An Accurate Transmitting Power Control Method in Wireless Communication Transceivers

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Abstract. Power control circuits are widely used in transceivers aiming at stabilizing the transmitted signal power to a specified value, thereby reducing power consumption and interference to other frequency bands. In order to overcome the shortcomings of traditional modes of power control, this paper proposes an accurate signal power detection method by multiplexing the receiver and realizes transmitting power control in the digital domain. The simulation results show that this novel digital power control approach has advantages of small delay, high precision and simplified design procedure. The proposed method is applicable to transceivers working at large frequency dynamic range, and has good engineering practicability.

1. Introduction

Wireless communication systems such as radar, mobile phones, base stations, walkie-talkies, bluetooth devices, etc., consist of both receiver and transmitter to interact with outside world. For a wireless communication transceiver, it is necessary to control the transmit signal power for the following reasons: the instability of transmission circuit and environmental effects give rise to unstable transmitted signals without power control; wireless cellular network is able to achieve precise set of cell size and better convergence performance with power control; power dissipation can be reduced and interference to other frequency bands can be minimized with appropriate power control [1], etcetera.

In order to realize transmission power control, we need to detect the power size of transmitted signal for the first step. [2] employs a logarithmic amplifier to detect the signal from the power amplifier (PA) output terminal and convert the power into voltage that contains voltage ripple due to the non-constant amplitude envelope of input signal, and compares that voltage with ramp control signal. The comparison result is transferred as PA's control voltage. However, the logarithmic amplifier is only suitable for signal with small variation in peak-to-average ratio (PAR), and the operation frequency range is relatively narrow. This method is more applicable to dedicated power measurement integrated circuits.

Analog Devices has developed the True Power Detection series of RMS-OC integrated circuits [3] in 2001. Its performance is hardly susceptible to environmental temperature, and has a high linearity characteristic. The shortcoming of the device is large power consumption as the supply voltage is 2.7 to 5.5V, and the working current reaches as large as 2mA.

Some researchers propose to reuse the receiver in the transceiver while transmitting so as to achieve power control. To address the influence lead by gain variation on the receiver path, the signal strength detection circuit is placed close to the antenna. However, if the received signal is relatively...
small compared to the receive path noise, the circuit will be difficult to achieve accurate detection and be susceptible to interference from nearby channels [4].

Most of the existing researches are based on analog measurement, although analog methods can achieve continuous measurement, their operation bandwidth is substantially low, and the analog circuits are generally tricky to design. Furthermore, the use of low-pass filter for average operation calls for very low cut-off frequency to ensure the stability of the result, meaning that the measurement speed is much slow. In view of this fact, this paper proposes a digital method to detect and control transmit signal power by multiplexing the receiver while it is idle. Operationally, the output signal of transmitter is coupled to the receiver input, and after a series of processing, it can be transformed into digital value representative of present attenuation. The power control word deduced by the attenuation value will be sent back to the attenuator on transmit path. Through this method, we can realize power control to transmitted signals with less extra circuit in a transceiver while ensuring performance.

2. System structure of power control

The power control system structure in a transceiver proposed in this paper is shown with reference to figure 1. Data to be transmitted is firstly provided to a digital-to-analog converter (DAC), the output of which is fed into a modulator. The modulated radio frequency signal is attenuated by an attenuator, and the output of the attenuator is provided to a power amplifier (PA) via a balun. Then the signal is amplified and transferred into an output filter. After filtered, the signal is passed to duplexer and isolator unit, which can alternatively allow an external signal at the antenna to be fed into a receiver circuit.

![Figure 1. System Structure of Transmit Power Control.](image)

The method offered in this paper is available in TDD mode only because it reuses the inactive receiver to perform power detection during transmitting. Since the transmitted signal is at high level with respect to received signal from outside, it is multiplexed into the receiver chain after the LNA. In other words, the signal coupled at the output port is applied via a downconverter input driver to the downconverter of receiving path. The output of the downconverter is amplified by a trans-impedance amplifier (TIA), the output of which is received by a low-pass filter, which attenuates blocking signals outside the channel. And the filter feeds an output to analog-to-digital converter (ADC). The digital output of ADC is fed into RMS module which develops a value indicative of received signal strength. The value is utilized to infer present attenuation value. And the attenuation value is passed to the control unit, which compares it with desired attenuation word from software and produces power control command to modules both at transmitting path and receiving path.

3. Theoretical design of power control system

3.1. Operating principle of signal strength detector

Power measurement of ac signals can be converted to measurement of true effective value of the signal voltage, which is generally defined as RMS. And the true RMS value of a signal is equal to the amount of direct current required to produce the same heat on the same resistive load.

Traditional method of detecting the effective value of voltage is achieved by the diode square law detection circuit or thermoelectric couple heating device. Both methods have many disadvantages, bringing about inaccurate measurement, poor linearity and thermal sensitivity, especially when
detecting small radio frequency signals. The characteristic range of the diode square law is very narrow, and the detection performance becomes poor when the signal is too small or too large, resulting in large measurement error. Thermoelectric couple heating device is complicated, fragile and easy to be damaged at oversized signal. With the development of analog integrated circuits, people have found new way to detect signal voltage [5]. The valid values are defined by the following formula

\[ V_{RMS} = \sqrt{\frac{1}{T} \int_0^T V^2 dt} \]  

(1)

Nonetheless, there still exists some drawbacks of the analog method. Analog circuits are usually tricky to design and has poor flexibility, and their operation bandwidth are relatively narrow, and the filters used to perform averaging operation tend to bring about large time delay. Due to the drawbacks of analog measurement mentioned above, we measure the RMS value with a digital method.

The amplitude of AC signal is always changing, but when we subdivide the time into infinite amount of extremely tiny time \( \Delta t \), the amplitude can be considered unchanged during that small time, we define that value as \( e(i) \). Hence, we can get

\[ \sum_{i=1}^{n} [e(i)]^2 \Delta t = E_{rms}^2 \]  

(2)

where \( n \) follows the formula below

\[ n = \frac{t}{\Delta t} \]  

(3)

Therefore, the power of a signal can be written as

\[ E_{rms}^2 = \frac{1}{n} \sum_{i=1}^{n} [e(i)]^2 \]  

(4)

That is,

\[ E_{rms} = \left[ \frac{1}{n} \sum_{i=1}^{n} [e(i)]^2 \right]^{1/2} \]  

(5)

According to above formula, firstly we need to discretize the analog signal. That operation can be realized through ADC sampling. When the sampling rate is much higher than the frequency of the measured signal, in other words, the time interval between the two sampling results of the ADC is very short, we can approximate that the amplitude of the measured signal does not change during \( \Delta t \). Then we take advantage of (5) to calculate the RMS. For periodic signals, we can use one or more cycles to calculate, whilst for signals with no significant period, we can specify some time to perform the sampling and calculation.

For the purpose of realizing linear relationship between signal power and attenuation control word, we need to convert the detected power value to a logarithm scale, so the output of RMS module is coupled to a LOG circuit. We define the output of the LOG circuit as “rssi” (abbreviation of “received signal strength indicator”).

3.2. Transmit power control method

3.2.1. Calibration work before power control. It is necessary to calibrate the circuits before performing regular power control. There are two purposes for calibration, one of which is to calculate the error between actual transmit power and ideal power, denoted by Trans_cal, and the other aim is to obtain the rssi value when the transmit signal power is maximum, defined as rssi_max_cal.

Resultant from channel delays, imbalances, and other signal impairments occurring within the transmitter chain, signals are often impaired while propagated. In other word, when the attenuator in front of the power amplifier receives a certain attenuation command, it is likely that the signal is not
transmitted at expected power. We need to figure out the error between the transmitted signal and the ideal signal before nominal power control. The calibration can be performed by transmitting a single tone signal with known power and gain, and measuring the output signal before antenna, and we can acquire the error as with the formula shows below,

\[
\text{trans\_cal} = \text{P\_meas} - \text{P\_des}
\]

(6)

where \(P\_\text{des}\) is the desired power and \(P\_\text{meas}\) is the measured power. For the purpose of facilitating subsequent operations, the power value used thereof is converted to logarithm scale, meaning its unit is dBm, and \(\text{trans\_cal}\) is expressed in dB.

It should be noted that besides the non-ideal factors existing in transmitting path, there are also some unpredictable deviations in detection path resulting in inaccuracy of the rssi value we conclude finally, like gain error, phase mismatch, temperature effect and interference from other frequency band, et cetera. To address the effects mentioned before, it may be desirable to perform another calibration.

In order to prevent the ADC in power control loop from clipping and raise the SNR of the detector path, we need to make convenient changes of amplifier gain on the detector path. Accordingly, we have to subtract the gain along the path from the estimated power value so as to obtain real signal power at the antenna. The gain error between theoretical value and the actual one, together with other non-ideal factors on detector path described hereinbefore will give rise to inaccuracy of the final rssi value, so we can develop a calibration test to store the all of the errors. In light of the power control method which will be covered in detail later, we take present power value minus maximum power to get present attenuation value, followed by comparing present attenuation value with desired attenuation value requested, the result of which can be utilized to deduce a new attenuation control word. Since we need maximum power value to be subtracted, we can store it as well as non-ideal factors of detector path in a register during calibration. Operationally, we transmit a signal with maximum power by set attenuation word to 0, and obtain a rssi value representative of the transmitted signal power plus amplifier gain of detector path at the output of the log circuit, we subtract the \(\text{trans\_cal}\) calculated above from that rssi value to eliminate the impact of the transmit path. The calculation is performed as shown in (7),

\[
\text{rssi\_max\_cal} = \text{rssi\_cal} - \text{trans\_cal}
\]

(7)

where \(\text{rssi\_cal}\) is the rssi value read during calibration, and the calculation result \(\text{rssi\_max\_cal}\) will be stored in a register. As long as a new rssi is deduced in the power control loop during transmitting, the attenuation at that time can be simply obtained in accordance with the following formula,

\[
\text{pre\_atten} = \text{rssi} - \text{rssi\_max\_cal} - \Delta g
\]

(8)

where \(\text{pre\_atten}\) stands for present attenuation, \(\text{rssi}\) indicates the measured signal power, and \(\Delta g\) represents the change of gain on detector path. It can be observed that the effects of non-ideal factors through detector path are removed by subtract operation, and the gain error is significantly shrunk.

3.2.2. **Iterative algorithm of power control.** The iterative method of generating attenuation control word can be expressed by (9),

\[
\text{atten}(n) = \text{atten}(n-1) + \text{err\_atten}
\]

(9)

where \(\text{atten}(n)\) stands for the attenuation control word for transmit burst number n, \(\text{atten}(n-1)\) represents the previous control word, and \(\text{des\_atten}\) is the desired amount of attenuation requested. It should be noted that \(\text{des\_atten}\) is a positive value, while \(\text{pre\_atten}\) deduced in accordance with (8) is negative, though both of the two indicate the degree of attenuation. In view of this fact, we add up the two together to acquire the error between their absolute value, and the error is added to current attenuation control word so as to get a new one. For example, if the attenuation detected is -10dB,
whereas the attenuation requested is -20dB, i.e., that the des_atten received by the system is 20dB, which means the sum is 10dB, therefore, the current attenuation word is added to 10dB to acquire new attenuation word. The advantage of this method is the capacity to track the amount of attenuation requested. Whenever a new des_atten appears, the error changes accordingly, and atten(n) will be updated in time. Therefore, once the power control loop settles down, subsequent signals will be transmitted with correct power regardless of how much attenuation command changes.

For a further description, since there is no previous rssi calculated for the first burst of transmission, the control word atten_1 should be set specially. We determine herein atten_1 as des_atten minus trans_cal, and utilize a mux module to select between the preset control word and the iterative one according to transmit clock.

Figure 2 gives a more detailed illustration of the control module in figure 1, and illustrates the operation process of power control as stated hereinbefore.

Therein Tx_clk enables the transmitter at each burst, so atten output from the control module is latched on the rising edge of Tx_clk. Det is an internal signal which goes high on the rising edge of Tx_clk and enables the power control circuit, and falls down to latch the pre_atten, so its high level should be maintained long enough to ensure an accurate and stable power detection. The mux module selects atten_1 to be the control word after the reset signal is pulled high, and selects closed control loop result on the falling edge of the first Tx_clk burst after reset.

3.2.3. Gain adjustment of the power detection path. As noted above, signals output from transmitter may have fluctuation in their power caused by attenuation changes, strength differences caused by different modulation ways, and offset through the transmit path, et cetera. If we detect the power with receive path without consideration of gain compensation, the SNR of detected signals may float and there may be peak clipping during ADC works. To ensure the accuracy of detected signal power, we add 10dB to the gain of TIA in receive path at every 10dB increment of desired attenuation. The initial gain is set and stored in a circuit register upon power up [1]. Through this method, the ADC can work normally and the SNR can be maintained over 20dB.

4. Simulation result of the proposed power control method
The method put forward in this paper can be verified simply through building a transceiver module with MATLAB/Simulink tool kits. During simulation, the modulated signal ready to be transmitted is a single tone constant waveform at a frequency of 0.8GHz, and the attenuation requested is set to 0dB, 30dB, 20dB and 10dB successively, the output signal waveform in time domain is illustrated by figure 3 and figure 4 shows the transition of signal amplitude during the first burst, we can see that it takes some time on the order of 6.6 usec for the transmitter to settle down. Figure 5 and figure 6 describe subsequent signal waveform transitions when attenuation control word increases and decreases respectively. It can be observed that transmitter can achieve flexible and accurate switching in power with little transition time after the first burst, which indicates the advantage of (9).
Figure 3. Transmitted Signal Waveform in Time Domain.

Figure 4. Transition of Signal Amplitude During the First Burst.
5. Conclusion

This paper points out the shortcomings of traditional power measurement methods, and puts forward power measurement method in the digital domain. It proposes to multiplex the receive path as signal detector in a transceiver while the receiver is idle. In addition, this paper uses subtraction and iteration to obtain the attenuation control word, which successfully eliminates the error through signal detection path, and keeps track of changes of attenuation command sent by the software. In summary, the proposed power control method introduces less additional circuit in a transceiver, and achieves power control to transmitted signals with the advantage of large frequency range, small delay and high precision. This new approach simplifies traditional circuit design and can be widely used in wireless communication transceivers.

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