Research on Threshold Characteristics of Telemetry Receive Channel

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Abstract. This article first explains the nature of the threshold effect. Combining various shipborne telemetry channels with regard to the threshold input signal-to-noise ratio, which is the most widely used channel test link for detection, a unified and universal calibration method is proposed: modulation calibration and carrier signal-to-noise calibration. According to the different background noise of the channel, it is divided into two ways: radio-frequency wired and wireless. The detailed, theoretical, and highly operable test procedures and steps are given. Finally, the dual-mode loop circuit is implemented. The dynamic tracking of the carrier can significantly reduce the threshold effect.

1. Introduction
The current shipborne telemetry receiving equipment is usually divided into two parts of frequency band transmission and baseband demodulation in terms of circuit design. Among them, the synchronous demodulation of digital baseband PCM signals or telemetry subcarrier signals has fully standardized, modularized, and Busization, but the reception and demodulation of frequency band signals has not yet formed a unified, standard mode. The diversity of frequency band modulation systems and demodulation methods determines the diversity of the reception channel form for frequency band signal transmission, and therefore also determines diversity of channel transmission characteristics.

2. The essence of the threshold effect
We take PCM-FM as an example to illustrate the nature of the threshold effect. The PCM-FM signal can be expressed as:

\[ s(t) = A \cos(\omega_c t + \varphi(t)) \]  \( (1) \)

PCM-FM signal carrier amplitude, angular frequency and initial modulation phase:

\[ \varphi(t) = \int_{-\infty}^{t} K(m(\tau))d\tau \]  \( (2) \)

The channel noise is narrow-band Gaussian white noise, which can be expressed as:

\[ V(t) \cos(\omega_c t + \theta(t)) = n_c(t) \cos \omega_c t - n_s(t) \sin \omega_c t \]  \( (3) \)
So for the channel demodulation unit (IF receiver), the input signal is a composite wave of signal and noise:

\[ A \cos(\omega_t t + \varphi(t)) + V(t) \cos(\omega_t t + \theta(t)) = V(t) \cos \psi(t) \]  \hspace{1cm} (4)

The useful information of the angle-modulation signal is in the phase of the signal, so we mainly study the phase of the synthetic wave.

\[
\psi(t) = \omega_t t + \varphi(t) + \arctg \frac{V(t) \sin[\theta(t) - \varphi(t)]}{A + V(t) \cos[\theta(t) - \varphi(t)]} \\
= \omega_t t + \theta(t) + \arctg \frac{A \sin[\varphi(t) - \theta(t)]}{V(t) + A \cos[\varphi(t) - \theta(t)]} \hspace{1cm} (5)
\]

In the case of a large input signal-to-noise ratio, that is, \( A \gg V(t) \), \( \psi(t) \approx \omega_t t + \varphi(t) + V(t) \sin[\theta(t) - \varphi(t)] / A \).

The function of the FM telemetry channel demodulation unit is frequency discrimination, that is, the differential phase is differentiated, so the demodulated output signal should be:

\[
v_d(t) = \frac{1}{2\pi} \left[ \frac{d\psi(t)}{dt} \right] - f_c = \frac{1}{2\pi} \left[ \frac{d\varphi(t)}{dt} \right] + \frac{1}{2\pi A} \frac{d}{dt} \left[ V(t) \sin[\theta(t) - \varphi(t)] \right] \]  \hspace{1cm} (6)

No further analysis of the noise component is given here, only the relationship between the output and the input signal-to-noise ratio at a large input signal-to-noise ratio is given:

\[ \frac{S_0}{N_0} = 3 \beta^2 (\beta + 1) \frac{S_i}{N_i} \]  \hspace{1cm} (7)

Equation (6) further shows that increasing the transmission bandwidth of the band signal (increasing the modulation degree) can increase the output signal-to-noise ratio, but increasing the transmission bandwidth is limited because the increase in bandwidth will introduce additional channel noise, while the input signal The power depends only on the carrier amplitude (the angle-modulated signals are all constant amplitude waves), and does not increase accordingly. Therefore, increasing the bandwidth in turn will reduce the input signal-to-noise ratio. When it decreases below the threshold, it will occur. Threshold effect, it can be seen that the phase of the synthesized wave does not contain an independent signal component that can be demodulated by the frequency discriminator, but becomes a noise component completely.

The above analysis also shows that due to the threshold effect, not only from the perspective of saving the frequency band, the modulation degree of the frequency band transmission cannot be set very high. The PCM-FM modulation degree is usually set to 0.7, and the PCM-PSK-PM modulation degree is usually not. More than 1.

3. Common Calibration Method for Threshold Input Signal-to-Noise Ratio of Shipborne Telemetry Channel

The calibration of the threshold input signal-to-noise ratio of the shipborne telemetry receiving channel is to verify the receiving demodulation performance of the channel. It is usually achieved by testing whether the baseband demodulation error is higher than the theoretical index under a certain modulation degree and threshold input signal-to-noise ratio of. The common calibration method is divided into two steps: the first step is the calibration of the modulation degree, and the second step is the calibration of...
the ratio of the signal power to the channel noise power spectral density. Because of the angle modulation signal, whether FM or PM, the signal bandwidth is related to the modulation:

\[ W_s = 2(\beta + 1)F_s \] (8)

From the above analysis, it is known that the output signal-to-noise ratio after the signal passes through the channel is related to the signal bandwidth, so the modulation degree calibration needs to be performed first. In the modulation degree calibration, regardless of FM or PM, the modulation degree is usually set to 0.7. This is because the current shipborne telemetry equipment is designed and developed in accordance with the American shooting range telemetry standard IRIG106-02. IRIG106-02 specifies the unidirectional peak frequency deviation of FM telemetry PCM-FM signals.

\[ \beta = \Delta f_{FM} / F_s = 0.35R_b / 0.5R_b = 0.7 \] (9)

Although IRIG106-02 does not stipulate the modulation degree of PM telemetry, it can be seen from the previous TT & C mode marine measurement and control tasks that the phase modulation degree has never been lower than 0.7. The modulation baseband signal must be a single tone sine wave. Because PCM-FM is a one-time modulation, the dynamic analog source of the demodulation chassis needs to generate a baseband AA code or 55 code, which is a binary 0101 ... square wave sequence, which is output through the bandpass. After the filter filters out the first harmonic component, it becomes a single tone sine wave. For PCM-PSK-PM, it is the secondary modulation method of the carrier by the PSK subcarrier, so it is only necessary to make the dynamic analog source of the demodulation case generate an unadjusted PSK single carrier.

**Figure 1. Modulation calibration block diagram**

Check the Bezier function table. When the modulation degree is equal to 0.7, the power spectrum of the carrier and the first harmonic component differ by 8.6dB. As shown in Figure 1, adjust the modulation degree potentiometer of the transmitter and monitor it with a spectrum analyzer. Check the output power spectrum of the transmitter to make the first harmonic component lower than the carrier by 8.6dB. At this time, the modulation of the angle modulation signal is 0.7.

The second step is to determine the signal-to-noise ratio using the following formula:

\[ (S/\Phi)_{db} = (E_b/N_0)_{db} + 10 \log R_b \] (10)

From the communication principle, the normalized signal-to-noise ratio depends only on the modulation method of the signal, and has nothing to do with the form of the receiving channel. For PCM-FM modulation, its value is equal to 13.5dB, and for PCM-PSK modulation, its value is equal to 12.8dB. Take a certain type of mission measurement and control TT & C status as an example: if its code rate is equal to 16KbPS, then the ratio of the PSK subcarrier power to the noise power spectral density can be calculated by formula (9) as 54.8dB. Only part of the carrier power is transferred to the harmonic component, and as mentioned earlier, this transfer makes the carrier and each harmonic have a fixed level allocation relationship (depending on the degree of modulation), so the PSK subcarrier S / The calibration of \( \Phi \) can be converted into a ratio of carrier to \( \Phi \) of 60.4dB. The reason why it is reduced...
by 3dB here is that the phase modulation of the carrier by the PSK subcarrier is double-sideband modulation. The power of any sideband is half the power of the entire signal. That is, the power of any sideband is 3dB lower than the power of the entire signal. Therefore, for S / Φ calibration, just adjust the dynamic analog source to output AA code or 55 code, and then adjust the output signal gain of the calibration transmitter so that the ratio of the carrier power to the channel noise power spectral density displayed by the spectrum analyzer is 60.4dB is sufficient.

The above calibration of the threshold input signal-to-noise ratio (S/Φ) C instead of S/N is because of the specific telemetry receiving channel (channel noise power spectral density Φ is determined at any certain position of the channel Quantity), according to the different signal bandwidth of the frequency band (that is, the code rate and modulation method), the selected receiver IF bandwidth is a certain amount, that is, the noise bandwidth B is a certain amount, so the noise power N = BΦ is also a certain amount Calibration, so calibrating (S/Φ) C is equivalent to calibrating S / N. The above calibration method has universal significance for any specific shipborne telemetry receiving channel.

4. Effect of carrier tracking loop on reducing threshold effect
The current shipborne telemetry channels use symmetric dual-mode rings without exception, in which the differential-mode ring completes dual-channel diversity, and the common-mode ring completes carrier tracking. As for the PCM-PSK-PM signal, it contains residual carrier components, so its The common mode circuit only needs to use ordinary carrier tracking phase-locked loop, while the carrier tracking of PCM-FM signals does not contain residual carrier components, so only non-linear circuits (including non-linear components such as phase discriminators) can be used. Circuit) to achieve carrier capture and tracking. Generally, common mode circuits use AFC (Automatic Frequency Control) loops to achieve it. In the following, we will prove in theory that common mode loops can effectively reduce carrier tracking while achieving carrier tracking. Channel input signal-to-noise ratio threshold, thereby improving the threshold characteristics of the channel.

![Figure 2. Common-mode loop phase model](image)

Because the frequency discriminator only works on the FM component of the input signal, and the fast-varying modulation component of the frequency discriminator output is suppressed by the loop filter, it does not participate in negative frequency feedback. Therefore, from Figure 2:

\[
\Delta f_p = \Delta f_i - \Delta f_i = -A_i K_d K_v F(f) \Delta f_p - \Delta f_i, \quad \Delta f_p = \frac{-\Delta f_i}{1 + A_i K_d K_v F(f)}
\]  

(11)

It can be seen from formula (10) that due to the action of the common mode loop, the slow frequency shift error component of the carrier center frequency contained in the input signal is reduced by \( A_i K_d K_v F(f) \) times by the loop. Compared with direct demodulation, at least the transmission bandwidth of the input signal is reduced by the slow frequency shift portion of the carrier center frequency (mainly the carrier Doppler frequency shift). Generally, the carrier Doppler frequency shift
can reach ± 60K ~ 100KHz. The remaining frequency difference of the mode loop is usually controlled within 1K, so the transmission bandwidth suppressed by the loop is 59K ~ 99KHz, that is, 4.7 ~ 4.9dB. Because the channel noise in this part of the transmission bandwidth is suppressed by the loop, the signal sent to the discriminator after mixing can be demodulated at an input signal-to-noise ratio lower than that of the ordinary discriminator, which is quite This reduces the threshold of the input signal-to-noise ratio.

5. Conclusion

The direct cause of the threshold effect is the non-linearity of the channel demodulation unit. At this time, the system (channel demodulation unit) can not consider the effects of the signal and noise separately. The form of the input excitation is as shown in equation (1). If the demodulation unit adopts coherent demodulation, the response of the system to the excitation satisfies the principle of linear superposition. At this time, the signal and noise can be applied to the system to get a response. At this time, the threshold effect can be greatly weakened and the input threshold Significantly reduced, thereby improving the threshold characteristics of the channel.

References

[1] Di Chang, Xia Zhang, Qiong Liu, Ge Gao, and Yue Wu. "Location based robust audio watermarking algorithm for social TV system." In Pacific-Rim Conference on Multimedia, pp. 726-738. Springer, Berlin, Heidelberg, 2012.

[2] Di Chang, Xia Zhang, and Yue Wu. "A Multi-Source Steganography for Stereo Audio." Journal of Wuhan University (Natural Science Edition) , 2013(3): 277-284.

[3] Xia Zhang, Di Chang, et al. "An Audio Steganography Algorithm Based on Air-Channel Transmitting." Journal of Wuhan University (Natural Science Edition) 57, no. 6 (2011): 499-505.

[4] Xia Zhang, Di Chang, et al. "Tree-like Dimensionality Reduction for Cancer-informatics." In IOP Conference Series: Materials Science and Engineering, vol. 490, no. 4, pp. 042028. IOP Publishing, 2019.