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BACK OFF ATTENUATOR (BOA) CALIBRATION OF SATELLITE PALOADS USING NOISE FLOOR METHOD

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ABSTRACT

In order to achieve the commandable gain, both the bent pipe type communication transponder (of any communication satellite) and navigation paylaod data transmitter (of any navigation satellite) usually employ the commandable attenuator, called the Back Off Attenuator (BOA). The BOA, basically the PIN diode type attenuator, is a part of the onboard driver amplifier prior to the final power ampliflifier of the satellite payload. For most of the communication payloads, the BOA ranges from 0 dB to 22 dB with a minimum step size of 2 dB. However, for most of navigation paylaods, it ranges from 0 dB to 12 dB with a minimum step size of 1 dB. There is a unique command code (called the BOA data command) for setting each BOA step. Prior to the launching of the satellite, it is very much needed to calibrate all the BOA steps accurately. In this paper, an innovative method, called the **Noise Floor Method** has been discussed in detail which could be employed for accurate calibration of the Back Off Attenuator (BOA) onboard the satellite payloads. Using this technique, the BOA calibrations of both the CDMA Ranging payload (bent pipe transponder) and the navigation paylaod (data transmitter) of IRNSS satellite have been carried out. The paper also contains these measured data of BOA calibration obtained by the innnovative method and their comparison with the measured data obtained by conventional method.

Keywords: *Back Off Attenuator (BOA), Code Division Multiple Access (CDMA), Indian Regional Navigation Satellite System (IRNSS), Integrated Spacecraft Testing (IST), Noise Floor, Spectrum Analyzer, Transponder.*

I. INTRODUCTION

The Back Off Attenuator (BOA), usually the PIN diode type attenuator [1, 2] is a part of the Driver Amplifier in a satellite's paylaod chain. For any communication transponder or navigation data transmitter, the Back Off Attenuator (BOA) steps are set using telecommand to achieve commandable gain [3-8]. For a bent pipe type communication transponder, the conventional technique by which the BOA calibration i.e., the BOA steps at IST (Integrated Spacecraft Testing) level are measured is as described [9] below:

From a microwave signal source, the RF input power to the communication transponder is selected in such a way that the payload transponder chain operates in its linear region (at least 10 dB below the saturation point). Keeping the input power level constant, the back of attenuator (BOA) is switched in from 0 dB to maximum value. As the BOA steps are switched ON one by one, the payload downlink power level will decrease in step in synchronism with the BOA step changes. The steps in the payload downlink power level are traced on Spectrum Analyzer in single sweep mode with zero span and BOA values are computed offline by measuring step size of the staircase like trace on Spectrum Analyzer, as shown in the Figures 3(a) and 4(a).

II. INNOVATIVE TECHNIQUE

An innovative technique, called the **Noise Floor Method** could also be adopted to measure the BOA steps of the satellite payloads. This technique does not require the pumping of any RF signal at the transponder input. Instead, the transponder noise floor level in the down link path is captured on the Spectrum Analyzer screen (in single sweep mode with zero span) during setting the different BOA steps as done in the conventional technique of BOA calibration. This technique will have several advantages over the conventional method. These include:

- Considerable reduction in BOA calibration testing time.
- No need of Uplink RF signal source.

- No need of unlink RF checkout interface and thereby no need of uplink path calibration.
- Does not require the determination of saturation point or nominal operating point of the satellite's payload prior to the execution of the BOA calibration test.
- Suitable for Transmitter type navigation payload (where uplink signal is not applicable or not available).
- Suitable during Pre-launch IST operations at the launch pad (where RF silencing is required) as a quick check.

2.1 The Basic Principle:
CDMA Ranging Payload is a bent-pipe transponder consisting mainly of Low Noise Receiver, Variable Attenuator & SSPA Transmitter in the chain [10]. The background Noise = KT_o is present at the Transponder input. Even without giving any RF input signal, this input noise will pass through the Transponder, get amplified & result in Noise output which is seen as a Noise pedestal in the Spectrum Analyzer trace depending on the Filter characteristics.

The Noise Power output from the Transponder is given [11] by the following equation]:

$$N_{out} = (FKT_oBW)G \qquad (1)$$

Where,
N_{out} = Noise Power output,
F = Noise Figure of the Transponder chain,
K = Boltzman's Constant,
T_o = Room Temperature (290^0 K),
B = Resolution Bandwidth of the Spectrum Analyzer in Hz,
G = Gain of Transponder.

In Log scale, the above equation can be written as:

$$N_{out}\,(dBm) = F\,(dB) - 174 + 10\log_{10}(B) + G\,(dB) \qquad (2)$$

Since Transponder Noise Figure & all measurement settings are constant throughout the measurement, the change in noise floor level could be obtained by differentiating both the sides of the above equation (2) and could be expressed as follows:

$$\Delta N_{out}\,(dB) = \Delta G\,(dB) \qquad (3)$$

Transponder gain is represented as:

$$G = [G_o\,(dB) – A\,(dB)] \qquad (4)$$

Where, G_o is the fixed linear gain in dB and A is the variable attenuation in dB.
Differentiating the above equation (4), one could write,

$$\Delta G\,(dB) = -\,\Delta A\,(dB) \qquad (5)$$

Where, ΔA (dB) is the BOA Step value.
Substituting equation (5) in equation (3),

$$\Delta N_{out}\,(dB) = -\,\Delta A\,(dB) \qquad (6)$$

From equation (6) it is evident that the change in noise floor level at the transponder output is numerically equal to the BOA step value set onboard the transponder. This means if the different BOA steps are switched ON one by one, the noise floor level will decrease gradually and thereby results the stair-case like trace on Spectrum Analyzer. The different step sizes of the displayed noise floor trace on spectrum analyzer will then represent the measured values of the BOA steps.

III.EXPERIMENTAL RESULTS AND THEIR COMPARISON

BOA calibrations for both main and redundant chains of CDMA Ranging Payload (basically, a transponder) and the L5 band and S band Navigation Payload (basically, data transmitters) of IRNSS-1I Navigation satellite were carried out using both conventional and innovative techniques.

3.1 CDMA Ranging Payload

The Noise Floor plots for both the Main & Redundant Transponder chains at 0 dB BOA are given in Figures 1 and 2. The staircase like Noise floor traces in the downlink path as appeared in the Spectrum Analyzer screen during measurements are shown in the following Figures 3 and 4.

The BOA steps computed from these traces using these two different techniques are shown in the Tables 1 and 2 below.
The comparison values are plotted in Figures 5 and 6.

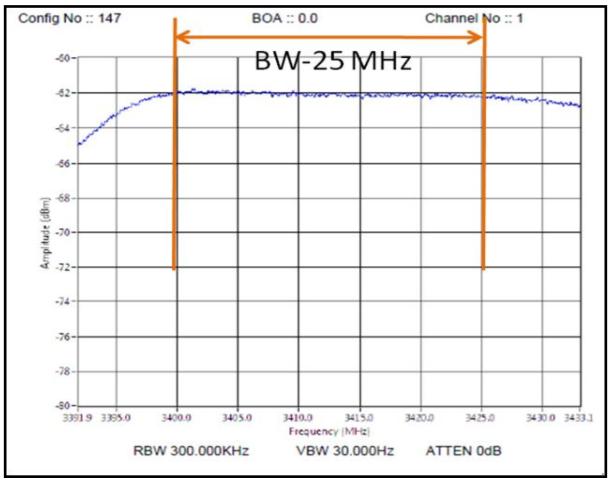

Figure 1: Transponder Main chain Noise Floor Plot with 0 dB BOA.

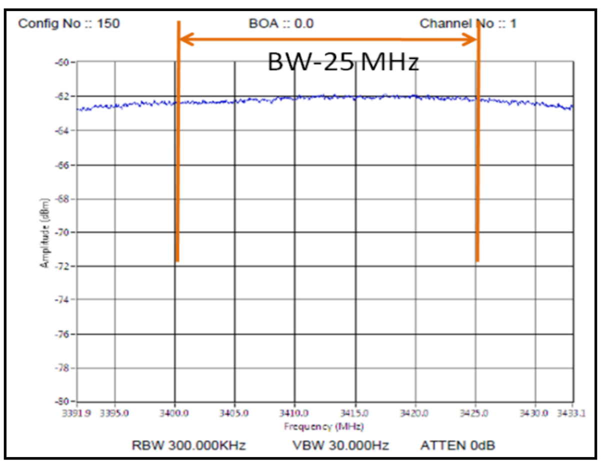

Figure 2: Transponder Redundant chain Noise Floor Plot with 0 dB BOA.

Downlink Traces as captured on Spectrum Analyzer during BOA calibration of the Transponder main and redundant chains using two methods are shown in Figures 3 and 4 below:

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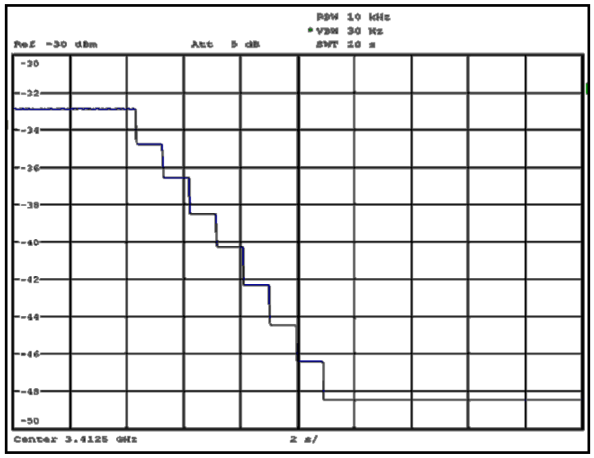
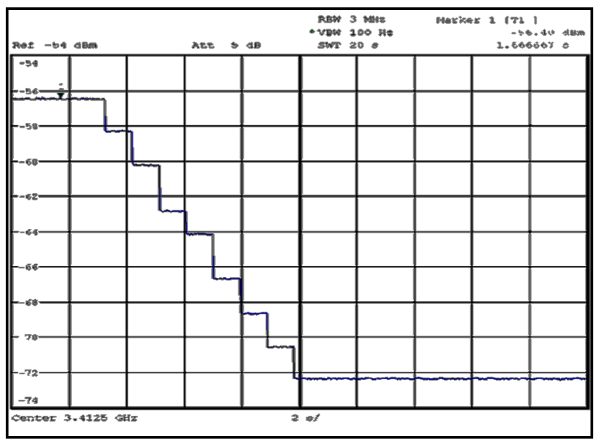
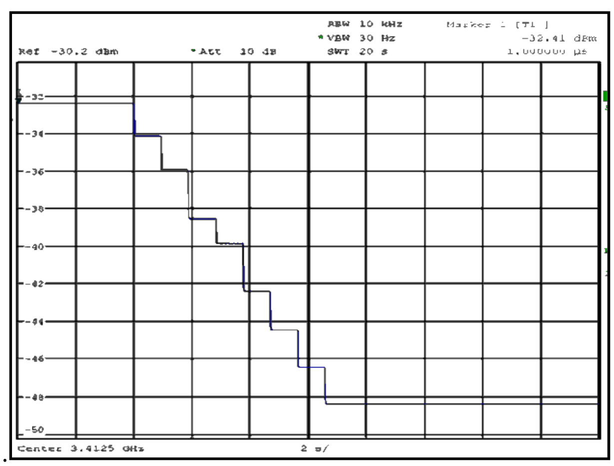


(a) Conventional Method



(b) Noise Floor Method:
Figure 3: Noise Floor traces on Spectrum Analyzer-CDMA Rangin Payload Main Chain



(a) Conventional Method

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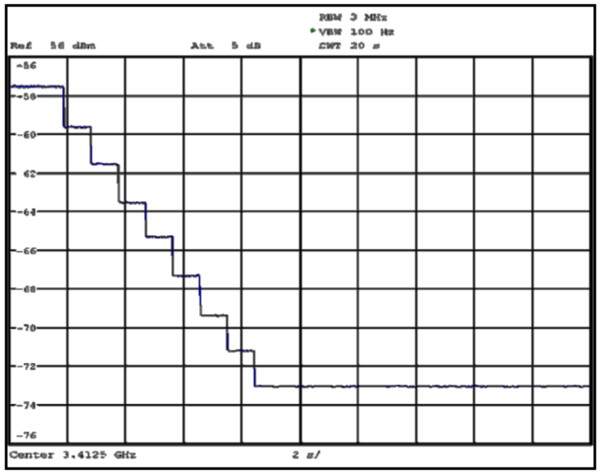

(b) Noise Floor Method

Figure 4: Noise Floor traces on Spectrum Analyzer - CDMA Rangin Payload Redundant Chain

As one of the important performance parameters of the satellite payload systems, the BOA calibration test is usually carried out for all the major IST (Integrated Spacecraft Testing) test phases during testing of the satellites. The BOA step values obtained during BOA calibration test of both the main and redundant chains of the CDMA Ranging Payload of IRNSS-1I satellite during clean room environment are shown in the Tables 1 and 2 below [12]. The results obtained from these two methods are also plotted in Figures 5 and 6 which show a close match between the two methods.

Table 1: IRNSS-1I BOA Calibration Results between the two methods for Main chain of CDMA Ranging Payload

BOA Set Value (dB)	**Measured Values of BOA Calibration Data for CDMA Main Chain**		Upper Limit	Lower Limit
	Noise Floor Method	Conventional Method		
2	2.1	2.0	3.0	1.0
4	4.0	3.9	5.0	3.0
6	6.0	5.9	7.0	5.0
8	7.8	7.6	9.0	7.0
10	9.8	9.7	11.0	9.0
12	11.9	11.8	13.0	11.0
14	13.7	13.8	15.0	13.0
16	15.5	15.6	17.0	15.0

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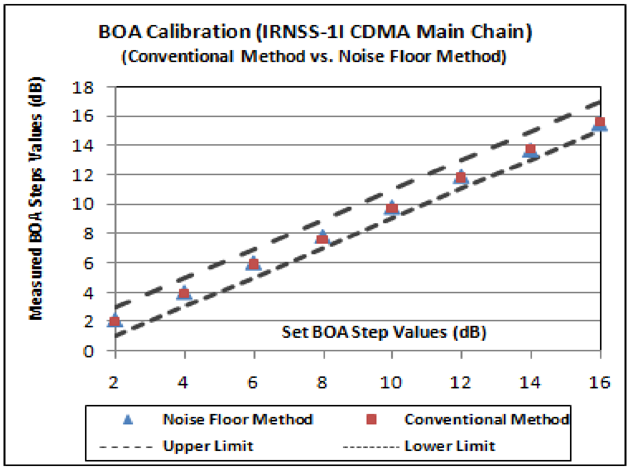

Figure 5: Comparison of BOA Calibration Results between the two methodsr for IRNSS-1I CDMA Ranging Payload (Main chain)

Table 2: IRNSS-1I BOA Calibration Results between the two methods for Redundant chain of CDMA Ranging Payload

BOA Set Value (dB)	**Measured Values of BOA Calibration Data for CDMA Redundant Chain**		Upper Limit	Lower Limit
	Noise Floor Method	Conventional Method		
2	2.0	1.8	3.0	1.0
4	3.8	3.7	5.0	3.0
6	6.4	6.3	7.0	5.0
8	7.8	7.6	9.0	7.0
10	10.3	10.1	11.0	9.0
12	12.3	12.2	13.0	11.0
14	14.1	14.2	15.0	13.0
16	15.9	16.0	17.0	15.0

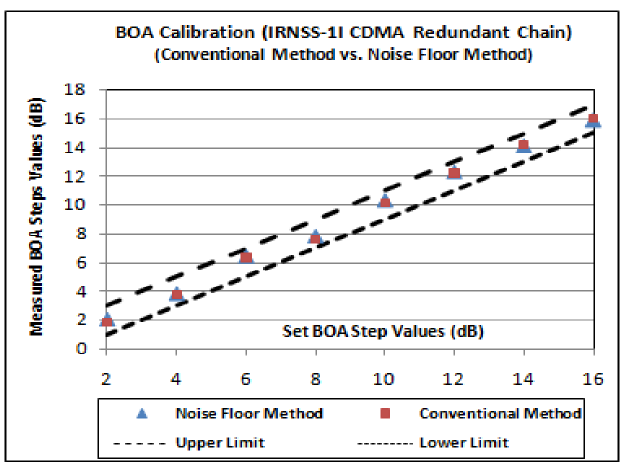

Figure 6: Comparison of BOA Calibration Results between the two methods for IRNSS-1I CDMA Ranging Payload (Redundant chain)

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3.2 Navigation Payload

Similarly, the BOA calibrations test in clean room environment and also at CATF (Compact Antenna Test Facility) and during in-orbit test at MCF (Master Control Facility), Hassan were carried out for both the L5 band and S band Navigation Payloads (which are basically the data transmitters, not the transponders) of IRNSS-1I satellite using the innovative method i.e., the noise floor method as discussed above. The results obtained during these test phases are very much comparable with the results obtained at subsystem level [12-14]. The Figures 7 to 10 below show the noise floor traces captured on a spectrum analyzer during BOA calibration at Integrated Spacecraft Testing (IST) level in clean room environment using the innovative method. The results obtained are then compared with the data obtained during subsystem level testing (which uses the conventional method). The comparison of the test results between the two techniques for these Navigation payloads of IRNSS-1I are shown in the Tables 3 to 6 and also shown graphically in Figures 11 to 14 below. It is to be noted that for the navigation payload (mainly the data transmitters used to broadcast the navigation messages over the service area), only the **noise floor method** could be adopted for BOA calibration at IST (Integrated Spacecraft Testing) level because there is no provision to uplink the low level RF signal at the transmitter input during different IST phases. For such navigation payloads, the BOA calibration using the conventional method is only possible during subsystem level testing.

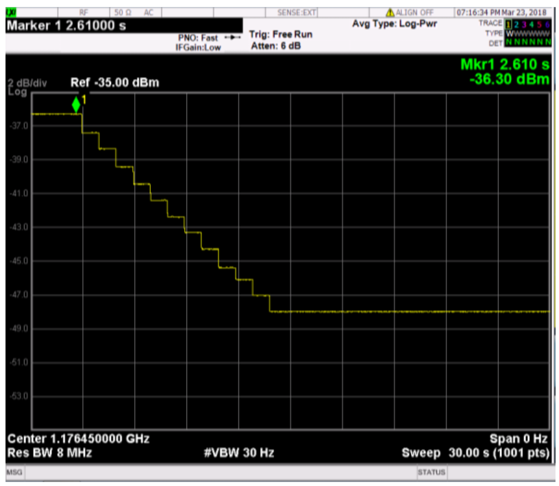

Figure 7: Noise Floor traces on Spectrum Analyzer-L5 band Navigation Payload Main Chain

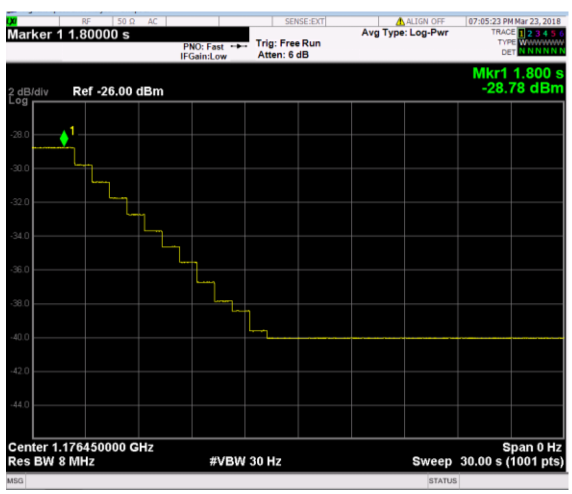

Figure 8: Noise Floor traces on Spectrum Analyzer-L5 band Navigation Payload Redundant Chain

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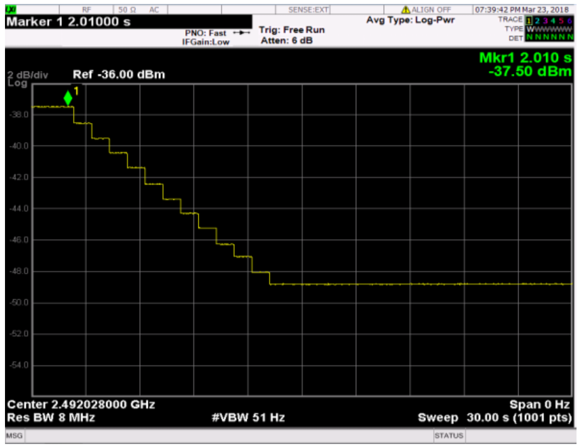

Figure 9: Noise Floor traces on Spectrum Analyzer-S band Navigation Payload Main Chain

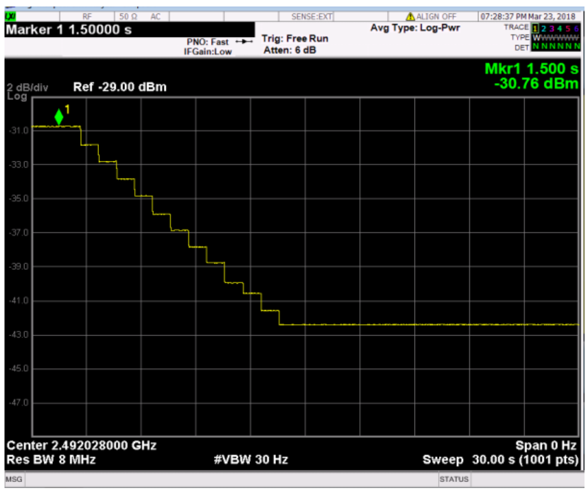

Figure 10: Noise Floor traces on Spectrum Analyzer-S band Navigation Payload Redundant Chain

The comparison of the test results between the two techniques are shown in the Tables 3-6 below:

Table 3: BOA Calibration Results Comparison for IRNSS-1I L5 Band Navigation Payload-Main Chain

BOA Set Value (dB)	**Measured Values of BOA Calibration Data -L5 Main Chain**	
	Noise Floor Method	Conventional Method
1	1.1	0.8
2	2.0	1.7
3	3.0	3.3
4	4.1	4.3
5	5.1	5.3
6	6.1	6.3
7	7.0	7.3
8	7.9	8.0
9	9.1	9.3
10	9.6	9.8
11	10.7	10.4
12	11.7	11.5

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Table 4: BOA Calibration Results Comparison for IRNSS-1I L5 Band Navigation Payload-Redundant Chain

BOA Set Value (dB)	Measured Values of BOA Calibration Data -L5 Redundant Chain	
	Noise Floor Method	Conventional Method
1	1.0	0.8
2	2.0	1.8
3	2.9	2.7
4	3.9	6.0
5	4.9	4.6
6	5.8	5.5
7	6.7	6.4
8	8.0	7.7
9	9.1	8.9
10	9.6	9.6
11	10.8	10.9
12	11.3	11.5

Table 5: BOA Calibration Results Comparison for IRNSS-1I S Band Navigation Payload-Main Chain

BOA Set Value (dB)	Measured Values of BOA Calibration Data -S Main Chain	
	Noise Floor Method	Conventional Method
1	1.1	1.1
2	2	2.1
3	2.9	3
4	3.8	3.9
5	4.9	5
6	5.8	5.9
7	6.8	6.8
8	7.7	7.8
9	8.5	8.7
10	9.6	9.7
11	10.6	10.8
12	11.5	11.7

Table 6: BOA Calibration Results Comparison for IRNSS-1I S Band Navigation Payload-Redundant Chain

BOA Set Value (dB)	Measured Values of BOA Calibration Data -S Redundant Chain	
	Noise Floor Method	Conventional Method
1	1.1	1.0
2	2.1	1.9
3	3.1	2.9
4	4.1	3.8
5	5.2	4.9
6	6.1	5.8
7	7.1	6.8
8	8.1	7.8
9	9.2	9.0
10	9.8	9.7
11	10.8	10.8
12	11.6	11.8

The comparison of the test results between the two techniques are also shown in the Figures below:

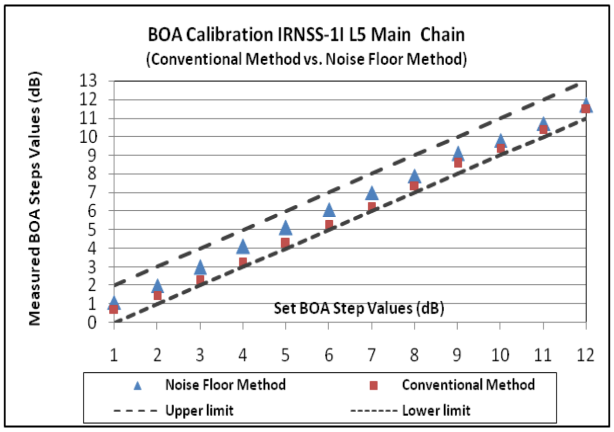

Figure 11: Comparison of BOA Calibration Results: IRNSS-1I L5 band Navigation Payload Maint chain

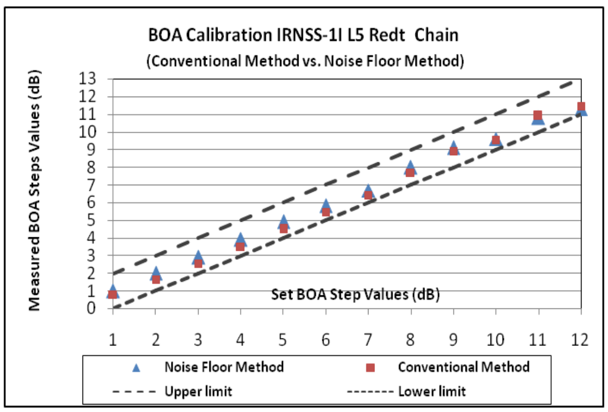

Figure 12: Comparison of BOA Calibration Results: IRNSS-1I L5 band Navigation Paylaod Redundant Chain

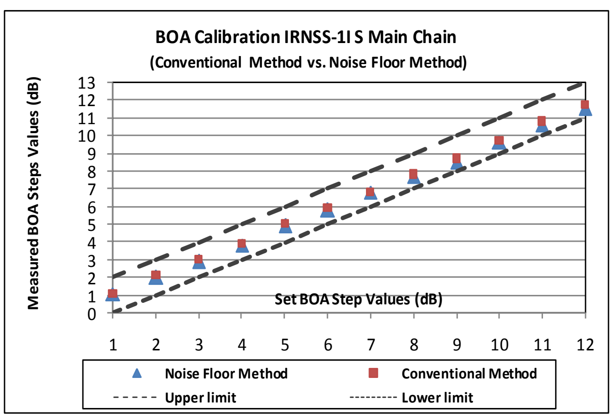

Figure 13: Comparison of BOA Calibration Results: IRNSS-1I S band Navigation Payload Main chain

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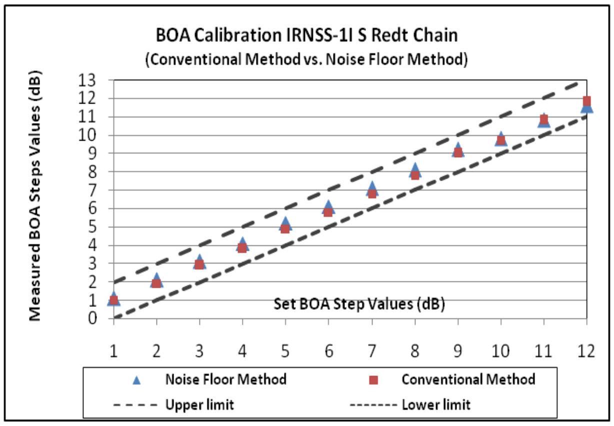

Figure 14: Comparison of BOA Calibration Results: IRNSS-1I S band Navigation Payload Redundant chain

IV. CONCLUSION

For the CDMA Ranging payload (bent pipe transponder), the comparison of BOA calibration data as depicted in Figures 5 and 6 show very good match between the two techniques as described above. The maximum deviation between the two methods is 0.2 dB, which is less than the measurement accuracy (= +/-0.5 dB) of the onboard BOA values. Similarly, for the Navigation payload (data transmitter), the comparison of BOA calibration data obtained independently by two methods and depicted in Figures 11 to 14 show very good match between the two techniques, the maximum deviation being 0.3 dB, which is again less than the measurement accuracy (= +/-0.5 dB) of the onboard BOA values. Therefore, one could conclude that the noise floor method as described in the paper could be used satisfactorily for accurate BOA calibration of both the bent pipe type payload transponder and the data transmitter type payload (such as the navigation payload) at IST level.

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VI. DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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