Chapter 62
Demonstration and Realization of Operating in a Wide Temperature Range for Compass System RDSS Terminal

Bin Tang, Chong Zheng and Zhi Liang

Abstract The RDSS service of Compass system has been applied in many fields. The RDSS service of Compass system is applied in many fields. The old RDSS terminal can not be used for all system coverage area because of its narrow operating temperature range. Based on the RDSS application environment, the new operating temperature range of RDSS terminal is established and demonstrated. In order to meet the new wide temperature range, the new technology for large capacity and strong current discharging in low temperature, and the new method to make RDSS terminal operate in a wide temperature range are put forward. The tests show that the new realization can provide a reference to design a wide temperature RDSS terminal.

Keywords Compass · RDSS terminal · Wide operating temperature range · Discharging in low temperature

62.1 Introduction

Compass satellite navigation system is composed of different satellite constellations. The Compass system can provide the service of active/passive real-time three-dimensional positioning, velocity, high-precision timing and short message communication for China and its surrounding region. In the service area of Compass, there are different temperature region, which include equatorial area, tropical area, subtropical area, warm area and cold area. In the north of 40 degrees north latitude, the temperature of many region is below −20 °C in winter. And the lowest temperature in the some areas of northeast China, Xinjiang, northern

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Tibetan Plateau can reach −40 °C in January. In the phase of the Compass test system, the Compass RDSS terminal mainly broke through the key technologies. Because of the key module and chip of the terminal were developed slowly, and the comprehensive study of environment adaptability for the terminal was lacked, the operating temperature range was only from −20 to 55 °C, especially the performance of low temperature was poor. In the course of operating, the receiving sensitivity, transmitting EIRP and the accuracy of transmitting frequency were influenced obviously in large temperature range, which made the RDSS terminal can not use for the full service area of Compass.

With the official opening of the Compass system, the application will be wide. In order to improve the reliability and stability of the terminal in application, it is necessary to consider the design of environment adaptability for the terminal. The high-performance GPS terminal, such as Defense Advanced GPS Receiver (DAGR) [1], Airborne SAASM Receiver [2], TruTrak GPS Receiver [3], which can operate in a wide temperature range from about −40 to 60 °C. The RNSS terminal of Compass can basically operate in this range after the key module chip are used. However, the Compass system RDSS terminal was still unreliable when operating in a wide temperature range. For example, the large capacity and strong current discharging for transmitting signal in low temperature is not realized. The gain will change when receiving and transmitting signal, the frequency of reference crystal will shift because of the change of temperature.

The operating temperature range of RDSS terminal is established and demonstrated in this paper based on the requirements of application environment. Then the performance of RDSS terminal is analyzed because of temperature changing in a wide temperature range. The new technology for large capacity and strong current discharging in low temperature, and the new method to make RDSS terminal operate in a wide temperature range are put forward. At last, the tests for these new technology are done.

62.2 Establishing the Operating Temperature Range

The application area for RDSS terminal is very wide, and mostly these terminal are used in outdoor. It is very important for RDSS terminal to have a wide operating temperature range.

62.2.1 Establishing the Lowest Temperature in China

According to GJB 1172.2-1991, the lowest temperature in China region is shown in Table 62.1 [4].

From Table 62.1, the total probability of less than −41.3 °C is lower than 36 %, so it can be deduced that the lowest temperature will not fall below −40 °C

Table 62.1 The probability of lowest temperature in China region cold

Temperature (°C)	Probability (%)
−41.3	20
−44.1	10
−46.1	5
−48.8	1

in the China region for most of the time. Therefore, the low-temperature operating range for terminal is changed from original −20 to −40 °C.

Similarly, the highest temperature in the China region is also given in the GJB 1172.2-1991, which changes between 30 to 43 °C. Because the terminal may be exposed to the sun in use, and the air temperature condition will be exasperate, the temperature will change from 30 to 63 °C. While the probability of higher than 60 °C is very low. Therefore, the high-temperature operating range for terminal is changed from original 55 to 60 °C.

62.2.2 Demonstrating the Operating Temperature Range

In the phase of Compass test system, the operating temperature range for RDSS terminal is only from −20 to 55 °C. The main limiting factors include: LCD display, low temperature performance of battery, and the stability in wide temperature range are not enough.

For display in low temperature, there is organic light-emitting diode display (OLED) screen in the market, which can operate from −40 to 70 °C [5]. By using of OLED, the problem of display in low temperature can be solved. For discharging in low temperature, there are some factory who can produce Li-ion battery working on −40 °C [6]. But the transmitting signal for RDSS terminal is burst spread spectrum signal, very strong current is need in transmitting. In order to improve standby time for the terminal, discharge capacity is need in low temperature. For the stability in wide temperature range, the pre-terminal has been showing instability when the temperature changes from −20 to 55 °C. The gain will change when receiving and transmitting signal, the frequency of reference crystal will shift because of the change of temperature. So the stability design for the new RDSS terminal operating in a wide temperature range is need.

62.3 Realizing Large Capacity and Strong Current Discharging in Low Temperature

RDSS terminal is needed to work in the condition of −40 °C for a long time, so its battery is needed to work with large discharge capacity in low temperature. The power of the terminal will be up to 30 W when transmitting signal, so its battery is needed to work with strong current. The low temperature of −40 °C is the biggest obstacle to achieving these power indicators. Therefore, it is necessary to solve the problems of large capacity and strong current discharging in low temperature.

62.3.1 Operating in Low Temperature

The research and development of low-temperature Li-ion battery is a hot topic. U.S. Army Research Laboratory has done a lot of research about low temperature performance of Li-ion battery. Their study show that the low temperature performance of Li-ion battery is mainly dependent on the electrolyte batteries [7, 8]. The electrolyte in the battery is used to convey ion and conduct current between the positive and negative role, it plays a vital role in increasing the capacity of the battery, enlarging temperature range, improving cycle efficiency and safety performance. The electrolyte is mainly composed of Li-ion salt, organic solvent and other additive. Currently, some domestic companies has developed the low-temperature electrolyte by using novel Li-ion salt, confecting multiple organic solvents, and adding functional additives. The key technology for the Li-ion battery operating in −40 °C has been broken through [6].

62.3.2 Discharging with Large Capacity and Strong Current

The core of Li-ion battery is composed of the electrolyte and the electrode. Realizing operating in low temperature mainly depends on the electrolyte, while realizing discharging with large capacity and strong current in low temperature mainly depends on the electrode. It is necessary to design new electrode for low temperature Li-ion battery.

1. The design of large capacity

   The carbon material of negative electrode is an important factor to increase the battery capacity. By trying on a lot of carbon material, a new artificial graphite is selected as the material of negative electrode. The experiments show that the discharge capacity reaches 330 mAh/g or more, the efficiency of first discharge reaches more than 93 %. And the workability of this artificial graphite is good, and it is easy to produce in batch production.

2. The design of strong current

   The material of anode determines the discharging performance of the battery. The important nature of the battery about voltage, working hours and stability is decided by anode material. The anode material of Li-ion battery includes lithium cobalt oxide ($LiCoO_2$), lithium manganese oxide ($LiMnO_2$), lithium iron phosphate ($LiFePO_4$), etc. Many studies and experiments showed that the capacity of

$LiMnO_2$ is unstable in high temperature, and it is easy transition to the spinel structure ($LiMn_2O_4$) in the process of discharging. If $LiFePO_4$ is used as anode material, the resistivity of the battery core will be large, the utilization of the electrode material is low, and strong current discharge is difficult.

$LiCoO_2$ is a good anode material in low temperature. In order to further improve the electrochemical properties of the electrode, increase its stability and reduce cost, some electropositive ions are put into the electrode, such as Ca^{2+}, Mg^{2+}, etc. to improve the conductivity of electrode, and strong current discharging is ensured [9].

62.4 Realizing the Stability in Wide Temperature Range

The new RDSS terminal is needed to work stably in wide temperature range from −40 to 60 °C. Through the components of the terminal can meet the wide temperature range by selecting or developing some individual components. But when these components are made into a whole terminal, the performance of receiving and transmitting will be affected, due to the large temperature range. It is necessary to study some stability technology to make the whole terminal work stably in a wide temperature range.

62.4.1 Gain Control

There are the same character for all amplifiers in the link of receiving and transmitting, their gain and power will increase in low temperature. It is opposite in high temperatures, and their gain power will reduce. In order to ensure that the whole receiving sensitivity and transmitter EIRP are not much affected, it is necessary to make the transceiver link total gain change little in the entire temperature range, and do some gain control in the transceiver link.

The gain in the receiving link of the terminal is about 90 dB, which will change largely between the high and the low temperature. The receiving gain will increase 4–6 dB in the conditions of −40 °C, and will reduce 4–6 dB in the conditions of 60 °C. The changes of the receiving gain are shown in Fig. 62.1. In the receiving link, the quantify amplitude of AD will change corresponding to the receiving gain. In the room temperature, the quantify amplitude of intermediate frequency signal is about 1 V, while it will become about 1.3 V in low temperature, becomes about 0.7 V in high temperature. So the key indicators of the terminal, such as receiving sensitivity will be affected.

In order to control the gain in the receiving link, a new automatic gain control (AGC) is added into the receiving link, which lies near the last amplifier as shown in Fig. 62.2.

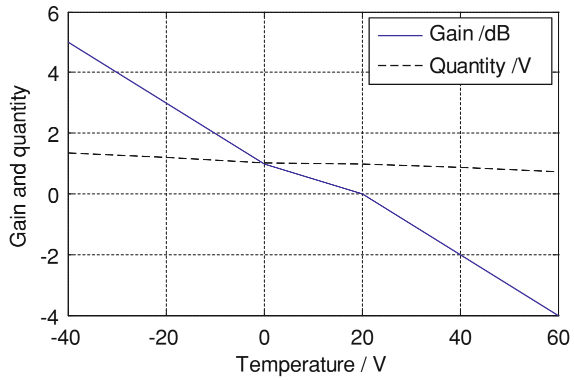

Fig. 62.1 The changing curve of receiving gain and quantity

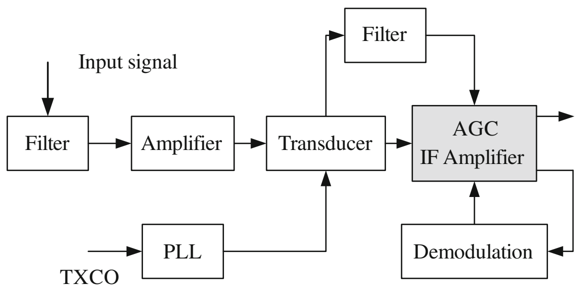

Fig. 62.2 Automatic gain control (AGC) in the receiving link

In low temperature, the gain of preamp will increase. When the final-stage amplifier detects the increase of the previous stage gain, the AGC will be automatically started, and the gain will be reduced. In high temperature, the gain of preamp will decrease, and AGC can automatically increase the gain. Therefore, the up-and-down of the receiving is overcoming, and the power of output noise will be steady. After AGC is put into the receiving link, the change of receiving gain is very small, so as to reduce the impact of A/D sampling in the back end.

There is also the same change in the transmitting link. Temperature compensation can be taken into the transmitting link to compensate the change of amplifier gain reversely. The principle of compensation is shown in Fig. 62.3.

After temperature compensation is taken into the amplifier of the transmitting link, the reverse compensation through the thermostat will make the gain of transmitting link change little in the entire operating temperature range. So the

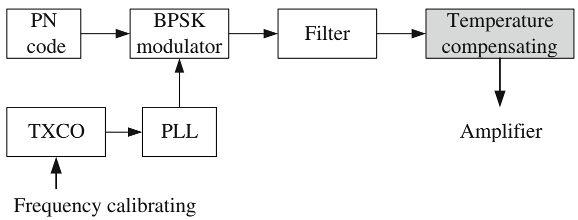

Fig. 62.3 The principle of temperature compensation

output of transmitting amplifier will be effected less, and the value of EIRP in the process of transmitting is insured to meet the requirement.

62.4.2 Frequency Accuracy Control

When working temperature changes, the reference oscillator in the terminal will drift with the change of temperature. The drift of reference oscillator will bring out two problems. First, the dynamic range of receiving frequency. Second, the transmitting frequency accuracy of the terminal will be out of the requirement of the Compass control system. Therefore, it is necessary to compensate the drift of the reference oscillator in the signal processing.

1. Frequency drift control for receiving signal

   When frequency drift of the reference oscillator is larger than 3 ppm, the difference of carrier frequency will be larger than 7.5 kHz, and the difference of code clock frequency will be larger than 12.3 Hz, which is out of DLL bandwidth of the terminal. At the same time, the difference of carrier frequency will bring a great loss of signal-to-noise ratio, and ultimately the satellite signal will lock difficult. The frequency drift control for the received signal is realized by controlling digital frequency synthesizer (DDS) to adjust code NCO and carrier NCO. So the center frequency of the code clock frequency and the carrier clock frequency will be changed to accommodate the frequency drift in a wide temperature range. After the frequency drift is calibrated, the receiving signal will be locked successfully.

2. Frequency accuracy control for transmitting signal

   When compass control system receives the signal from the terminal, the requirements for frequency accuracy is better than 5×10^{-7}. In order to get this accuracy, the signal processing to receive and transmit carrier is designed based on one VCO. So the code clock of the receiving signal can be used to calibrate the frequency error, and the transmitting clock will be controlled. After repeatedly corrected, until the transmitting frequency error reaches a specified range. Through the above process of closed-loop frequency correction, the transmitter frequency of the terminal will meet the requirement of compass control system. The control process of transmitting frequency is shown in Fig. 62.4.

62.5 Experiment and Verification

62.5.1 Discharging Test in Low Temperature

By stirring and wound, the new polymer core is composed of the low temperature electrolyte and the electrode above. Fully charge this polymer core (single-core),

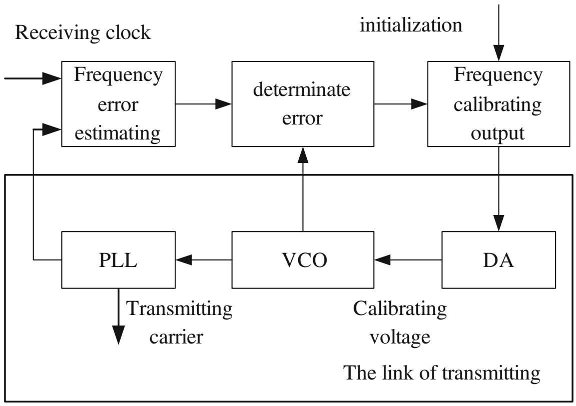

Fig. 62.4 The control process of transmitting frequency

and put in the condition of −40, −20 °C, and room temperature respectively for 4 h. Then discharge the core to 3.1 V as 0.5 °C. In different temperature, the discharge capacity of the core compare with room temperature. The discharge capacity is about 80 and 68 % respectively for −40 and −20 °C. The curve of discharging is shown in Fig. 62.5. The discharge performance of the new polymer core is well to meet the requirement of capacity in low temperature.

Fully charge this polymer core, and discharge it with 0.5, 1 and 2C respectively. The different ratios with 0.5C are calculated. The discharge curve of the core at different current is shown in Fig. 62.6. The discharge capacity of 1C and 2C current is about 94.2 % and 82.4 % compare with 0.5C respectively, which indicates that the new core have good discharge performance and can discharge with strong current. The maximum current is up to 4 A.

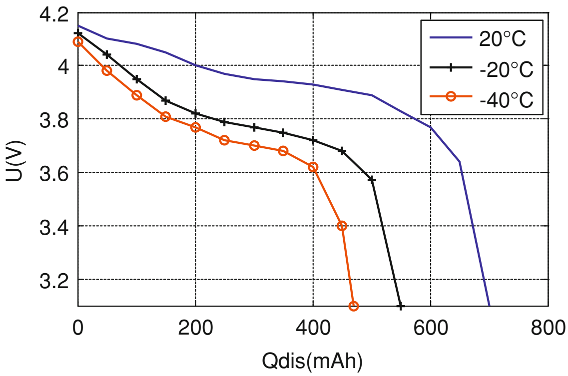

Fig. 62.5 The curve of discharging in different temperature

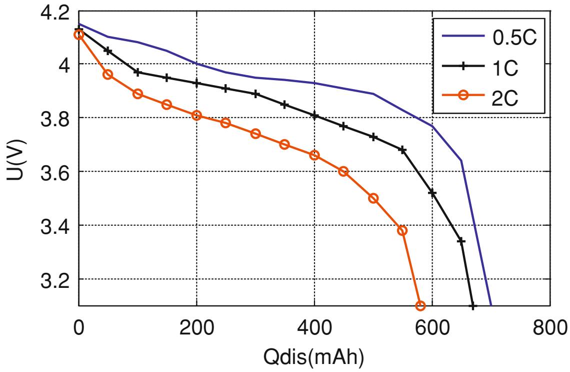

Fig. 62.6 The curve of discharging in different current

62.5.2 Stability Test in Wide Temperature Range

Add automatic gain control to the last amplifier in the receiving link, and adjust the gain reversely based on the temperature change. In the condition of −40, −20, 0, 20, 40 and 60 °C, the gain of receiving link and the quantify voltage are tested, as shown in Table 62.2.

The tests show that the quantify voltage for intermediate frequency signal can be controlled within 0.1 V or less in a wide temperature range. So it will be a very small influence on AD sampling, and the receiving sensitivity of terminal will be eligible.

Add temperature compensation to the link of transmitting, and compensate the gain change based on the temperature change. In the condition of −40, −20, 0, 20, 40 and 60 °C, the gain and output power of the transmitting link are tested, as shown in Table 62.3.

The tests show that the gain fluctuation of the transmitting link is small, and the change of 10 W amplifier output is also small. So the EIRP of the terminal will be eligible after adding temperature compensation.

Table 62.2 The gain and quantity after adding AGC

Temperature (°C)	−40	−20	0	20	40	60
Gain (dB)	90.6	90.3	90.1	90	89.7	89
Quantity (V)	1.07	1.04	1.01	1	0.97	0.95

Table 62.3 The gain and power after adding temperature compensation

Temperature (°C)	−40	−20	0	20	40	60
Gain (dB)	55.5	55.3	54.9	55	55.1	54.7
Power (dBm)	40.5	40.3	39.9	40	40.1	39.7

62.6 Conclusion

In this paper, the operating temperature range of RDSS terminal is established and demonstrated based on the requirements of the Compass system RDSS service. The analysis points out that the low temperature discharge performance of the battery, the gain change in wide temperature range, the reference crystal varies with temperature are main factors for the old RDSS terminals can not operate in a wide temperature range. The new technology for large capacity and strong current discharging in low temperature, and the new method to make RDSS terminal operate in a wide temperature range are put forward. These new design can provide a reference design for wide temperature RDSS terminal.

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