NAVISP
EL1-065

NAVISP Element 1
Final Presentation
EL1-065 “e-Loran antenna for handheld devices”

European Space Agency

Background

- The following slides describe the work undertaken by Roke Manor as part of the European Space Agency’s NAVISP EL1-065 programme
  - Contract No. 4000141771/23/NL/RR/kg

- The aim of the task was to develop a miniature eLORAN antenna for hand-held applications.

- eLORAN antennas are traditionally very large. The **key risk** is that reducing the size of the antenna significantly reduces the performance.

- The project was divided into research and development tasks, with the final task resulting in the delivery of a prototype antenna to ESA.

Introduction to eLORAN

- eLORAN (Enhanced LOng RAnge Navigation) is a land-based navigation system, which has evolved from the LORAN system that was originally developed by the USA during WW2.

- The system consists of a of a network of high power, land-based radio transmitters that have traditionally allowed mariners and aviators to determine their position
  - The system focused mainly on the northern hemisphere

- With the advent of GNSS, the LORAN system was nearly phased out. However, with increasing incidents of GNSS jamming and spoofing, the interest in the system has once again intensified.

- Today, eLORAN is seen as a system that can complement GNSS services (e.g. in indoor/urban canyons/underground/dense foliage areas) while at the same time providing a high degree of redundancy during GNSS outage
  - It has a reported positional accuracy of ±8m

Introduction to eLORAN (2)

- eLORAN and its predecessor LORAN-C operate at a frequency of 100kHz in the LF band, with a signal bandwidth of 20kHz (20%).

- As with other wireless electrical systems, an antenna is used to receive the signal. In a conventional receiver with a resonant antenna, the antenna length is directly proportional to the signal wavelength. With a wavelength of λ=3000m, the conventional monopole antenna size is impractical.

- The following sections describe the results of the investigation and development of small eLORAN antenna for hand-held applications.
  - The project was divided over four Tasks, as per the ESA contract no. 4000141771/23/NL/RR/kg

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Research work

- The State-of-the-Art survey focused on looking at currently available (or potential) eLORAN antenna technologies with the final aim of selecting the best way forward for a new antenna design for hand-held applications.

- This then continued with putting forward the preferred eLORAN antenna option, followed by the firming-up of the design requirements.

Survey of the State of the Art (1)

- A survey into existing and potential technologies for eLORAN antennas was conducted by Roke.
- This involved solutions that had been previously identified (by Roke), as well as new solutions that may have emerged since the last survey was conducted.
- The solutions looked at are shown below:

Existing Roke Work	New Antenna Solutions
Short E-Field Whip Antenna	Magnetoelectric Antenna
Conventional Ferrite Rod Antenna	Dual eLORAN Antenna
Black Hole Antenna	
Zero-Impedance Antenna	
MILOR Antenna	

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Survey of the State of the Art (2)

- The Short E-field Whip Antenna
  - In general, they are most suited to applications where a short monopole can be mounted on a ground plane, for example on a car or ship. But can also be used in niche applications (hence not ignored)
  - Antennas must be placed away from any vertical conducting objects – this includes people (as this shorts the E-field).

- MILOR Antenna
  - UK Patent No. 2492463; 14 May 2014 (held by Roke Manor). Size = 50mm x 50mm x 35mm.
  - 20% bandwidth at 100kHz (that is needed for eLORAN applications).
  - Utilises two orthogonally placed ferrite rods (with circuitry) encased in an IP67 rated case.
  - Proven in field trials at eLORAN frequencies, but difficult to manufacture (low yields).

- Possible future technology:
  - Magnetoelectric Antenna

Trade-Off Analysis

- The research from the previous section was summarised and scored based on criteria that were indicative to the maturity of the technology and their potential use in handheld devices.

- The following criteria and sub-criteria (see table) were applied in the comparison (weighing) of the identified concepts.

POINT RATING	SIZE EFFICIENCY	MATURITY OF CONCEPT	SUITABILITY FOR eLORAN	SUITABILITY FOR HANDHELD
	Required sensitivity in:			
1	100 x 100 mm	Concept theory only	Not tested at LF	Not suitable
2	75 x 75 mm	Concept detailed in papers	Tested at LF, but not at 100kHz	Suitable in niche environments
3	50 x 50 mm	Concept used in lab	Tested at 100 kHz	Suitable in some environments
4	25 x 25 mm	Concept used in trials	Experimented with eLoran	Suitable in most environments
5	< 10 x 10 mm	Concept used in products	System test with eLORAN	Suitable in all environments

Trade-Off Analysis (2)

- The Short E-field antenna scores high in the ranking because of the maturity (and potential size) of the technology.
    - However, this type of antenna is not suitable for handheld applications, as they generally require a ground plane and that they need to be placed away from any vertical conducting objects (inc. people).

- Magnetoelectric antennas also score high, as the antennas are small (i.e. die-size). The disadvantage with this technology is that it is still in its infancy
    - Limited developments happening predominantly in lab-based environments

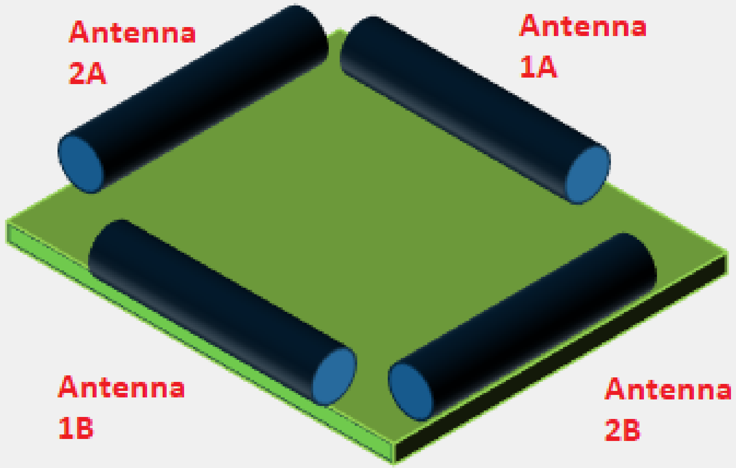
- The MILOR antenna, on the other hand, is more advanced design. It is small enough in size to be used in a handheld device, and its performance at the eLORAN frequencies has been proven in field trials.
    - The disadvantage of this is its repeatability in manufacturing in the current implementation.

Detailed Design

- One of the main drivers of the antenna design was to make the antenna more repeatable in manufacturing, especially if large quantities are required.

- The design utilised the same ferrite material as the MILOR design, but at a different length and diameter (40mm x 6mm).

- The new configuration decided upon was for two ferrite rods per channel (with two channels in total).
  - The two ferrite rods (per channel) double the induced voltage which gives an improvement on the SNR.



- Active circuit simulations were performed using the LTSpice software (from Analog).
  - With the rod antenna calculation being made in an Excel spreadsheet.

Detailed Design (2)

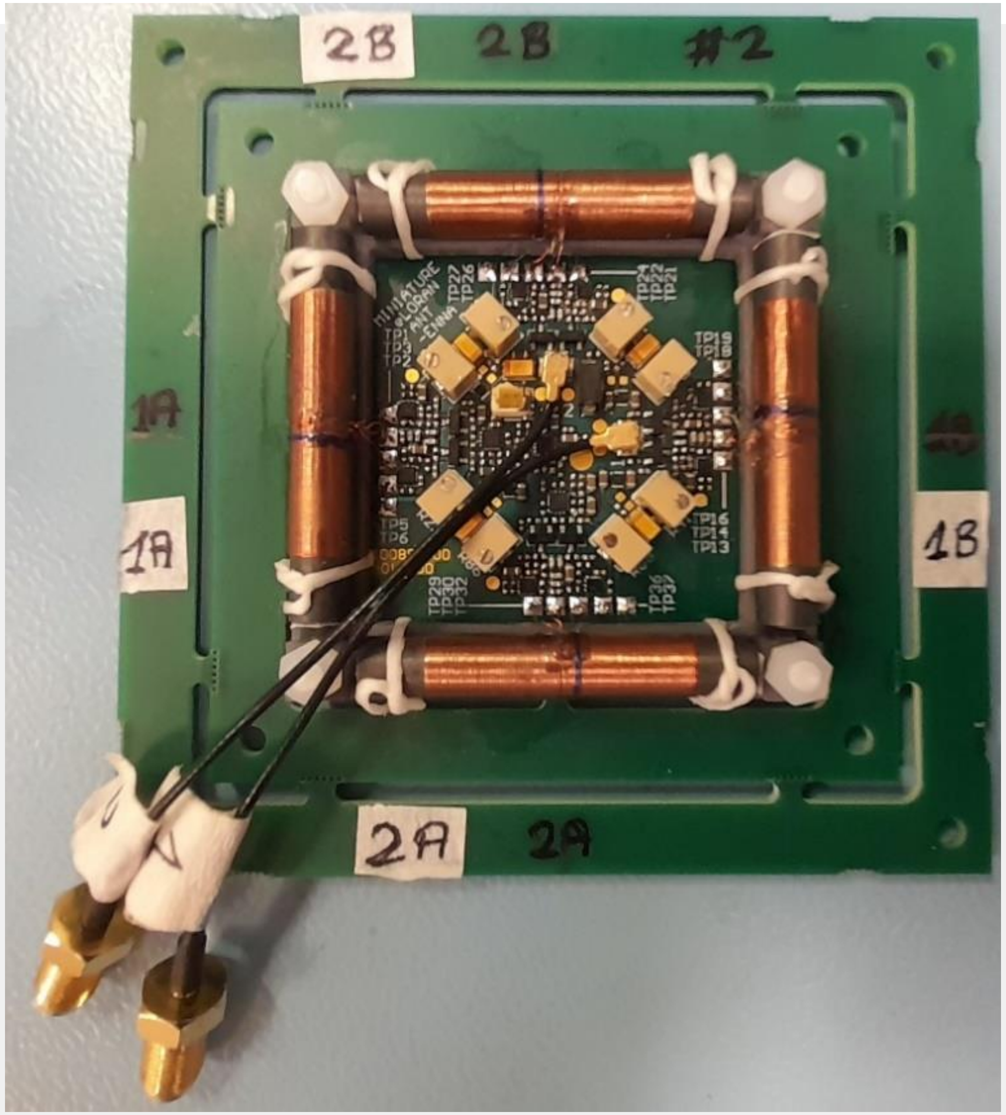
- In order to make the design robust and easy to manufacture, it was decided to use operational-amplifiers (only), with several amplifier stages.
- A low noise (best in the market) voltage regulator was also used
  - To regulate the slowly decreasing Lithium-Ion battery voltage
- All devices were from reputable manufacturers (e.g. Renesas, Analog, On-semi)
  - All devices are currently active and therefore unlikely to occur obsolescence issues in the near-future
- The choice and placement of the active devices in the design was made in a such a way as to minimise the overall current consumption
  - With an intended hand-held application, a Lithium-Ion battery power source was assumed (V_{DC}~3.6V).

Testing

- The plan was for all the testing to be carried out at Roke Manor, in Romsey (UK).
- Roke has extensive antenna testing facilities (CTIA, EMC) as well as various screened (Belling-Lee, High-Voltage-Testing-Facility) chambers that provide an ideal background for low noise measurements at LF.
- Roke also have a good stock of calibrated (RF and DC) test equipment that can be used to perform the required measurements.
- And more importantly, Roke have in their possession a custom screened chamber dedicated to the measurements of antennas at LF (~100kHz).
    - From previous MILOR development work.

eLORAN Antenna – Fully Assembled PCB

- The wound ferrite rods were then placed onto the PCB and the end wires were soldered on.
- At this stage, the testing of the eLORAN antenna could start.
- Most of the measurements were completed in a lab environment.
- With the exception of the noise floor measurements which were completed in a screened chamber.



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eLORAN Antenna – Testing

- The noise floor measurements (in the Belling-Lee chamber and the HVTF) are shown below.

Test Results Summary

- A full summary of the test results is shown below.

PARAMETER	VALUE	PARAMETER	VALUE
Antenna type	Dual-channel H-field	**Electric antenna factor**	< 25dB/m
Radiation pattern **(total of 2 channels)**	Omni-directional in azimuth	**DC Voltage**	3.6V nominal
Central frequency	100kHz	**DC Current**	24mA typical
Antenna bandwidth	20kHz	**Maximum external dimensions**	55mm x 55mm x 14mm
Equivalent noise referred electric field strength (10 kHz Bandwidth)	51dBµV/m	**Antenna RF connector type**	U.FL (or SMA via short adapter cable)
High-level signal without clipping	>110 dBuV/m	**Operating temperature**	-30 to 65°C (by design)

Summary

- The existing ROKE MILOR patented design was used as a springboard for the design of the new eLORAN antenna for hand-held applications.
- Strengths:
  - The design was implemented successfully with low SWaP and form-factor
  - The solution is ideally suited to a hand-held application.
  - The design is manufacturable.
- Weaknesses:
  - The sensitivity is slightly less than expected, but a solution has been found for the next iteration.
  - Fields of application:
  - Suitable for all application where reliable timing or positioning is required.
- Working with ESA:
  - ESA is at the forefront of GNSS research. eLORAN's role is as a backup for GNSS. Working with ESA ensures that eLORAN developments will fulfil this role is the best way.

Exploitation

- In the short term the antenna is likely to be made ready for field trials:
  - Encase antenna in a protective enclosure.
  - The enclosure to also include a Lithium-Ion battery.
- In the medium term, Roke plan to implement modifications to the antenna active circuit.
  - Aim being to further improve the antenna noise level and overall performance.
- Finally, the antenna is to be integrated with a dual-channel eLORAN receiver (EL1-080).
  - Initially to aid receiver testing.
  - But ultimately as a single integrated (hand-held) unit.

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