AGC Calibration Accuracy

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Currently, measurement of received signal power at the DSN stations is performed by calibrating the automatic gain control voltage as an indicator of received signal power level. Errors in the AGC voltage vs signal power level calibration are identified and the overall AGC calibration accuracy is estimated.

I. Introduction

At present, DSN Standard Test Procedure No. 853-51 4A-07 Rev B is used to calibrate the receiver automatic gain control (AGC) voltage vs the received carrier power so that the Digital Instrumentation Subsystem (DIS), the Telemetry and Command Processor (TCP), and the voice report all yield an accurate estimation of the received spacecraft carrier power. Fifteen AGC voltage/signal level pairs covering a 30-dB range are used in the calibration. The test transmitter output signal level is adjusted to the desired calibration levels using the Y-factor technique of power ratio measurements.

The AGC voltage/signal level pairs are used by the DIS to generate a third-degree polynomial curve fit. The TCP performs a seven-point best fit straight line approximation to the calibration data. Received spacecraft signal power estimation is performed independently by the DIS and TCP. The DIS samples the receiver AGC voltage and calculates the corresponding carrier power using the third-degree polynomial established in the AGC calibration. Similarly, the TCP samples the AGC voltage and estimates the received signal power using its linear approximation of the AGC voltage/signal power relationship.

This report presents a discussion of the theoretical aspects and limitations of the AGC voltage vs received CW signal power calibration procedure.

II. Procedure

The signal level calibration consists of four major steps. Each of these major steps will be examined, and those items which appear to limit the accuracy of the calibration will be identified. An attempt will be made to place a bound on each of these discrete error contributions and to estimate the overall AGC calibration accuracy.

A. Step 1: Y-Factor Calculations

In order to calculate the Y-factors that are required to input the desired test transmitter signal levels, it is first necessary to obtain measured values for:

- T_{op} effective system noise temperature, K
- B uncorrected bandwidth of the 10-kHz bandpass filter in the Y-factor detector assembly
- G gain factor of the Y-factor detector assembly

These parameters, along with the desired input carrier power levels from the test transmitter, are used by the Y-factor computer program DOI-5343-SP-B to calculate the Y-factors used in the AGC calibration. The formula used by the DIS to calculate the Y-factors is:

$$Y_{dB} = 10 \log \left\{ 1 + \text{antilog} \left[\frac{pad + P_c + 198.6 - G}{10} - \log (T_{op} \cdot B) \right] \right\} \tag{1}$$

where

pad = test transmitter reference step attenuator calibrated value, dB.

P_c = test transmitter carrier power, dBm.

198.6 = Boltzman's constant

In order to evaluate the accuracy of the calculated Y-factors, it is first necessary to define the errors in the measured system parameters. These errors are:

$\triangle T$ = the error in the measured value of system operating temperature, K

$\triangle B$ = the error in the measured value of the 10-kHz crystal filter bandwidth in the Y-factor detector assembly

$\triangle G$ = the error in the measured value of the gain factor, dB

$\triangle pad$ = the error in the calibrated value of the test transmitter reference step attenuator

The error $\triangle Y$ in the calculated value of Y can now be expressed as

$$\triangle Y = \frac{\partial Y}{\partial (pad)} \triangle pad + \frac{\partial Y}{\partial G} \triangle G + \frac{\partial Y}{\partial T_{op}} \triangle T_{op} + \frac{\partial Y}{\partial B} \triangle B \tag{2}$$

where

$\frac{\partial Y}{\partial (pad)}$ = the sensitivity of the Y-factor calculation to an error in the *pad* value

$$= \frac{10^x}{1 + 10^x} \tag{3}$$

$\frac{\partial Y}{\partial G}$ = the sensitivity of the Y-factor calculation to an error in the gain factor

$$= -\frac{10^x}{1 + 10^x} \tag{4}$$

$\frac{\partial Y}{\partial T_{op}}$ = the sensitivity of the Y-factor calculation to an error in the measured value of system noise temperature

$$= -\frac{4.34 \cdot 10^x}{(1 + 10^x)\, T_{op}} \tag{5}$$

$\frac{\partial Y}{\partial B}$ = the sensitivity of the Y-factor calculation to an error in the measured value of the 10-kHz filter bandwidth.

$$= -\frac{4.34 \cdot 10^x}{(1 + 10^x)\, B} \tag{6}$$

where

$$X = \frac{pad + P_c + 198.6 - G}{10} - \log (T_{op} \cdot B) \tag{7}$$

The error $\triangle Y$, in the calculated value of each Y-factor will result in an error in the setup value of carrier power of $\triangle P_c$. Solving Eq. (1) for P_c yields

$$P_c = 10 \log (10^{Y/10} - 1) + 10 \log T_{op} + 10 \log B - pad - 198.6 + G \tag{8}$$

The sensitivity of the setup value of carrier power to the error in the calculated Y-factors is obtained by taking the derivative of P_c with respect to Y. We obtain

$$\frac{\partial P_c}{\partial Y} = \frac{10^{Y/10}}{10^{Y/10} - 1} \tag{9}$$

Therefore, the error in the setup signal level due to the Y-factor errors is given by

$$\triangle P_c = \frac{\partial P_c}{\partial Y} \triangle Y \tag{10}$$

or

$$\triangle P_c = \frac{10^{Y/10}}{10^{Y/10} - 1} \triangle Y \tag{11}$$

In order to evaluate the calibration signal level error contributions discussed so far, it is necessary to assign values to $\triangle T_{op}$, $\triangle B$, $\triangle G$, and $\triangle pad$. These four values are given below:

(1) The measured value of T_{op} has a worst case (3σ) error of 1.3 K (Ref. 1).

(2) The accuracy of the measured value of bandwidth is limited primarily by the accuracy of the Airborne Instrument Laboratories (AIL) precision attenuator. The precision attenuator is used to calibrate the filter attenuation as a function of frequency. The accuracy of the precision attenuator over the range used for this calibration is 0.06 dB (Ref. 2), corresponding to a bandwidth error of 140 Hz.

(3) The gain factor accuracy is limited by the precision attenuator and is approximately 0.03 dB.

(4) The capability exists to calibrate the test transmitter step attenuators to an accuracy of 0.05 dB. This is the accuracy of the reference step attenuator (*pad*) value.

The AGC calibration errors introduced by the Y-factor calculations are summarized in Table 1.

B. Step 2: Calibration Signal Level Adjustments

The second major step in the AGC calibration is to set up precise test transmitter signal levels using the Y-factor equipment. Three major factors which limit the accuracy of the calibration signal level settings are:

(1) The resetability and nonlinearity of the precision attenuator. For Y-factors such that 4 dB $\leq$ Y $\leq$ 16 dB, the precision attenuator accuracy is approximately 0.04 dB.

(2) The operator's ability to "eyeball average" the strip chart recorder trace and to duplicate that average by adjusting the test transmitter output level. The inherent limitations of this technique result in an additional worst case error contribution of 0.05 dB.

(3) The procedure of using the test transmitter step attenuator to decrease the signal power in two 10-dB steps to provide three calibration points for each of the five calculated and set up Y-factors. This procedure results in calibration signal power errors (in 10 of the 15 calibration points) of not more than 0.05 dB.

These three error sources and their net worst case error contribution to the signal level adjustments are summarized in Table 2.

C. Step 3: AGC Voltage Measurements

The third phase of the calibration is the measurement of the noisy AGC voltage. The AGC voltage is averaged over a 100-s interval by the 2401C integrating voltmeter and is then displayed. The principal sources of error to be considered include:

(1) The CW power stability of the test transmitter (Ref. 3). The published specification of 0.5 dB is not representative of actual performance over the five short periods (7 to 10 min each) during which the calibration signal level must remain constant. It is assumed that the power stability of the test transmitter over these short time periods is 0.05 dB.

(2) The maser gain stability over the period of time (approximately 1 h) that it is used during the AGC calibration and the accuracy to which its gain can be set. The short-term fixed position gain stability is 0.05 dB/10 s and the long-term gain stability is 0.5 dB/12 h (Ref. 4). The total calibration error due to the maser gain adjustment and gain variation is assumed to be not greater than 0.15 dB.

(3) The receiver gain stability. The receiver gain stability during the AGC calibration is assumed to be 0.05 dB.

(4) The variance of the 100-s averages taken by the integrating voltmeter due to the variance of the AGC voltage. The variance of the AGC voltage can be calculated by using the results of Chapters 7 and 8 of Tausworthe (Ref. 5). It has been shown by Lesh (Ref. 6) that the variance of the 100-s averages is related to the variance of the AGC voltage by:

$$\begin{aligned} \sigma_A^2 &= \sigma_{AGC}^2\left[\frac{2\tau}{T} + \frac{2\tau^2}{T^2}\left(e^{-\frac{T}{\tau}} - 1\right)\right] \\ &\approx \frac{2\sigma_{AGC}^2\,\tau}{T} \end{aligned} \quad (12)$$

for T/τ large, where

σ_A^2 = the variance of the 100-s sample

σ_{AGC}^2 = the variance of the AGC voltage

T = the integration time (100 s)

τ = the closed loop AGC time constants

$$\tau = \begin{cases} 2.69 \text{ s (narrow)} \\ 0.241 \text{ s (medium)} \\ 0.283 \text{ s (wide)} \end{cases}$$

The accuracy of Step 3 of the AGC calibration is plotted as a function of signal level in Fig. 1.

D. Step 4: Manual Gain Control (MGC) Sampling and Curve Fitting

The fourth major step in the AGC calibration is the process of adjusting the MGC voltage to the value obtained in Step 3, sampling these voltages with the DIS and TCP, and performing the seven-point best fit (TCP) and the third-degree least squares curve fit (DIS). The three parts of this phase of the calibration will be considered separately:

(1) The MGC voltage stability and setability will create an error not exceeding 0.002 V or 0.02 dB.

(2) Gain stability, zero offset and linearity specifications for the AGC isolation amplifier (Ref. 7) indicate a maximum error contribution by this component of 0.1 dB. If the digital voltmeter is used to check the zero offset, gain, and linearity while the amplifier adjustments are made, this maximum error can be reduced to approximately 0.02 dB.

The error contributions of the TCP analog multiplexers will not be greater than 0.0025 V (Ref. 8), and the accuracy of the TCP analog-to-digital converter (ADC) is 0.0035 V (Ref. 9). These two errors result in an additional TCP worst-case calibration error of 0.06 dB. Similarly, the DIS analog multiplexer (Ref. 10) and analog-to-digital converter (Ref. 11) errors result in an additional DIS calibration error of approximately 0.04 dB.

(3) The AGC voltage/signal level pairs are used by the DIS to generate the third-degree polynomial curve fit. The TCP performs a seven-point best fit straight line approximation to these data. A study by Lesh (Ref. 12) of a similar calibration technique indicates that the calibration error contribution by the DIS curve fitting process is less than 0.01 dB. Similarly, the TCP calibration error introduced by the straight-line approximation does not exceed 0.02 dB.

A tabulation of the MGC sampling and curve fitting errors is given in Table 3.

IV. Total AGC Calibration Accuracy

The total worst case AGC calibration error is obtained by combining the results of Tables 1 through 3 with Fig. 1. Figure 2 is a plot of the total AGC calibration error vs signal level. A probable error scale is included by making the assumption that the worst-case error is a 3σ value of the calibration error. It should be noted that there is no significant difference between the DIS and TCP accuracies, since most of the calibration errors result from sources that are common to the DIS and TCP.

V. Summary

This step-by-step view of the AGC calibration procedure has hopefully identified the principal sources of calibration errors. The calibration errors associated with each of the four calibration phases have been estimated. It has been shown that the AGC calibration accuracy is largely a function of two factors:

(1) Calibration of all hardware associated with the AGC calibration including:

Test transmitter.
Maser.
Receiver.
50-MHz AIL precision attenuator.
Y-factor detector assembly (10-kHz bandpass filter).
AGC isolation amplifier.
TCP and DIS analog multiplexers and ADCs.

(2) The accuracy to which system measurements and adjustments are made by the operator.

It is important to note that this report is concerned with only the calibration accuracy of the receiver AGC voltage as an indicator of the CW power level at the receiver input reference plane. The AGC calibration accuracy (Fig. 2) should not be confused with the overall accuracy of spacecraft signal level reporting. Many other factors are involved, including:

(1) DSS antenna gain variations and pointing errors.

(2) Maser gain variation as a function of antenna pointing angle.

(3) Uncertainties in path loss.

(4) Long-term equipment stabilities.

These would have to be considered in a study of the overall spacecraft signal-level reporting accuracy.

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Table 1. Y-factor calculation errors

Error source	Value	Worst-case error contribution, dB
ΔT = system temperature error	1.3° K	0.18
ΔB = bandwidth error	140 Hz	0.06
ΔG = gain factor error	0.03 dB	0.03
Δpad = pad value error	0.05 dB	0.05
Y-factor calculation worst-case error total		0.32

Table 2. Signal level adjustment errors

Error source	Value, dB
Precision attenuator	0.04
Test transmitter adjustments	0.05
Test transmitter step attenuator	0.05
Calibration signal level error (worst case)	0.14

Table 3. MGC Sampling and curve fitting errors

Error source	Value, dB	
MGC voltage adjustments	0.02	
AGC isolation amplifier	0.02	
Analog multiplexers and A/D's	(TCP) 0.06	(DIS) 0.04
Curve fitting	(TCP) 0.02	(DIS) 0.01
Worst-case total	(TCP) 0.12	(DIS) 0.09

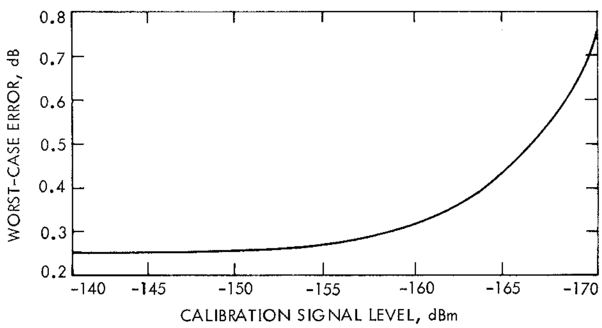

Fig. 1. AGC voltage measurement error

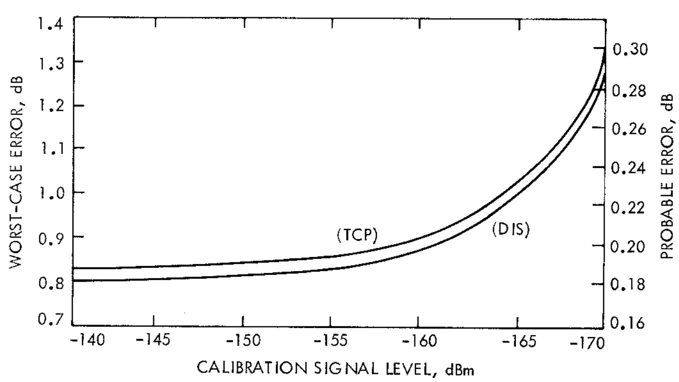

Fig. 2. Total AGC calibration accuracy