# EGNOS TRAN: Broadcasting EGNOS messages over the Eurofix datalink

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## Biography

Gerard W.A. Offermans received an M.Sc. degree in Electrical Engineering from the Delft University of Technology in 1994, and a Ph.D. from the same university in October 2003. Together with Mr. Arthur Helwig he developed, implemented and prototyped the Eurofix system. Gerard Offermans is author of over 20 papers on radio navigation, for some of which he received the Best Student Paper award. Currently, he uses his specialized knowledge on Eurofix, Loran-C and satellite navigation as Technical Director of Reelektronika for a number of projects, among which implementation of Eurofix in NELS, the integration of Loran-C and Chayka in a European Commission's Tacis project, and the development of the European satellite system Galileo in the GALA project. Mr. Offermans is chairman of the ILA GAUSS Standardization Group, a group under the wings of the International Loran-C Association, which encourages the use of integrated radionavigation systems based on GNSS and Loran-C/Chayka technology through documents for standardization and information of such systems.

Professor Durk van Willigen retired in 2000 from Delft University where he held the chair on Electronic Navigation Systems for 11 years. He guided a group of students and scientists working on GPS and Loran-C signal processing, Eurofix. His group is taking part in NASA's Aviation Safety Program Synthetic Vision. He is now full-time CEO of Reelektronika, a small consultantancy on integrated navigation and radar, which he founded in 1975. Dr. van Willigen is the recipient of the Medal of Merit of the ILA (1996), the ION Thurlow Award (1999) and the Gold Medal of the Royal Institute of Navigation in 2000. In 1999 he became elected Fellow of the RIN. Prof. van Willigen is chairman of the Board of the GAUSS Research Foundation.

Arthur W.S. Helwig received an M.Sc. degree in Electrical Engineering form the Delft University of Technology in 1995 and a Ph.D. from the same university in October 2003. Together with Mr. Gerard Offermans he designed, implemented and prototyped the Eurofix system. Mr. Helwig is specialized in the software-receiver design, a novel concept for developing (integrated) navigation and communication receivers, where radio signals are A/D converted at high rates and digitally processed in software. Besides awards for a number of scientific papers on radionavigation systems, he also received national and international awards for his software development skills.

Jürgen Seybold, M.Sc. is Senior Advisor with TeleConsult Austria. From 1988 to 1997 Mr. Seybold was consultant/advisor with the German Civil Aviation Agency (DSF) in the ICAO AWOP. From 1994 to 2001 he represented his company in the RTCA, Euro-Sky and the Space-Forum of the German Aerospace Industries Association. Since 1998 Mr. Seybold is chairman of the Aviation Commission, and member if the Scientific Council of DGON.

Günther Abwerzger (1974) received his M.Sc. of Geodesy at Graz University of Technology in 2000. From 2000 to 2001 he was working for the Space Institute of the Austrian Academy of Sciences. In 2001, he joined TeleConsult-Austria where he has mainly been involved with software development in navigation. Currently, he is finishing his dissertation entitled "Integration of Loran-C and GNSS on raw-data level".

Antonio Salonico is a system engineer at Telespazio SpA (Italy). Coming from a satellite communication and TT&C background he is now the program manager of the EGNOS TRAN project. He holds a M.S. in electronic engineering from the University of Rome Tor Vergata.

## Abstract

EGNOS and WAAS DO-229 SBAS messages are intended for transmission data rates of 250 bps. To make the data also available in urban and polar areas where SBAS signals are often not available, it is in the ESA EGNOS TRAN program investigated whether the data set can be reduced so it matches the ITU-R Loran-C data broadcast channel specifications while not deteriorating the SBAS accuracy and integrity performances. Two approaches have been investigated: a local-area and a wide-area concept. In both concepts the basic EGNOS data was received through an EGNOS receiver installed at the Loran-C station at Sylt, Germany. The local-area concept converted the EGNOS DO229 into correction data for the location of the transmitter station. These data are then broadcast by Eurofix in the same way as it is done today with the pre-

sent DGPS service. The more advanced approach which offers good accuracy at large distances from the Loran-C station is a typical wide-area service. This required new data conversion algorithms to reduce the 250 bps EGNOS DO 229 SBAS data stream to a modest 30 bps data rate while maintaining good accuracy and integrity performance. New message types containing this wide-area information have been designed, and this system is also implemented at the Sylt station. Special receiver algorithms have been developed that can reconstruct from these special Eurofix message types a RTCM SC-104 DGPS message that can be applied by most commercial DGPS receivers. The large advantage of this approach is that it offers high position accuracy over a very large service area. The range of a Eurofix transmitter is up to 2,000 km. This means that such services may then become available in the Polar Region and in areas with restricted view to the SBAS satellites like in cities, forests and valleys.

The paper discusses the background philosophies of the data reduction process and it describes the resulting new message types. Finally, real-life measured DGPS performances from the Eurofix station at Sylt will be shown.

Telespazio has been the project manager of this ESA EGNOS TRAN project which successfully ended in June 2003. Reelektronika designed and implemented the system while TeleConsult Austria was in charge of all real-life measurements.

## Introduction

WAAS, EGNOS and SBAS are approaching the operational status rapidly, and many potential users may benefit from improved GPS accuracy, but more importantly from external integrity services. Originally planned as an augmentation service primarily for aviation, it is now trying to acquire a broader user group, especially the huge land application markets.

As the differential range- and rang-rate data as well as the integrity data are brought to the user via geo-stationary satellites broadcasting GPS-like signals in the L1 band, users in urban or mountainous environments suffer from frequent shadowing of the SBAS satellite signals. Identical problems are encountered in the Polar Region, an area rapidly increasing in importance due to polar flights between the US, Europe and Asia.

To reduce the signal's shadowing problem it has been investigated by US and European scientists whether the transmission of augmentation data through additional time modulation of the Loran-C pulses could help to overcome the problem. Loran-C signals do penetrate city canyons quite easily, and the Polar Region can also be covered by joining the American, Canadian, Russian and European Loran-C/Chayka stations as a wide area data provider in addition to the regular SBAS services. United States' and European researchers had two different approaches in respect of the method to broadcast data via the existing Loran-C infrastructure. In Europe, Eurofix with its 30 bps data broadcast providing DGPS and integrity data is on air since 1997. Its modulation technique is now described in the RTCM SC-104 standard, as it is in the ITU-R Recommendations M.589-3. The Eurofix data rate does not meet the WAAS or EGNOS data rate of 250 bps. For that reason US researchers preferred more complex modulation techniques on the Loran-C signals allowing 250 bps to meet the WAAS requirements. As there is a relation between data throughput, deterioration of the Loran navigation performance, and maximum range and reliability of the data transfer, it is quite complex to suggest a solution that can meet all requirements. This is one of the reasons that the US and Europe preferred different solutions.

Due to the large discrepancy between the needed and the available data rates of WAAS/EGNOS and Eurofix, respectively, the only remaining solution was to minimize the EGNOS data content as far as possible such that the wide area performance was maintained without exceeding the data rate capability of Eurofix.

## EGNOS Data Reduction

The limited Eurofix data rate of about 30 bps is well below the required 250 bps sent by the SBAS geo-stationary satellites. Three different solutions may still offer DGPS and integrity service to users. The first approach is to compute DGPS correction data from the received EGNOS data for the position of the Loran Transmitter station. This local-area technique is well known, and its performance is comparable with the performances of Eurofix and radio beacon stations. To minimize data latency the corrections are sent in an RTCM SC-104 type-9 structure. The major disadvantage of this technique is the loss of performance with distance from the station due to spatial decorrelation. As users can mostly receive at least three Loran-C stations simultaneously, and assuming that all stations broadcast local-area DGPS correction data, the user might combine the correction data from all stations in a RAAS like solution. So, this is the second solution which is not further investigated as already much work has been done on the topic. The third, and also the most interesting solution is broadcasting wide-area correction data derived from the EGNOS data derived either from a SBAS satellite or via the EGNOS data network. This forced the team to critically analyze the total content to the EGNOS data according to the RTCA DO229 standard to see which data could be left out or derived from Loran-C infrastructure parameters without deteriorating achievable accuracy and timely integrity warnings.

As Selective Availability was set to zero in May 2000, a major data rate saving can be obtained by reducing the update rate of the fast corrections of the measured pseudoranges of the GPS satellites. The next step was to provide only the information the user needs when in the coverage area of the used Eurofix station. This allowed a further reduction in the number of Ionospheric Grid Points, the related vertical Ionospheric Vertical Delays, and finally the number of satellites as only those satellites that may be in view of the user in the Eurofix coverage area around the transmitter (2,000 km range) are serviced.

This scrutinizing on data to send made that even with the rather low Eurofix data rate of about 30 bps position accuracies could be obtained that are not worse than that of EGNOS via SBAS. The EGNOS-based integrity information is broadcast in full through the same channel.

The Eurofix data broadcast standard allows 16 different message types. Three are allocated to broadcast DGPS and DGLONASS messages in an RTCM SC-104 compatible format, one is assigned to a short message emergency broadcast, while other messages can be implemented, such as UTC timing synchronization and Differential Loran-C services. Type 8 has been allocated to the transmission of EGNOS TRAN (ETRAN) data. The ETRAN message type is further divided into 8 different sub types, called ETRAN Types.

The five tables below list the way the transmissions of the EGNOS TRAN data are structured.

**Eurofix type 8**
**ETRAN type 0 – Do not use**

Source : EGNOS message 0

| Field | Bits | # bits | Units | Range |
|---|---|---|---|---|
| Eurofix Type | 1-4 | 4 | | 16 |
| ETRAN Type | 5-7 | 3 | | 8 |
| Body (all zeroes) | 8-56 | 49 | | |
| CRC | 57-70 | 14 | | |

**Eurofix type 8**
**ETRAN type 1 – Fast correction (2 satellites/message)**

Source: EGNOS message 2, 3, 4, 5 (fast corrections)

| Field | Bits | # bits | Units | Range |
|---|---|---|---|---|
| Eurofix Type | 1-4 | 4 | | 16 |
| ETRAN Type | 5-7 | 3 | | 8 |
| Satellite ID | 8-15 | 8 | | 256 |
| Fast correction | 16-27 | 12 | 0.125 m | -256 – 255.875 m |
| UDREI | 28-31 | 4 | | 0-16 |
| Satellite ID | 32-39 | 8 | | 256 |
| Fast correction | 40-51 | 12 | 0.125 m | -256 – 255.875 m |
| UDREI | 52-55 | 4 | | 0-16 |
| Spare | 56 | 1 | | |
| CRC | 57-70 | 14 | | |

**Eurofix type 8**
**ETRAN type 2 – Fast and slow correction (1 satellite/message)**

Source: EGNOS message 2, 3, 4, 5,(fast corrections)
EGNOS message 25 (slow corrections)

| Field | Bits | # bits | Units | Range |
|---|---|---|---|---|
| Eurofix Type | 1-4 | 4 | | 16 |
| ETRAN Type | 5-7 | 3 | | 8 |
| Satellite ID | 8-15 | 8 | | 256 |
| Fast correction | 16-27 | 12 | 0.125 m | -256 – 255.875 m |
| UDREI | 28-31 | 4 | | 0-16 |
| IOD | 32-39 | 8 | | 256 |
| δaf0 | 40-50 | 11 | 2-31 s | 2-21 s |
| Spare | 51-56 | 6 | | |
| CRC | 57-70 | 14 | | |

**Eurofix type 8**
**ETRAN type 3 – Slow correction (1 satellite/message)**

Source: EGNOS message 25 (slow corrections)

| Field | Bits | # bits | Units | Range |
|---|---|---|---|---|
| Eurofix Type | 1-4 | 4 | | 16 |
| ETRAN Type | 5-7 | 3 | | 8 |
| Satellite ID | 8-15 | 8 | | 256 |
| IOD | 16-23 | 8 | | 256 |
| δaf0 | 24-32 | 9 | 2-31 s | 2-23 s |
| Δx | 33-40 | 8 | 0.250 m | -32 – 32 |
| Δy | 41-48 | 8 | 0.250 m | -32 – 32 |
| Δz | 49-56 | 8 | 0.250 m | -32 – 32 |
| CRC | 57-70 | 14 | | |

**Eurofix type 8**
**ETRAN type 4 – Ionospheric grid**

Source: EGNOS message18 (Ionospheric grid mask)
Eurofix station coverage area & grid points in view

| Field | Bits | # bits | Units | Range |
|---|---|---|---|---|
| Eurofix Type | 1-4 | 4 | | 16 |
| ETRAN Type | 5-7 | 3 | | 8 |
| Grid Sub ID | 8-9 | 2 | | 4 |
| Total Subs | 10-11 | 2 | | 4 |
| IODI | 12-13 | 2 | | 0-3 |
| IGP mask bits | 14-53 | 40 | | |
| Spare | 54-56 | 3 | | |
| CRC | 57-70 | 14 | | |

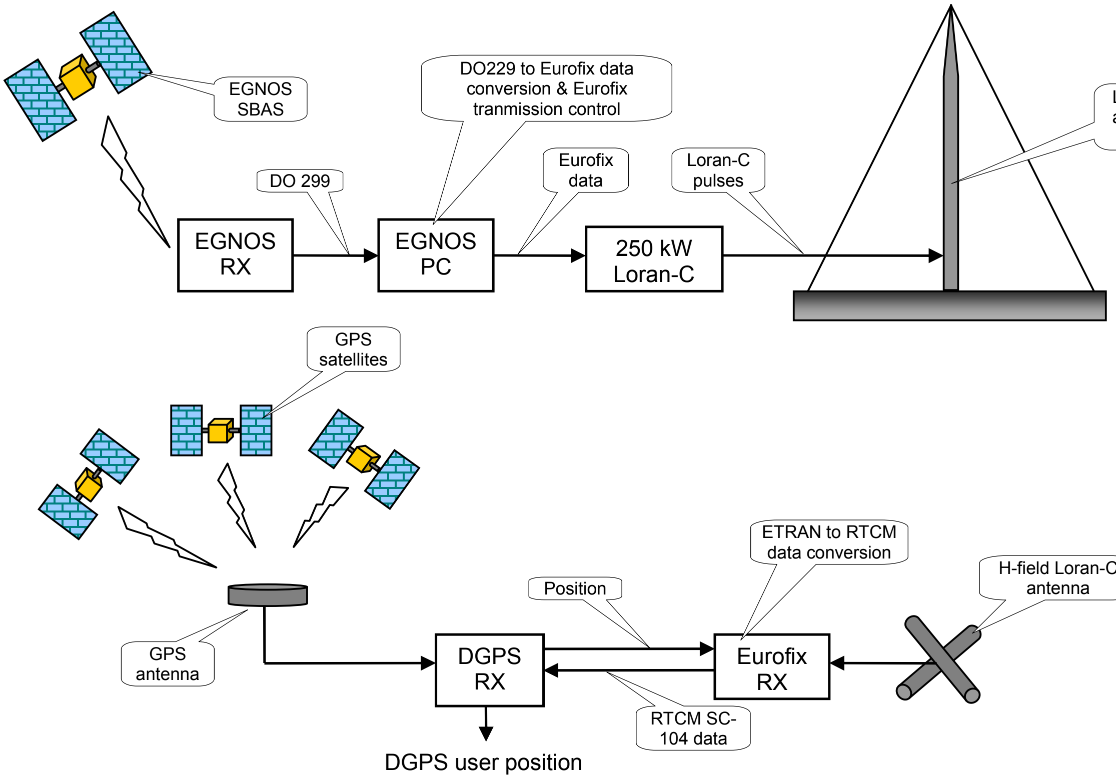

*Figure 1 – ETRAN Wide-area system setup*

**Eurofix type 8**
**ETRAN type 5 – Ionospheric grid delay parameters (3 IGPs/message**

Source: EGNOS message 26

| Field | Bits | # bits | Units | Range |
|---|---|---|---|---|
| Eurofix Type | 1-4 | 4 | | 16 |
| ETRAN Type | 5-7 | 3 | | 8 |
| IODI | 8-9 | 2 | | 0-3 |
| First Grid point | 10-17 | 8 | | 160 |
| IGP vertical delay estimate | 18-26 | 9 | 0.125 m | 0-63.875 m |
| Grid IVEI | 27-30 | 4 | | 0-15 |
| IGP vertical delay estimate | 31-39 | 9 | 0.125 m | 0-63.875 m |
| Grid IVEI | 40-43 | 4 | | 0-15 |
| IGP vertical delay estimate | 44-52 | 9 | 0.125 m | 0-63.875 m |
| Grid IVEI | 53-56 | 4 | | 0-15 |
| CRC | 57-70 | 14 | | |

## Interleaving of ETRAN Data

The broadcast of the five different ETRAN messages is interleaved such that considering the dynamics of the ionospheric delays, and the satellite ephemeredes and clock errors the resulting position accuracy is approximately optimal while still meeting the alert time requirements for integrity messages.

A number of interleaving rules has been developed which is given below:

a. Two satellite corrections to one ionospheric correction are broadcast.

b. Two fast to one slow satellite corrections are sent. The fast corrections are in ETRAN type 1; the slow corrections are contained in ETRAN type 2 or 3.

c. One ionospheric grid (ETRAN type 4) to seven ionospheric grid positions (ETRAN type 5) is broadcast.

For the Eurofix ETRAN transmissions, a total of 113 IGP point are broadcast per Loran-C station. This means that 3 type-4 (grid) + 38 type-5 messages (IGP data) are interleaved 2 to 1. So, approximately 123 (= 3 times 41) messages must be sent before all IGP data is acquired at the user. As the update rate of one Eurofix message at the 6731 rate at Sylt equals to once per two seconds, an ETRAN cold-start acquisition time requires 246 seconds.

*Figure 2 – ETRAN receiver specially developed for the measurement campaign.*

*Figure 3 – ETRAN antenna setup. From left to right the antennae for the EGNOS SBAS, Eurofix integrity monitor, Eurofix data link monitor, and the Eurofix reference GPS receivers.*

As most Loran-C stations are dual-rated, the effective data rate will be increased nearly by a factor of two.

### Setup at Provider Side

The ETRAN wide-area system setup is shown in Figure 1. Via an EGNOS receiver the SBAS satellite provides the DO-299 data to the EGNOS PC. There the DO-229 data are unpacked and reformatted into the ETRAN Eurofix messages. These data are sent to the Eurofix pulse time-modulator which controls the firing of the high-power pulse generator in the transmitter. Figure 3 and 4 show the antennae and the equipment rack as installed in Sylt, Germany. At the receiver side the signals are first demodulated and decoded. Then the ETRAN messages are converted into standard RTCM SC-104 DGPS messages that can be interpreted by most DGPS receivers. The approximate position of the GPS receiver must be sent to the Eurofix receiver in order to calculate the optimum correction data for the position where the receiver actually is. Figure 2 depicts the modified Loran-C/Eurofix receiver as has been used throughout the measurement campaign.

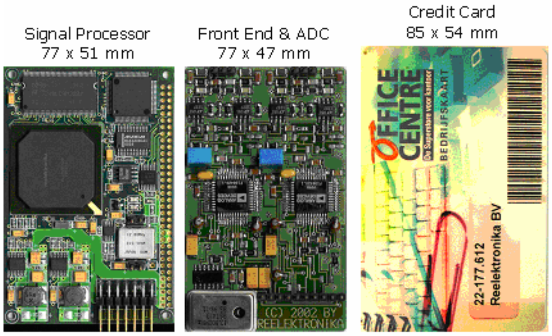

*Figure 5 – New DPS-based high performance integrated GPS/Loran-C/Eurofix receiver. Dimensions are approximately 77 x 51 x 20 mm.*

*Figure 4 – ETRAN equipment rack at Eurofix station Sylt, Germany. From top to bottom are EGNOS receiver, modem & power supply, ETRAN PC, Eurofix receiver & power supply, 2 GPS receivers & modem, CPU switch, integrity monitor PC, Reference station PC, and a UPS at the bottom.*

This rather simple and straight-forward setup providing true wide area DGPS service has an enormous coverage area. By installing ETRAN on all European or American Loran-C stations, both continents will be fully covered. As the costs are low, this can be a powerful backup for the SBAS service in all areas where the user experiences SBAS outages.

### Measurements

Extensive tests have been carried out in the Netherlands, Germany and Sweden to analyze the performance of the local-area as well as of the wide-area ETRAN concept. The results highly depend on the local reception conditions of the GPS signals. If the signals suffer from multipath or shadowing, then ETRAN can not improve the results. The ETRAN system showed that in many areas where the SBAS signals could not be received, like in urban areas or forests, the ETRAN signals could still be received and the EGNOS-based augmentation data decoded.

Table 1 gives some performance data of Eurofix, ETRAN, EGNOS and GPS acquired in Delft, the Netherlands. Availability of ETRAN is less than 100% due to the fact that ETRAN has to use the secondary rate of Sylt which is

*Table 1 – Some performance data of Eurofix, ETRAN, EGNOS and GPS acquired in Delft, the Netherlands.*

| **System** | | **Eurofix** | | | **ETRAN** | | | **EGNOS** | | | **GPS** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Numerical Results** | | N | E | Pos | N | E | Pos | N | E | Pos | N | E | Pos |
| General | Total # of observed epochs | 958 | | | | | | | | | | | |
| | Blunders | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Availability | Total # / percentage | 958 / 100% | | | 904 / 94.4% | | | 957 / 99.9% | | | 958 / 100% | | |
| | DGPS #/percentage | 958 / 100% | | | 904 / 94.4% | | | 957 / 99.9% | | | N/A | | |
| Total Position | # of meas. | 958 | | | 904 | | | 957 | | | 958 | | |
| | Mean | -1.11 | 0.15 | 1.12 | -0.30 | 0.04 | 0.30 | 0.41 | 1.14 | 1.21 | -2.34 | 0.38 | 2.37 |
| | Std dev. (1 sigma) | 0.42 | 0.29 | 0.51 | 0.66 | 0.52 | 0.84 | 1.29 | 1.54 | 2.01 | 0.50 | 0.41 | 0.64 |
| DGPS only | # of meas. | 958 | | | 904 | | | 957 | | | N/A | | |
| | Mean | -1.11 | 0.15 | 1.12 | -0.30 | 0.04 | 0.30 | 0.41 | 1.14 | 1.21 | N/A | N/A | N/A |
| | Std. Dev. | 0.42 | 0.29 | 0.51 | 0.66 | 0.52 | 0.84 | 1.29 | 1.54 | 2.01 | N/A | N/A | N/A |
| HDOP | Mean | 1.08 | | | 1.07 | | | 1.00 | | | 1.00 | | |
| | Std. dev. | 0.13 | | | 0.19 | | | 0.02 | | | 0.03 | | |
| COP (case A) | Failure | 0 / 0.0% | | | 0 / 0.0% | | | 2 / 0.2% | | | 0 / 0.0% | | |
| COP (case B) | Failure | 0 / 0.0% | | | 0 / 0.0% | | | 13 / 1.4% | | | 0 / 0.0% | | |

blanked. This made the link slightly less robust as quite some pulses were missing. As Sylt is about 400 km from Delft, spatial decorrelation is still very minor which made that the correctness of correction data for Delft from Eurofix and ETRAN are nearly equal.

Unfortunately, no tests have been carried out yet in the Polar Region where the contribution of ETRAN may show a very significant improvement over SBAS [1] [2].

The current developments on advanced Loran-C receivers in the United States as well as in Europe will aid to provide ETRAN capability with miniature equipment. As these ETRAN receivers are also full-blown high-performance Loran-C receivers, a powerful back-up for the navigation functionality is achieved too. Figure 5 shows a European development of miniature Loran-C/Eurofix receivers that could also decode the ETRAN signals.

## Conclusions

The tests and analyses have shown that a cost-effective and reliable backup service for WAAS/EGNOS SBAS services over very large areas can be obtained from supplying wide-area information derived from the WAAS/EGNOS networks via Eurofix or Loran-Comm to users in all areas where the SBAS services suffer from outages. Upgrading the existing Loran-C and Chayka stations in the US, Canada, Europe and Russia might also offer DGPS and integrity services in the Polar Region.

## Acknowledgements

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