing and testing of the radio.

The difference of the maximum gain setting and the scaled output power is then added, by the adder (503), to the maximum gain setting. The sum of these signals is then used as the corrected maximum gain setting. This
30 real-time modification of the detected power helps mitigate the errors introduced by temperature variations and aging of the transmitter PAs. In other words, if the difference between the maximum gain setting and the real-time measured power value is 0, then no correction is necessary. If there is a difference between the two, the difference is used to correct the maximum gain setting.
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Referring to FIG. 3, a digital comparator (301) detects when the output of the transmit gain summer (210) equals or exceeds the maximum gain setting. The comparator (301) controls a 2:1 multiplexer (302) that outputs the maximum allowable setting when the output of the summer (210) exceeds the

maximum allowable setting. When the output of the summer (210) is less than the maximum allowable setting, the multiplexer (302) outputs the direct output of the summer (210). This prohibits the transmitter from exceeding its maximum operating point.

5 The closed loop power control section (206), illustrated in FIG. 4, accumulates the power control commands sent on the forward link by the controlling radio cell site and outputs a gain adjust signal. The power control commands are collected in an accumulator (401). The operation of the accumulator (401) is controlled by the power control limiting section (205) when the transmit PA (201) is outputting the maximum allowable power.

10 When the output of the summer (210) changes from being less than to equal or greater than the maximum allowable setting, the output of the closed loop power control accumulator (401) is latched into a flip-flop (402). While the output of the summer (210) is equal to or greater than the maximum allowable setting, as determined by the comparator (403) and NAND gate (404) circuit, an AND gate (405) masks off any closed loop power control up commands that would force the accumulator (401) above the flip-flop's (402) latched value. This prevents the accumulator from saturating during power limiting yet allows the closed loop power control setting to change anywhere below the latched value.

20 An alternate embodiment of the process of the present invention is illustrated in FIG. 6. In this embodiment, a power limiting control system is employed based on accumulator feedback control. The system operates by first measuring the output power of the PA (609) using a power detector (610). The detected power is then digitized by an ADC (611) and compared to a maximum allowable setting by the comparator (601). If the output power is greater than the maximum setting, the power limiting accumulator (602) begins turning power down by reducing the gain of the variable gain amplifier (608). If the output power is less than the maximum setting the power limiting accumulator (602) returns to a 0 dB correction value.

30 In this embodiment, a closed loop power control limiting function (604 and 605), similar to the preferred embodiment, is employed. However, the trigger for the closed loop power control limiting function is a comparator (603) that detects when the power limiting accumulator (602) is limiting the output power by comparing the accumulator (602) output to 0 dB with the comparator (603). The linearizing compensation tables, similar to the tables in the preferred embodiment, are added into the transmit gain control using a summer (606).

35 In another alternate embodiment, illustrated in FIG. 7, a power limiting control system is employed that is based on the closed loop power control ac-

cumulator (702). The system operates by first measuring the output power of the PA (705) using a power detector (706). The detected power is digitized (707) and compared to a maximum allowable setting by the comparator (701). If the output power is greater than the maximum setting, the closed loop power control accumulator (702) is modified to turn the amplifier (704) power down by one step each 1.25 ms until the output power is less than the maximum setting. If the output power is less than the maximum setting, the closed loop power control accumulator is not modified. The linearizing compensation tables, similar to the preferred embodiment, are added into the transmit gain control using a summer (703).

In yet another embodiment, illustrated in FIG. 8, a power limiting control system is employed that is based on integral feedback control. The system operates by first measuring the output power of the PA (808) using a power detector (809). The detected power is digitized (810) and input to an integrator (801) that follows the equation:

$$\frac{1}{K} \cdot \int (\text{Setpoint} - \text{Detected}) dt.$$

The integrator (801), generating a gain control signal, saturates at 0 dB and -63 dB of correction. The gain control signal is thus limited within a range. If the output power is greater than the setpoint, the integrator turns down the output power of the amplifier (807) at a rate based on the integration constant K until the setpoint is reached. The integrator is allowed to turn power down by as much as 63 dB. If the output power is less than the setpoint, the output of the integrator (801) will be forced to zero, thus not adjusting output power.

In this embodiment, a closed loop power control limiting function (803 and 804), similar to the preferred embodiment, is employed. The trigger for the closed loop power control limiting function, however, is a comparator (802) that detects when the power limiting integrator (801) is limiting the output power. The linearizing compensation tables, similar to the preferred embodiment, are added into the transmit gain control using a summer (805).

In still another embodiment, illustrated in FIG. 9, a power limiting control system is employed that is based only on a measure of receive power, as determined by the R_x power lookup table (902), and the closed loop power control setting as opposed to actual output power. The transmit power limiting and closed loop power control limiting function (901) can be implemented with either the preferred embodiment using the saturating accumulator (903) or one

of the alternate embodiments. However, only the receive power and closed loop power control setting are used to estimate transmit output power.

Most of the heat generated by a radio is from the PA and the DC regulator that supports the PA. This generated heat, plus the ambient
5 temperature, may exceed the temperature capability of many components in the radio. The preferred embodiment of the present invention, illustrated in FIG. 10, controls the transmit power based on temperature.

This embodiment uses temperature sensors, such as thermistors, placed near heat sensitive components or near the components that generate the
10 majority of the radio's heat, the PA and the DC regulator. The PA output power is then adjusted based on the temperature of these components. This can be accomplished by adjusting the maximum gain setting signal created by the PA limit threshold control (209) in FIG. 2, included in the power detector block (1020) of FIG. 10. This allows the radio's maximum transmit output
15 power to be adjusted either up or down based on the measured temperature. The transmit power level is monitored so that it is not reduced below those levels required by the IS-95 or IS-54 standards.

Referring to FIG. 10, the transmit AGC (1035) is coupled to the transmit PA (1015). The DC regulator (1010) regulates the DC power to the PA (1015). A
20 power detector (1020) determines the power of the signal transmitted by the PA (1015) and feeds that information to the power control circuit (1030). The power detection can be performed as described in the embodiment of FIG. 2.

The power control circuit (1030) uses the temperature detected by the temperature sensors (1025) along with the detected transmit power to adjust
25 the transmit AGC gain through a control input. The power control circuitry (1030) can be implemented in several ways.

One method generates a control signal that is proportional to the amount of required transmit power adjustment for a measured temperature. The control signal is summed into the transmit gain control section of the radio
30 detailed in FIG. 2 to reduce the transmit output power, thus lowering the temperature. This signal generation and summation could be performed by either or both digital and analog circuitry using sampled or continuous versions of the required signals.

Other embodiments adjust output power based on measured tempera-
35 ture and transmit output power by adjusting a stepped gain block such as a switchable attenuator in the transmit chain. This gain block can be placed at several different locations in the chain. Additionally, the output power could be adjusted by varying the DC bias point or main DC supply voltage of the PA.

While FIG. 10 shows the AGC (1035) and PA (1015) as being separate, other embodiments use a variable gain PA. The variable gain PA has a gain control input coupled to the power control circuitry (1030) and is control in the same manner as the above embodiment.

- 5 The power adjustment performed by the embodiment of FIG. 10 does not cause a problem with either the CDMA specification, IS-95, or the AMPS specification, IS-54. IS-95 relaxes the transmit power output requirements at high ambient temperatures. IS-54, while not specifically relaxing the power output requirements, allows a +2 dB and -4 dB variation in transmit power at
10 any given power level. Part of this range can be used to reduce the transmit power level at high ambient temperatures.

- The benefits of the embodiment of FIG. 10 are illustrated in FIG. 11. This graph shows that without the temperature adjustment, the internal temperature of the radio continues to rise as the ambient temperature rises. With the
15 temperature adjustment of the present invention, the radio's internal temperature begins to level off after reaching a predetermined ambient temperature.

- In summary, the process of the present invention ensures that the transmitted sidebands and synthesizer phase noise of a radio transmitter remains within a predetermined specification by limiting the maximum output
20 power. This power limitation is accomplished by a control loop including a calibration look-up table. Therefore, a radio using the process of the present invention would not exceed it's nominal maximum power level due to the cell issuing too many power turn-up commands. The radio limits the power output even when the cell erroneously decides the radio power should be increased.



CLAIMS

1. A temperature compensated power amplifier apparatus
2 comprising:
a variable gain amplifier having a control input, the variable gain
4 amplifier transmitting a signal;
a power detector, coupled to the variable gain amplifier, for generating
6 a power value of the signal;
a temperature sensor for generating a temperature signal; and
8 a power control circuit, having a first input coupled to the power
detector, a second input coupled to the temperature sensor, and an output
10 coupled to the control input of the variable gain amplifier, the power control
circuitry adjusting the variable gain amplifier in response to the power value
12 and the temperature signal.
2. The apparatus of claim 1 and further including a direct current
2 regulator coupled to the variable gain power amplifier for providing power to
the amplifier.
3. The apparatus of claim 1 wherein the temperature signal is
2 indicative of a temperature of the variable gain power amplifier.
4. A temperature compensated power amplifier circuit comprising:
2 an automatic gain control amplifier having a control input;
a power amplifier coupled to an output of the automatic gain control
4 amplifier, the power amplifier transmitting a power amplified signal;
a power detector, coupled to an output of the power amplifier, for
6 generating a power value of the power amplified signal;
a temperature sensor for generating a temperature signal; and
8 a power control circuit, having a first input coupled to the power
detector, a second input coupled to the temperature sensor, and an output
10 coupled to the control input of the automatic gain control amplifier, the power
control circuitry adjusting the automatic gain control amplifier in response to
12 the power value and the temperature signal.
5. A temperature compensated power amplifier apparatus
2 comprising:
an automatic gain control amplifier having a control input;



4 a power amplifier coupled to an output of the automatic gain control
amplifier, the power amplifier transmitting a power amplified signal;
6 a power detector, coupled to an output of the power amplifier, for
generating a power value of the power amplified signal;
8 a plurality of temperature sensors, each temperature sensor generating
a temperature signal; and
10 a power control circuit having inputs coupled to the power detector and
the plurality of temperature sensors, the power control circuit having an
12 output coupled to the control input of the automatic gain control amplifier, the
power control circuit adjusting the automatic gain control amplifier in response
14 to the power value and the plurality of temperature signals.

6. The apparatus of claim 5 and further including a direct current
2 regulator coupled to the power amplifier.

7. The apparatus of claim 6 wherein the plurality of temperature
2 signals each indicate a temperature of a component of the apparatus.

8. A radio having the capability of transmitting a signal in a wireless
2 environment, the radio comprising:

a modulator for generating the signal to be transmitted;

4 an automatic gain control amplifier having a control input, the automatic
gain control amplifier being coupled to the modulator for providing gain to the
6 signal to be transmitted;

a power amplifier coupled to an output of the automatic gain control
8 amplifier, the power amplifier transmitting a power amplified signal;

a power detector, coupled to an output of the power amplifier, for
10 generating a power value of the power amplified signal;

a plurality of temperature sensors, each temperature sensor generating
12 a temperature signal indicative of a temperature of a predetermined
component in the radio; and

14 a power control circuit having inputs coupled to the power detector and
the plurality of temperature sensors, the power control circuit having an
16 output coupled to the control input of the automatic gain control amplifier, the
power control circuit adjusting the gain of the signal to be transmitted in
18 response to the power value and the plurality of temperature signals.

9. A temperature compensated power amplifier apparatus, the
2 power amplifier having a maximum gain setting, the apparatus comprising:



- a variable gain amplifier having a control input, the variable gain
- 4 amplifier transmitting a signal;
- a power detector, coupled to the variable gain amplifier, for generating
- 6 a power value of the signal;
- a temperature sensor for generating a temperature signal;
- 8 a gain threshold controller, coupled to the power detector and the
- temperature sensor, for generating an adjusted maximum gain setting from
- 10 the maximum gain setting in response to the temperature signal; and
- a power control circuit, having a first input coupled to the power
- 12 detector, a second input coupled to the temperature sensor, and an output
- coupled to the control input of the variable gain amplifier, the power control
- 14 circuitry adjusting the variable gain amplifier in response to the power value,
- the adjusted maximum gain setting, and the temperature signal.