# Measurements of Integration Gain for the Cospas-Sarsat system from Geosynchronous Satellites


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## Abstract

The GOES-R satellite is the first satellite to use a standard straight bent pipe transponder with no on-board re-modulation to support Search and Rescue (SAR) operations. Here, we report on the link measurements with a high fidelity satellite transponder simulator made up of satellite EDU (Engineering Design Units) components using an uplink from a beacon simulator and received by a GEOLUT (GEOsynchronous satellite Local User Terminal). We also report on the first ever measurements showing the performance gain obtained by the signal integration performed by the GEOLUT. In addition, a simulator made of commercially available off-the-shelf components assembled to develop the test plan was found to perform very close to the high fidelity simulator.

In this paper, we describe what message integration is, how it is implemented in the particular satellite receiving station model used for this tests, and show the measured improvement in message decoding due to this integration process. These are the first tests to quantify the integration gain and are the first tests on the new SARSAT standard for the bent pipe (no onboard re-modulation) repeater used in GOES-R. An inexpensive satellite simulator to run test scripts built from off the shelf components was also found to have the same performance as a high fidelity simulator using actual satellite EDUs.


## Background

The NOAA-SARSAT is part of the 43 country Cospas-Sarsat organization that detects and locates aviators, mariners, hikers and mountain climbers in distress. These individuals carry distress beacons which get activated when they run into trouble. Various satellites relay the signals from the distress beacons to ground stations around the world.

The existing Cospas-Sarsat system is a multilayered system that relies on LEO (low earth orbit) and GEO (geosynchronous earth orbit) satellites, and in the near future MEO (medium earth orbit) satellites including GPS. Discussed in this paper are measurements made with the GEO ground user terminal (GEOLUT) in the SARLab at the NASA Goddard campus. . Until recently geolocation was possible only with LEO satellites using Doppler techniques. Since the GOES spacecraft are in geosynchronous orbit, the Doppler cannot

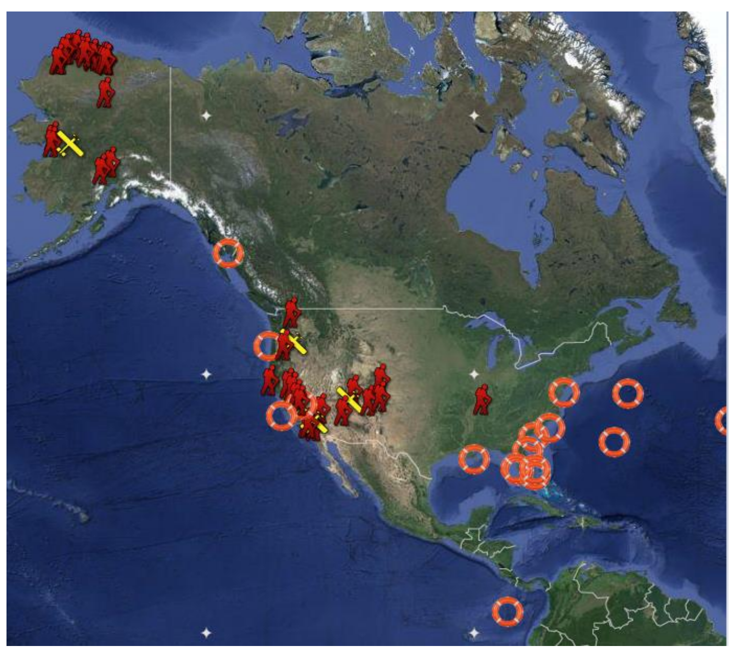

**Figure 1: Western Hemisphere SARSAT rescues in 2014 (ref 1)**

be used. GEO satellites, although they cannot be used for geolocation, provide near instantaneous alerting. With the increased use of GPS, locating the transmitter in real time with Geo satellites is possible.

To illustrate the importance of this service, Figure 1 is a graphic from the NOAA website showing the number of rescues in the Western Hemisphere through July 2014. This system has saved over 37,000 lives since 1982.

Figure 2 shows an overview of the entire system.

The measurements presented here are for the 406 MHz distress beacons and the digitally encoded identification information they transmit.

The beacons transmit an approximately 1/2 second burst signal with a digital message once every 50 seconds until the batteries run out of power. The beacons are low cost, light weight and hence low power transmitters. To recover these weak signals, GEOLUTS integrate multiple received bursts until either a successful message decoding is achieved or failure declared.

When beacons are activated in the field, they have an arbitrary orientation reducing their antenna gain and obstructions may also adversely impact the signal. SAR typically asks projects to use a $5*10^{-5}$ BER to allow for simple testing using PRN codes. To run a BER test through the whole link as was done in this test requires a more complex undertaking as the beacon simulator and GEOLUT equipment are not easily transportable.

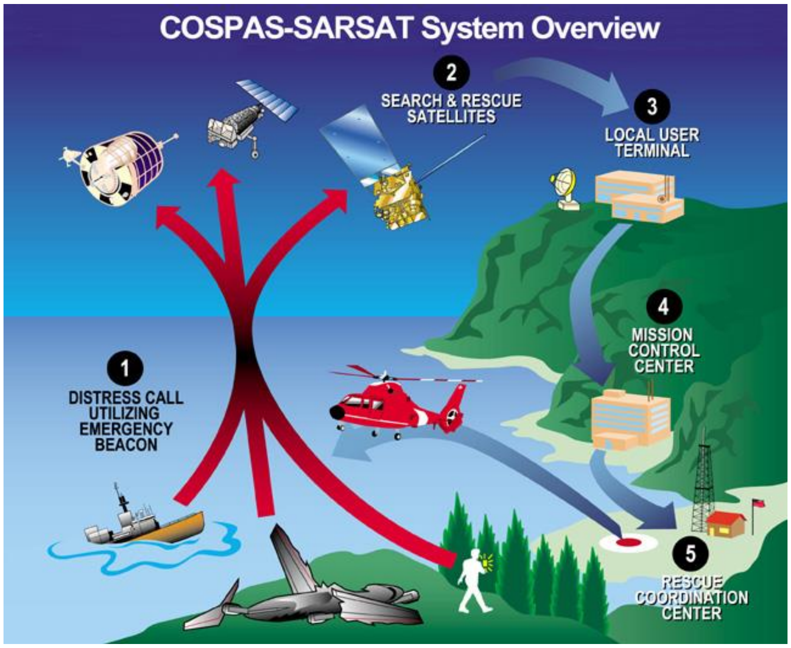


**Figure 2: Overview of the Search and Rescue System (Ref 2)**

## Test Description

System performance tests were conducted at the Search and Rescue Laboratory (SARLab) at NASA Goddard using beacon signals sent through a high fidelity satellite transponder simulator and successfully received by SAR operational ground equipment.

The Search and Rescue Mission Office and the GOES-R program used a beacon simulator, spacecraft engineering design units (EDUs), and GEOLUT to make a high fidelity test of compatibility. This allowed the tests to take place at the Goddard SARLab and avoided impacting the overall spacecraft build schedule that using the actual spacecraft would entail.

The SARLab used a Beacon simulator, a high fidelity emergency beacon emulator which produces short and long messages at different frequencies and power levels as needed to suit the purposes of the test to send beacon signals. A high fidelity spacecraft simulator and the SARLab's GEOLUT were to test whether the new design could result in a successful beacon reception and message decoding by the GEOLUT and measure the effect of integration gain on the received messages.

The availability of the EDU was limited as the support electronics and support staff were also needed for the GOES fabrication. To minimize the impact of satellite development, the The SARLab team also developed and built a GOES-R satellite simulator using commercially available components which greatly helped with both the procedure development and the actual EDU test as many problems were discovered and resolved long before the EDU components showed up.

The data desired was the percentage of successful message decodings vs. the GEOLUT received C/No. The test was set up to first calibrate the C/No of the radio frequency link which was critical; although the GEOLUT reports a C/No, its accuracy was unknown. A more complete description of the calibration process is discussed in the detailed test set up section.

Therefore the test procedure was run first using the SARLab's satellite simulator and then through the engineering satellite transponder equipment (EDU) with and without message integrations to determine the overall integration gain. A comparison was also performed with the GOES-13 operational spacecraft which does have an on board re-modulator. Those results are shown in figure 6.

GEOLUT message Integration was first described in a paper written and presented in 1988 (Ref 4). The paper described the method of integration considering three factors: frequency, time and cross correlation so that only bursts from the same beacon are integrated together. The paper went on to describe in detail the three factors but it did not show any results on integration gain actually achieved. Briefly, before two bursts can be integrated, they must match closely in frequency (<10 Hz), satisfy a time difference constraint imposed by the 50 second burst repetition period and finally satisfy a cross correlation computed by a (complex conjugate) dot product of the two bursts and comparing the magnitude to a threshold. Once it passes thee three tests, the bursts from the same beacon and can be integrated. However the paper did not consider how the bursts from the integration process would be counted. This facet is addressed in detail later in the paper since it affects the calculated integration gain.

**Message Details and Test Procedure Design**

This section describes the Cospas-Sarsat message structure, the GEOLUT requirements, how the GEOLUT works, how integration works and will introduce two approaches to how the integrated results are counted and the test procedure used.

1. *Cospas-Sarsat Message Structure*

This test utilized what Cospas-Sarsat calls a short message, 112 bits in length. It is comprised of:

- (bits 1-15) 15 bits of alternating 1's and 0's for receiver demodulator acquisition
- (bits 16-24): a 9 bit frame sync pattern which is uncoded
- (bits 25-85) A protected (coded) data field of 61 information bits known as PDF1
- (bits 86-106) A 21 bit BCH check bit field, known as BCH1 for the employed (82, 61) BCH1 code. This is a shortened (127,106) BCH code that has the capability of correcting 3 bit errors.
- (bits 107-112) Last 6 bits are not protected and have a variety of uses.

The GEOLUT used in the test is a model GEOLUT-600, originally build by EMS Technologies of Ottawa Canada, now part of Honeywell. This report will focus on the features unique to this GEOLUT. There are other GEOLUT vendors, who may do things differently so the results in the paper only apply to Honeywell (EMS) GEOLUTs.

2. *Cospas-Sarsat GEOLUT Integration Process*

Cospas-Sarsat put a number of processing requirements in a functional specification (C/S T.009, Ref 3) that all GEOLUTS must comply with. The are details on the integration process are:

- The 9 bit frame sync pattern is unprotected (uncoded) and must be received perfectly in order for further GEOLUT processing to occur. Any burst that have errors in the frame sync pattern are discarded.
- The message is valid when there are 2 or fewer errors in the part of the message consisting of PDF1+BCH1. Note this is less than the 3 error correcting capability of the BCH code.
- Integration is allowed but it is not defined in the relevant Cospas-Sarsat documents. When it is done, it must follow certain procedural and reporting requirements. This allows for different algorithmic implementations of this function. It also does not specify how the integrations are to be counted which allows for multiple interpretations.
- The number of integrations must be reported.
- If there is no activity for 20 minutes from a beacon, any integration data is cleared.

The process of the Honeywell (EMS) GEOLUT on message integration is shown in figure 3

**Issue on how the number of integrated messages are counted**.

The GSFC Search and Rescue Mission Office has currently two options on how the integrated messages are counted, as there is no Cospas-Sarsat standards or requirements in this area. Both are described below.

The first method is to count all resulting messages from the integration process. For example, if 8 received bursts occur prior to a successful message decoding, then one counts the 8 resulting digital messages as 8 message acquisitions. Note the Honeywell GEOLUT fills in each of the 8 bursts with the identical successfully decoded message.

The second method is to count only one resulting message. Using the above example, there is only one successful decoding of the 8 integrated bursts one counts only the one successful decoding as the one message acquisition. While the other 7 bursts will have the same decoded digital message in this Honeywell GEOLUT, they are not independent of the one countable message burst.

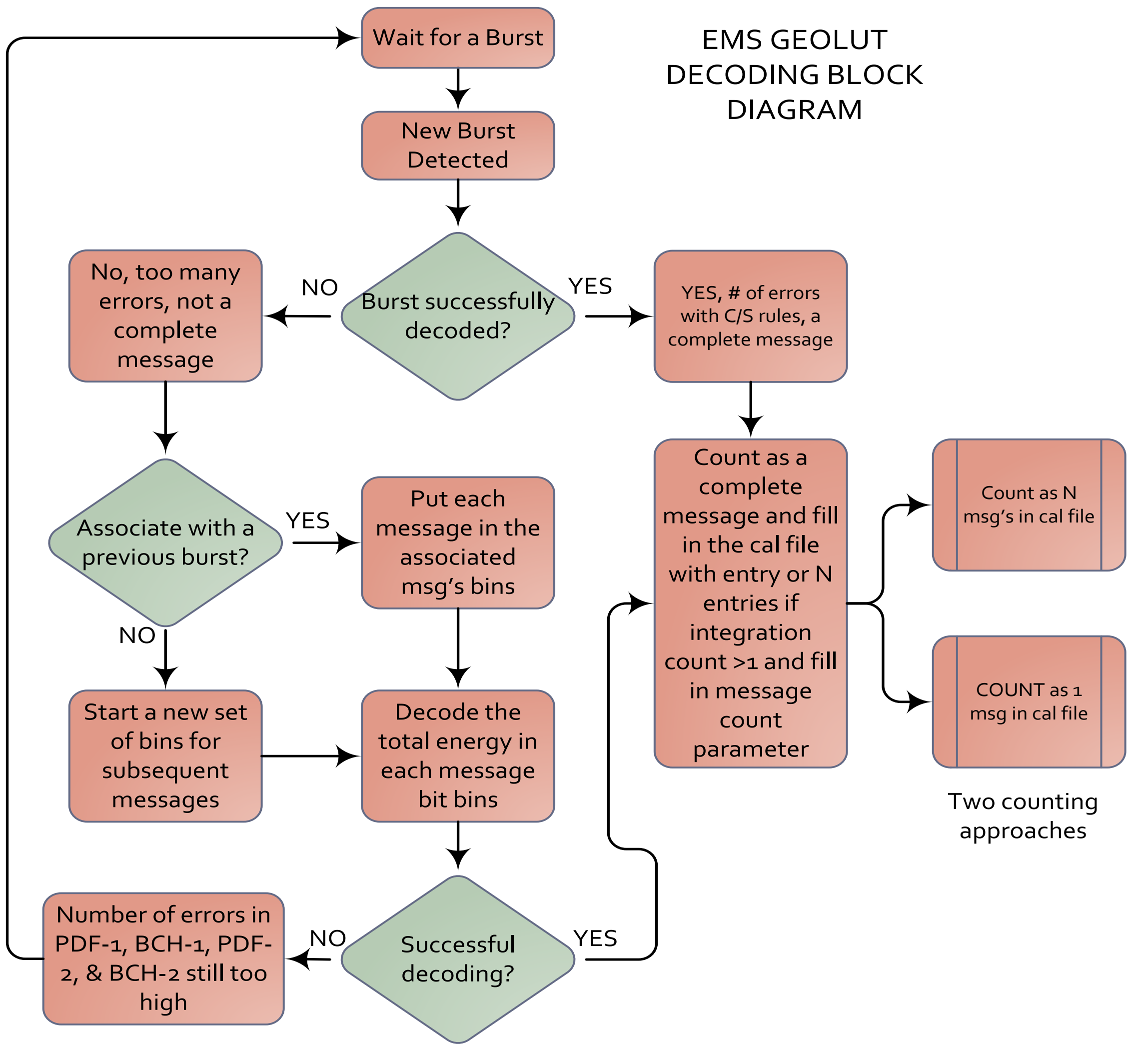


**Figure 3 Signal and decision flow for SAR short message**

While neither method is more correct than the other, the first method is easier to perform data reduction as one doesn't have to group all the integrated burst together and only count one of them. There is no Cospas-Sarsat specification concerning this issue, so another GEOLUT vendor may implement integration by a completely different method.

## Test set up

Figure 4 shows the test set up with the SARLab's satellite simulator as a substitute for the EDU to develop test scripts. This configuration was used to calibrate the test set up prior to EDU arrival. During the actual compatibility test, the configuration shown in Fig. 5 was used- substituting the GOES-R EDU for the SARLab's satellite simulator. Since this equipment is on the test bench, signal and noise levels must be set as if the transponder were in space. The uplink attenuators shown in Figures 4 and 5 ensure the beacon transmitted noise and signal levels are the same for the SARLab's satellite simulator and EDU transponder inputs. Similarly the noise and signal levels at the receiver in the GEOLUT are also carefully set with the downlink attenuators so that the SARLab's satellite simulator configuration matches the expected levels from the EDU and the real satellite.

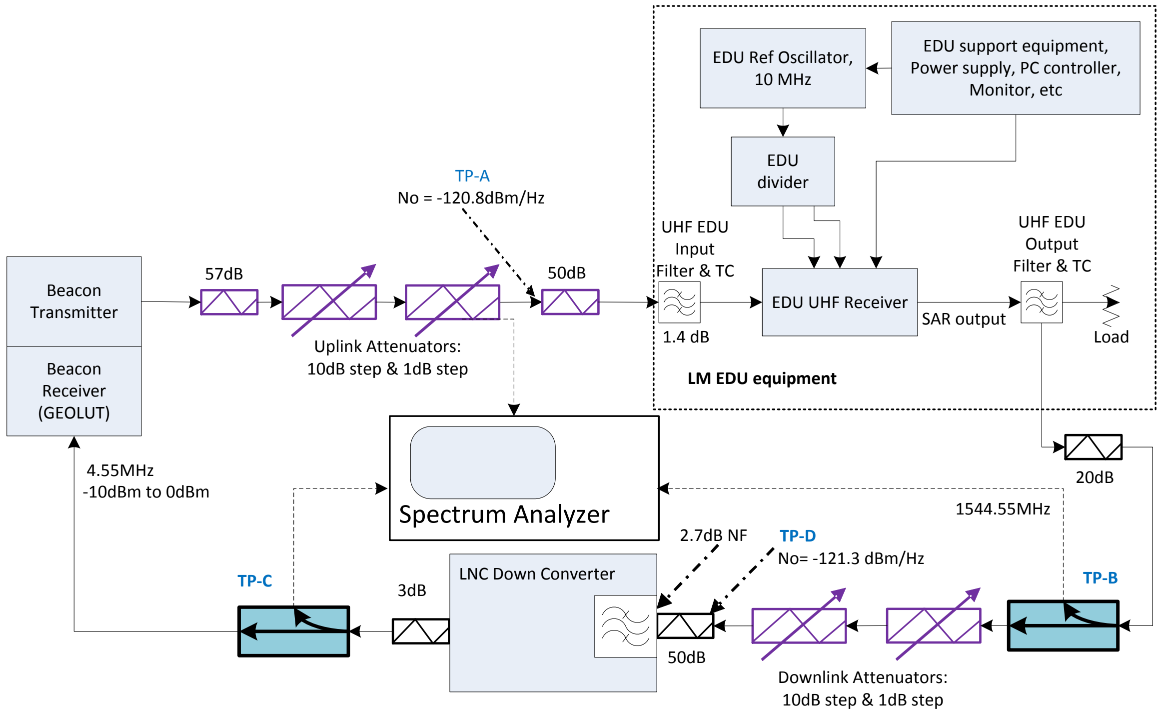


**Figure 5: SARLab's test set up to check out EDU test transponder**

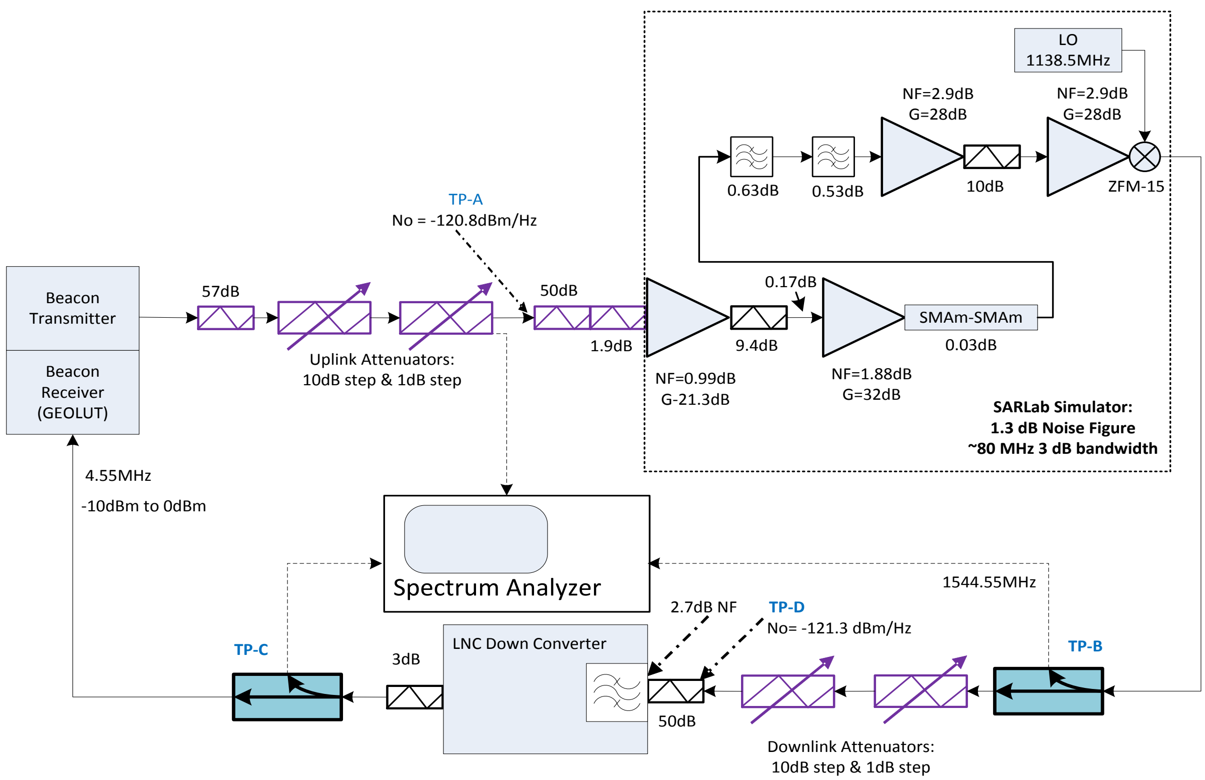


**Figure 4: SARLab's test set up to check out their Satellite Simulator**

Test equipment calibration gives the releation between uplink attenuator settings and C/No as measured at test point C (TP-C). Figure 6 shows the calibration curves for each test point shown in Figure 4 vs the uplink power into the SARlab's satellite simulator.

The upper right box in figure 4 shows the items that make up the SARLab's satellite simulator design. The rest of the figure shows the test set up to test the satellite simulator.

Similarly, figure 5 shows the test setup with the EDU equipment replacing the satellite simulator. C/No was rechecked at TP-A, B and C again to ensure accurate results, and were in fact very similar to the C/No measurements with the SARLab's satellite simulator.

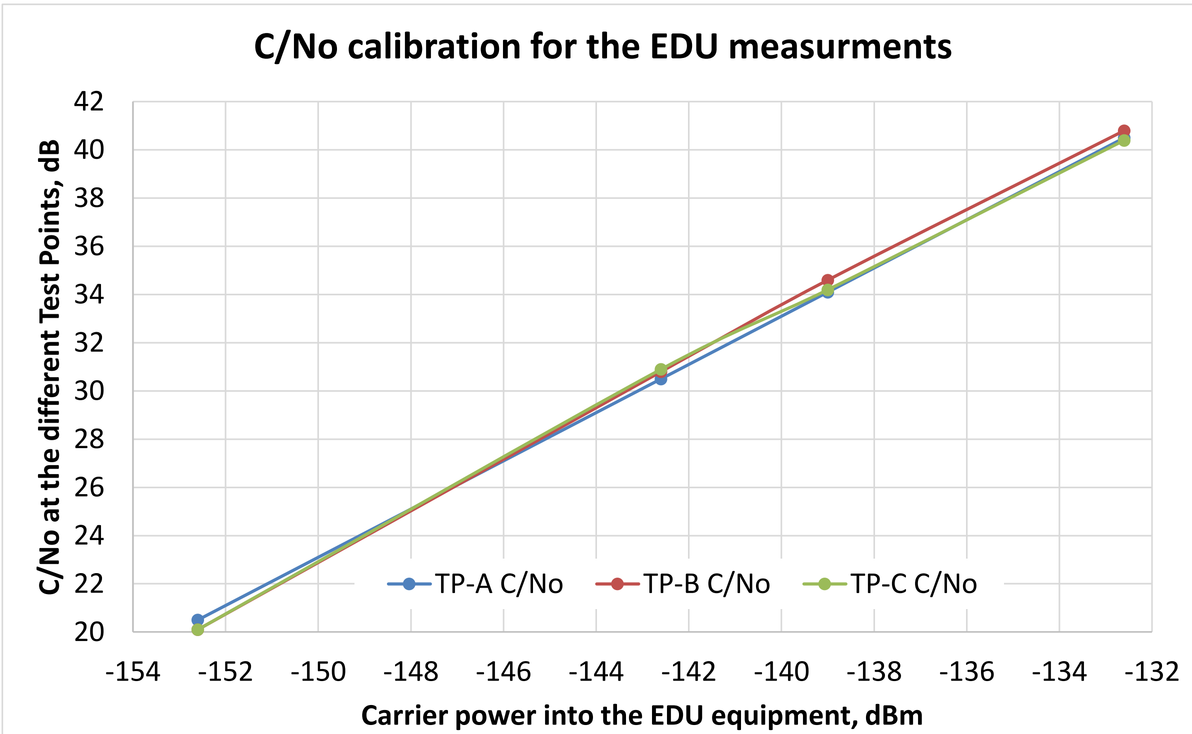


**Figure 6: Calibration curves for each test point**

## Results

Figure 7 shows comparison of results with the SARLab satellite simulator, GOES-R spacecraft EDUs, and over the operational GOES-13 spacecraft in orbit using count method 1. This was done to check the overall performance of the SAR service of GOES-R with the current GOES-N series (GOES 13, which has on-board re-modulation.

1000 messages were used to give a reasonable statistical result, although there were still some statistical blips as expected.

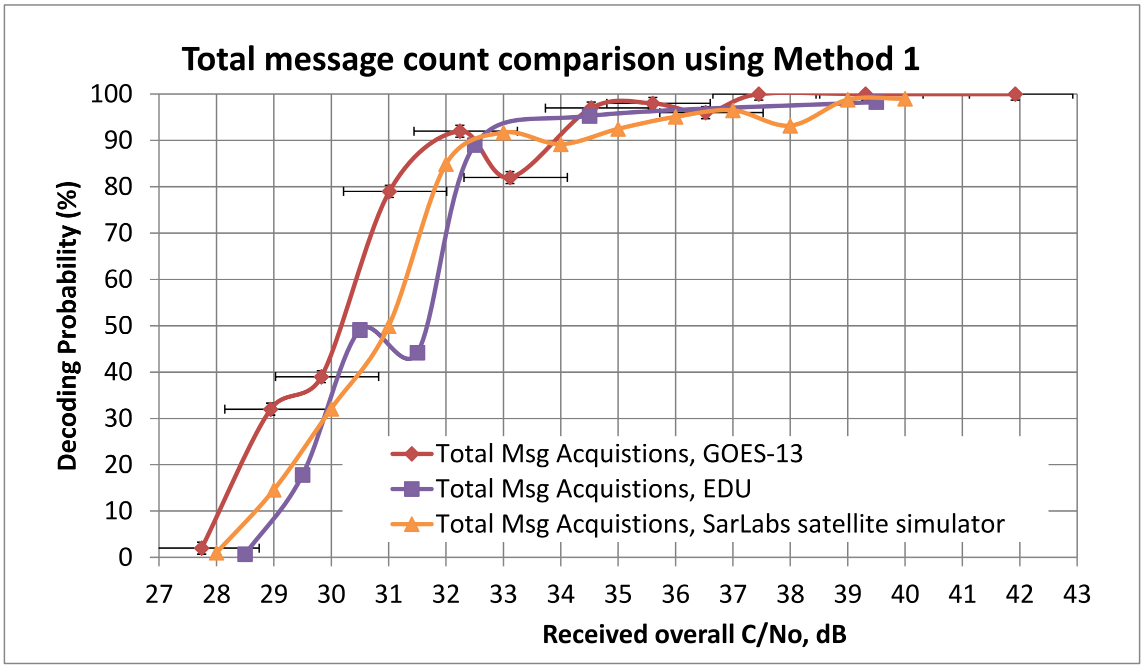


**Figure 7, Comparison of integrated message data**

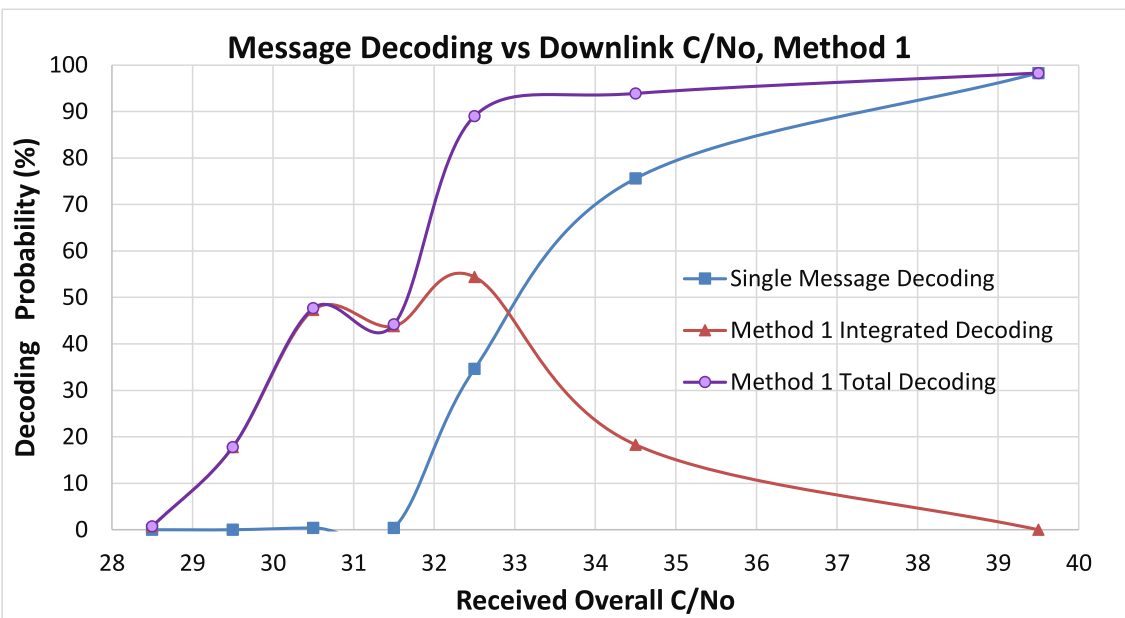


**Figure 8, Integration results from the EDU measurements using method one – counting all integrated messages as separate messages**

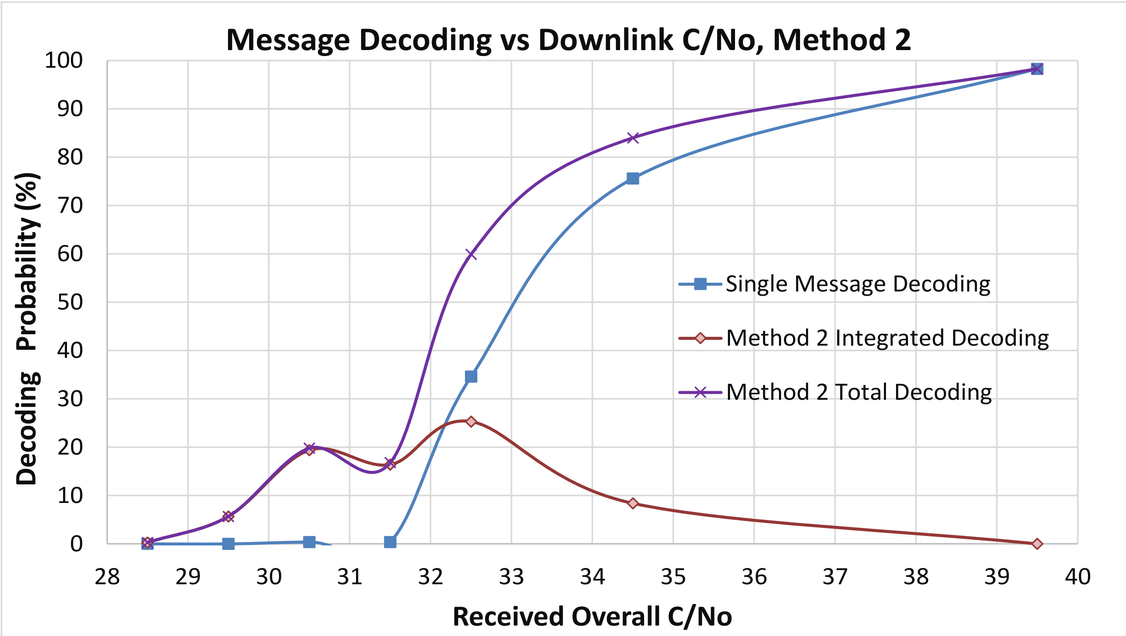


**Figure 9: Integration results from the EDU measurements using method two - counting all integrated messages as one message acquisition**

In figure 8, one can see that the integration gain using method 1 maxes out at about 3.5 dB, and in figure 9 the integration gain using method 2 maxes out at about 1.5 dB.

In addition the C/No results verified the 1.3dB Noise Figure of the EDU UHF receiver. Also as expected the EDU receiver worked well below the Cospas-Sarsat minimum specified uplink power of -139 dBm.

This result has been confirmed by the SARLab running another test in April 2014 using only the SARLAb's satellite simulator. In that test, measurement points were taken every 0.5 to 1 dB steps in C/No to generate more complete curve instead of the 6 points taken in this EDU test. Those results are shown below in figure 10.

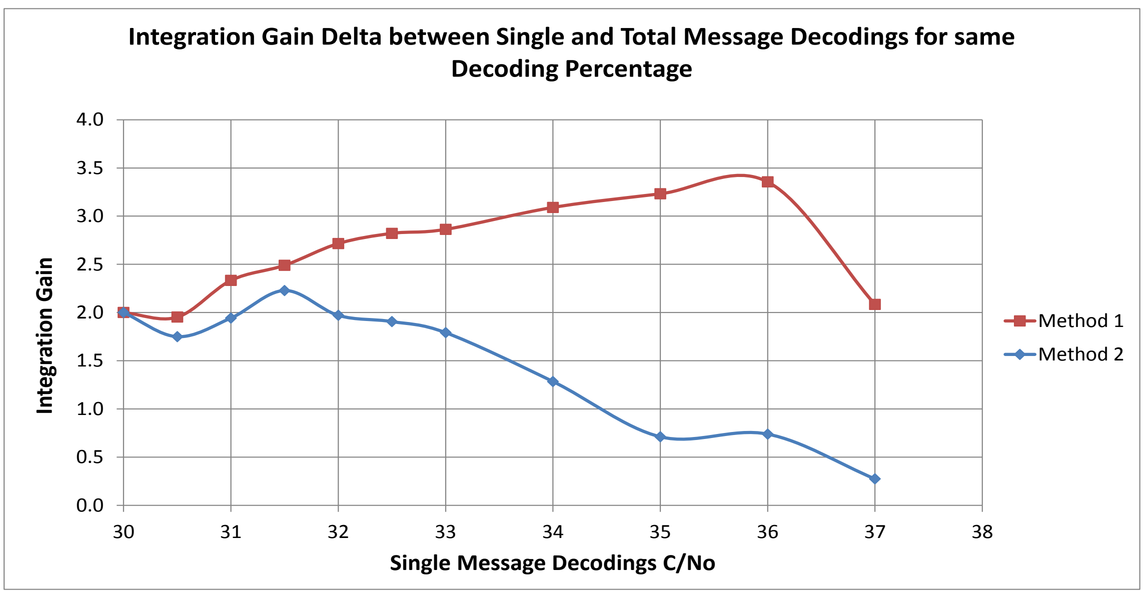


**Figure 10, Further Measurements with the SarLab's Satellite Simulator**

## Conclusion

This is the first time the SAR transponder has ever tested prior to launch, it is the first test through a bent pipe satellite transponder (no on-board re-modulation), and the first measurement of integration gain. The test confirmed that the required performance will be met. SARLab developed new tool – a satellite simulator which proved its value in the procedure development process.

Since the message is made of coded and uncoded components, calculating the theoretical BER for a given C/No is not simple even without considering integration gain. The major LUT vendors claim not to have run performance tests. Cospas-Sarsat has minimal specifications on how it should be accomplished and reported. In the development leading up to the EDU test, the SARLab developed two possible approaches counting the integrated bursts.

A final note to reiterate that this conclusion only applies to Honeywell GEOLUTs. Other vendors GEOLUTs may present the data differently and may or may not show all the bursts that went into an integrated detection. This issue is external to the GOES–R project and deserves further study by Cospas-Sarsat to ascertain which approach will yield more realistic result when the satellite is launched.

## Acknowledgments

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[2]http://www.sarsat.noaa.gov/satellites1.html

[3]http://www.cospas-sarsat.int/en/documents-pro/system-documents

Specifically the T.001 and T.009 documents

[4]Flikkema, P.G.; Davisson, L.D.; Sessions, W.B., "The US SARSAT geosynchronous experiment: ground processor description and test results," *Satellite Systems for Mobile Communications and Navigation, 1988., Fourth International Conference on* , vol., no., pp.203,207, 17-19 Oct 1988