A Study on the TT&C Engineering Telemetry Test

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Abstract. This paper uses the theoretical analysis of communication and signal system to calculate the power spectrum of NRZ code and PSK signal, which reveals the bandwidth selection problem often used in equipment, and derives the most commonly used calculation conversion formula in calibration. Finally, the analysis and compared two calibration methods.

1. Introduction
For the S-band unified measurement and control system TT&C engineering telemetry, the statistical telemetry error rate Pe is used as a major pre-war test indicator under the normalized signal-to-noise ratio Eb/N0=12.8dB, which is important for testing the performance of the equipment itself. In the past, the test of this index largely followed the method of the device when it was tested: using the local noise source and the test filter, the root mean square value of the signal and noise was measured by the rms voltmeter. Eb/N0. The disadvantage of this method is that the noise is not the noise of the actual channel. In actual combat, the signal is also taken from the digital filter instead of the test filter, so the method can not truly reflect the performance of the system. In addition, the rms voltmeter is not a standing measuring instrument, so now basically do not use this method, but use the signal source to generate the analog PSK subcarrier through the joint test transponder and the downlink channel, and use the spectrum analyzer to measure the S/Φ method. Therefore, it is necessary to theoretically analyze and compare the two calibration methods.

2. Power spectrum of NRZ code
In actual combat, the pattern used in TT&C engineering telemetry is the bipolar non-return-to-zero code NRZ-M. In order to analyze the problem, we first analyze the spectrum of the NRZ code. The power spectral density of the NRZ code is:

\[ S(f) = T_b S_n^2 (\pi T_b f) \] (1)

From the power spectral density expression of the NRZ code, the main lobe width of the signal (the frequency bandwidth from zero frequency to the first zero crossing point) is 1/Tb=Rb, and the main lobe is generally taken as the bandwidth of the signal, which is numerically equal to the code rate Rb.

3. Binary phase shift keying PSK
The TT&C telemetry uses the NRZ code as the baseband signal, and the band modulation method uses the binary phase shift keying PSK: the binary digital signal is used to control the phase of the carrier, so that the carrier phase of the modulated equal amplitude and constant carrier frequency and the digital signal to be transmitted are modulated. Corresponding. Wherein the 0 phase represents the number 1, and the π phase represents the number 0. The PSK signal has been modulated into a constant amplitude (constant envelope) and phase discontinuous waveform sequence, which can be
regarded as the result of directly multiplying the NRZ code by the carrier. Therefore, the spectrum of the PSK signal should be the convolution of the NRZ code spectrum with the carrier spectrum, ie:

$$S_{PSK}(\omega) = \frac{1}{2\pi} T_b S_a^2 (\omega T_b / 2) \ast \pi A_b [\delta(\omega - \omega_0) + \delta(\omega - \omega_0)] = \frac{A_b^2 T_b}{4} \{ S_a^2 (\omega + \omega_0) \frac{T_b}{2} + S_a^2 (\omega - \omega_0) \frac{T_b}{2} \}$$ (2)

It is known from formula (2) that the PSK signal carries the spectrum of the NRZ code to the carrier frequency \(f_0\), which is equivalent to the double-side band amplitude modulation of the analog signal, so the bandwidth should be \(2R_b\). This is why the bandwidth selection of the digital filter in the demodulation chassis should be greater than \(2R_b\).

4. Various calculation relations of power signal-to-noise ratio in calibration

The average power \(S\) of the entire PSK signal can be obtained from the expression of the above PSK power spectral density.

$$S = \int_{f_c-R_b}^{f_c+R_b} S_{PSK}(f)df = \frac{A_b^2 T_b}{4} \int_{f_c-R_b}^{f_c+R_b} [S_a^2 \pi(f + f_0)T_b + S_a^2 \pi(f - f_0)T_b]df$$ (3)

Since the square of the \(S_a\) function is difficult to integrate, the average power of the signal is generally not used in the above equation, and the relationship of the bit energy is used to solve the problem. The energy of one symbol of the PSK signal is called bit energy and is represented by \(E_b\).

$$E_b = \int_0^{T_b} S_{PSK}(t)dt = A_b^2 T_b$$ (4)

$$S = \frac{E_b}{T_b} = E_b R_b = A_b^2$$ (5)

The channel noise is Gaussian white noise, and its average power is:

$$N = N_0 B_n$$ (6)

\(N_0\) is the white noise power spectral density. The power signal to noise ratio is:

$$\frac{S}{N} = \frac{E_b R_b}{N_0 B_n} = \frac{E_b}{N_0} \frac{R_b}{B_n}$$ (7)

Equation (7) is expressed in dB as:

$$\left( \frac{E_b}{N_0} \right)_{dB} = \left( \frac{S}{N} \right)_{dB} + 10 \log R_b - 10 \log B_n$$ (8)

\(\left( \frac{E_b}{N_0} \right)_{dB}\) is called normalized signal to noise ratio. Signal and noise power can also be expressed as the mean square of the signal and noise:

$$S = E^2 [X(t)] = V_S^2$$

$$N = E^2 [N(t)] = V_n^2$$ (10)

The root values \(V_S\) and \(V_n\) of \(V_S^2\) and \(V_n^2\) can be measured directly using the rms voltmeter.
\[
\left(\frac{S}{N}\right)_{dB} = 10\log\left(\frac{V_S^2}{V_n^2}\right) = 20\log\left(\frac{V_S}{V_n}\right) = \left(\frac{E_b}{N_0}\right)_{dB} + 10\log R_b - 10\log B_n \tag{11}
\]

\[
\left(\frac{E_b}{N_0}\right)_{dB} = 20\log\left(\frac{V_S}{V_n}\right) - 10\log R_b + 10\log B_n \tag{12}
\]

This formula is the most basic formula used in scaling.

5. Calibration method used in the test
Since the test is for the index test of the telemetry subsystem, it does not have the channel part that is available only after the equipment is shipped. Therefore, the noise of the actual channel can only be simulated by the noise source. The test connection diagram is given below:

![Test block diagram](image)

Figure 1. Test block diagram

The device has previously tested the bandwidth Bn of the test filter before the test, and according to the basic formula:

\[
\left(\frac{E_b}{N_0}\right)_{dB} = 20\log\left(\frac{V_S}{V_n}\right) - 10\log R_b + 10\log B_n
\]

\((V_S\) is set to 1V) \(V_n\) can be calculated according to the above formula.

Let's take the theoretical bandwidth equal to 2Rb as an example to illustrate the adjustment method: first turn off the noise and only add the signal, adjust the variable attenuator R1, so that the rms voltmeter displays \(V_S\); then turn off the signal and only add noise, adjust the variable attenuator R2, so that The rms voltmeter shows \(V_n\); finally, both the signal and the noise are added to the error code.

It can be seen that the scaling of this method reflects the performance of the test filter, while the actual task uses a digital filter instead of a test filter. The actual bandwidth of the digital filter and the bandwidth of the test filter must be different and must be introduced. Calibration error, which also includes human error readings of the unavoidable rms voltmeter. In addition, the noise generated by the noise source is not the actual channel noise, so this calibration method does not truly reflect the actual performance of the device.

6. Currently used calibration methods
In order to reflect the performance of the device more realistically, we are more using the spectrum analyzer to measure the S/\(\Phi\) of the actual channel.
The analog signal source first generates an unadjusted PSK subcarrier signal (since the spectrum of the PSK subcarrier signal of the NRZ code is a continuum with a certain shape, the spectrum obtained by phase-modulating the main carrier must also be a continuous spectrum. The spectrum analyzer can only display the power spectral density value of a single point, so the PSK subcarrier without the NRZ code must be selected for phase modulation—that is, single carrier calibration. The analog downlink RF signal is formed by the secondary modulation of the joint test transponder, and becomes the intermediate frequency signal through the downlink radio frequency channel such as the field amplifier and the down converter, and then the value of the $S/\Phi$ measured by the spectrum analyzer is equal to the threshold value by adjusting the signal gain. Step 2: Set the analog signal source to generate the PSK subcarrier signal of the NRZ code, send it to the TTC IF receiver after the RF channel, and demodulate the telemetry PSK subcarrier. Finally, the digital filter of the telemetry subcarrier is demodulated. And the demodulator completes the synchronous demodulation error detection. It can be seen from the connection block diagram that the whole signal flow is all real equipment in actual combat, the noise is the noise of the downlink channel, and the $S/\Phi$ value measured by the spectrum analyzer has no artificial reading error, so this method can more truly reflect the performance of the device.

Where $\Phi$ is the power spectral density of the noise,

$$\Phi = N_0$$  \hspace{1cm} (13)

$$S/\Phi = S/N_0 = \frac{E_b R_b}{N_0}$$  \hspace{1cm} (14)

Equation (14) is expressed in dB as:

$$(S/\Phi)_{dB} = (E_b / N_0)_{dB} + 10 \log R_b$$  \hspace{1cm} (15)

The value of the threshold is $$(S/\Phi)_{dB} = 12.8 + 10 \log 16000 = 12.8 + 42 = 54.8 dB$$.

The formula assumes:

$$R_b = 16 \text{kbps}$$  \hspace{1cm} (16)

What is emphasized here is that the spectrum analyzer measures the $S/\Phi$ of the first harmonic component generated by the telemetry subcarrier after the secondary modulation of the primary carrier, and the telemetry subcarrier uses the phase modulation system for the secondary modulation of the primary carrier. The phase itself is a nonlinear modulation in which the first harmonic component is the spectral component of the truly modulated signal - the spectral component of the telemetry subcarrier. However, in addition to the first harmonic, many higher harmonic components are
generated, and since the modulation of the telemetry is not high (\( \beta = 1 \) rad), the energy of the higher harmonics is substantially negligible compared with the first harmonic, so the spectrum is we can't see the higher harmonic components on the instrument. The spectrum of the intermediate frequency downlink signal with the PSK displayed by the spectrum analyzer as a single carrier is given below:

\[
\text{Figure 3. Single-carrier secondary modulation IF downlink signal spectrum}
\]

It can be seen from the spectrogram that the phase-modulated spectrum of the PSK subcarrier is double-sided, and the power of the two sidebands is equal, which is equal to half of the PSK subcarrier power:

\[
S_{\text{upper sideband}} = S_{\text{lower sideband}} = \frac{1}{2} S \quad (17)
\]

\[
S_{\text{upper sideband}} / \Phi = S_{\text{lower sideband}} / \Phi = \frac{1}{2} \frac{S}{\Phi} \quad (18)
\]

The signal to noise ratio of each sideband is: \((S/\Phi)_{\text{dB}} = 54.8 + 10 \log_{10} \frac{1}{2} = 54.8 - 3 = 51.8 \text{dB}\)

Therefore, the \((S/\Phi)_{\text{dB}}\) of each sideband read from the spectrum analyzer should be equal to the \(S/\Phi\) calculated by the \(E_b/N_0\) conversion formula and then reduced by 3dB. This should be especially noted.

7. Conclusion
From the above analysis, we can conclude that the second method is obviously superior to the first method. In addition to being simple and easy to operate, it is more important to reflect the overall performance of the device more realistically because it is system-level. Testing, while the former method is a system-level test, we should use more system-level testing in the equipment index test.

References
[1] Feng Yuxi. Principles of Communication Systems. Beijing: Tsinghua University Press 2013: 30-42.
[2] Wu Dazheng. Signal and Linear System Analysis. Beijing: Higher Education Press 2016: 79-91.
[3] Li Wanshan, Yuan Yujie. Telemetry Remote Control Technology. Beijing: Equipment Command Technology College Press 2010: 43-55.
[4] Liu Yuncai, Fang Hongrui, Zhang Fang. Telemetry and remote control system. Beijing: National Defense Industry Press 2010: 20-38.