eLoran and Amateur Radio – A Study in Coexistence

Dr Paul Williams[1]
Professor David Last[2]
Dr Nick Ward[1]
[1] *General Lighthouse Authorities of Great Britain and Ireland (GLAs)*
[2] *Consultant to the GLAs*

Biographies

Dr Paul Williams: Dr. Paul Williams is a Principal Engineer with the Research and Radionavigation Directorate of The General Lighthouse Authorities of the UK and Ireland, based at Trinity House in Harwich, England. As the technical lead of the GLA's eLoran Work Programme, he is involved in planning the GLAs' maritime eLoran trials and works on a wide range of projects from real-time differential-Loran system development to the quality assurance of Loran ASF data. He holds BSc and PhD degrees in Electronic Engineering from the University of Wales, is a Chartered Engineer, an Associate Fellow of the Royal Institute of Navigation and is a board member of the International Loran Association.

Professor David Last: David Last is a Professor Emeritus in the University of Wales. He is the Immediate Past-President of the Royal Institute of Navigation and a former President of the International Loran Association. David is a Chartered Engineer who has published many research and policy papers on navigation systems and acts as a consultant on radio-navigation and communications to companies and to governmental and international organisations. He is an instrument-rated aircraft pilot and user of terrestrial and satellite navigation systems - and has been a licensed Radio Amateur for 50 years!

Dr Nick Ward: Dr. Nick Ward is Research Director for the General Lighthouse Authorities of the UK & Ireland, with responsibilities for radio-navigation and communications projects, including Automatic Identification Systems (AIS), as well as research & development strategy. He has been closely involved with the international standardization of Differential GNSS and AIS and was chair of the IALA Radio-navigation and AIS Committees. He is now vice-chair of the IALA e-Navigation Committee, is a Chartered Engineer and a Fellow of the Royal Institute of Navigation.

Abstract

Loran stations share the radio frequency band around 100 kHz with many other transmissions. Interference to Loran reception from communications signals is well understood and controlled. This paper, in contrast, examines the effect of Loran on a specific communications service: amateur radio operation at 136 kHz.

Loran transmissions are high-powered, and broad-band by low-frequency standards. Although most energy is confined between 90 kHz and 110 kHz, spectral lines can be detected over a much wider bandwidth. Radio amateurs transmit extremely low-powered, exceptionally narrow-band, signals over very long distances in their 136 kHz band (typically, 135.7-137.8 kHz). This paper investigates the effect of the new UK Loran station at Anthorn on 136 kHz reception in its area. It also examines the Radio Regulations of the International Telecommunication Union in respect of potential interference between these two services.

Measurements of Anthorn's emissions at a site approximately 30 km from the station are presented. Exceptionally, these allow the power radiated in each individual Loran spectral line to be estimated, at around both 100 kHz and 136 kHz. They confirm that there are no spurious emissions in the amateur radio band. The sideband energy radiated by Anthorn at 136kHz is just 50 microwatts per spectral line, or 6.8 milliwatts per kilohertz of bandwidth.

Even with these miniscule radiated power levels, though, the strengths of Loran spectral lines can exceed those of received amateur radio signals in the region around the station. Since worldwide this is a common situation, radio amateurs have developed innovative techniques for co-existence with Loran. These include directional receiving antennas and cancellation of the interference from local Loran stations. The paper will also show how radio amateurs now employ transmissions so

narrow that they can be slipped into gaps of a few Hertz between Loran spectral lines.

Given current studies of new eLoran stations world-wide, the feasibility of installing band-stop notch filters at 136 kHz in transmitters will also be discussed.

Introduction

Loran-C, and now Enhanced Loran (eLoran), occupy a broad spectrum centred on 100 kHz. They share a frequency band with many other services. Europe used to have more than a thousand transmissions between 50 kHz and 150 kHz, most of them of narrow bandwidth. A good deal of research has been devoted to the interference these signals cause to Loran reception.

These studies have shown that a carrier that falls on one of Loran's spectral lines causes much more interference than one that falls in between. The choice of Group Repetition Intervals (GRIs) for the Loran chains of the North-West European Loran-C System (NELS) took this into account. The GRIs are odd multiples of 10µs: an example is 6731, which is also the product of two prime numbers. These unusual GRI values were selected to minimise the number of Loran spectral lines that coincided with the many carrier frequencies of the Decca Navigator system. Decca Navigator has now gone from Europe, leaving a much quieter frequency band.

The research also demonstrated that Loran is more vulnerable to carrier waves than to broad-band noise interference. GPS is the other way round; this is yet another of the many ways in which Loran and GPS complement one another and avoid common failure modes.

Although much attention has been paid to interference by neighbouring services to Loran, there has been very little study of interference the other way round. Partly this is because such interference is rare: most of the neighbouring transmissions are high-powered signals with narrow receiver bandwidths that admit very little Loran spectral energy. But chiefly it is because these signals all lie outside the frequency range from 90-110 kHz which contains 99% of the Loran signal energy.

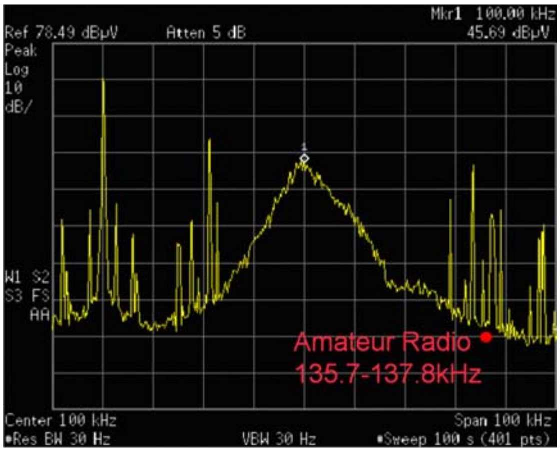

Figure 1: Spectrum from 50kHz – 150kHz

Interference by Loran to neighbouring signals

One service, however, did come under additional pressure in the United Kingdom when the new Loran station at Rugby first appeared in 2005, and subsequently its replacement at Anthorn, Cumbria, in 2007. This was the amateur radio service in the frequency band around 136 kHz. From Figure 1 it would appear that 136 kHz is so far from 100kHz as to be well down the skirt of the Loran spectrum, where there should be almost no Loran signal components. As we will see, that is indeed the case. However, radio amateurs using this band often radiate signals of very low power: below 1 W. Yet with these, they achieve transatlantic or even longer-range communications. The extremely weak signals received under those conditions may well suffer interference from a Loran transmitter close to the receiver.

Such interference has been reported in the region around Anthorn, accompanied by a complaint that the Loran station was radiating "spurious transmissions". In this paper we report an investigation into whether that allegation was correct.

Spurious and out-of-band transmissions

The ITU Radio Regulations are very precise on the subject of spurious and out-of-band transmissions [1].

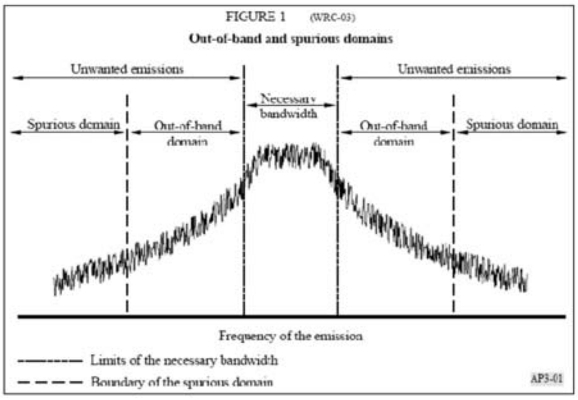

Figure 2: Spurious and Out-of-band transmissions (From [1])

Figure 2 shows the spectrum of a representative signal. The spectrum of “Unwanted emissions” includes “Out-of-band” power immediately outside the minimum necessary bandwidth.

This results from the modulation process. “Spurious” emissions are different: they include harmonics, parasitics, inter-modulation products, and frequency-conversion products: in short, unwanted components, which the designer can, and should, engineer out.

In respect of Figure 2, the ITU say that, for a signal of 20 kHz nominal bandwidth centred on 100kHz (such as Loran), the “spurious domain” lies below 60 kHz and above 140 kHz. Thus, the amateur radio band from 135.7-137.8 kHz, lies in Loran’s out-of-band domain. Any radiation within that amateur radio band from Anthorn cannot be “spurious”, but would be an out-of-band emission. It might, nevertheless, be a problem to those receiving extremely weak amateur radio signals.

Measuring the Anthorn spectrum

To determine the level of any such “out-of-band” emissions that Anthorn might be radiating, a precision spectrum analyser and calibrated loop antenna were set up at a test site in a quiet rural location, 33km from the station.

Figure 3 shows the spectrum measured there, from 50 kHz to 150 kHz. The Anthorn transmission, centred on 100 kHz, is clearly visible. Its spectrum has fallen away by 21dB at 90 kHz and by 16 dB at 110 kHz. These figures are within 2 dB of a reference spectrum established by Megapulse Inc., the transmitter manufacturer. The asymmetry here is largely due to the increase of antenna efficiency with frequency. From Figure 3 it is clear that, at least close in, the spectrum looks to be that of a normal Loran transmission.

Below 90 kHz and above 110 kHz, Figure 3 shows the narrow-band signals of many other services: the potential “carrier-wave interferers” to Loran. At this receiving site, the strongest of them is the 60 kHz signal of MSF, the UK’s national frequency standard, also now transmitted from Anthorn. Its function is to synchronise clocks, and certain telecommunications systems, to atomic time.

The red dot marks the amateur radio band. From this broad frequency plot, the Loran spectrum appears to be well over 40 dB down at 136 kHz compared to its level at 100 kHz. And, there is no obvious evidence of any significant unwanted emissions.

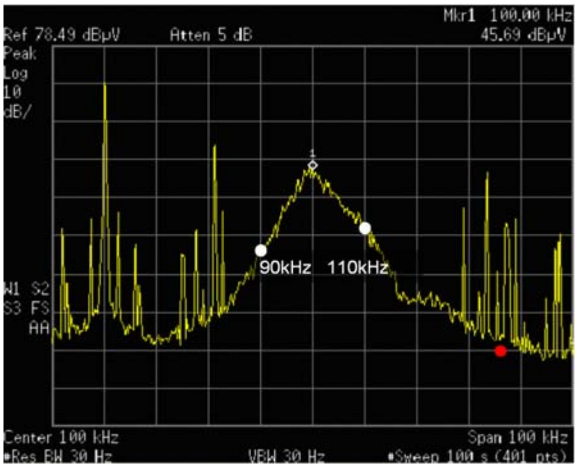

Figure 4: Spectrum from 50kHz-150kHz at 33km from Anthorn

Figure 4 focuses on the amateur radio band from 135.7-137.8 kHz. There are powerful transmissions just below and above it. But within the band, no component stands out above the noise.

To look even more closely for evidence of Loran transmissions here, we devised a technique that let us examine the spectrum of the band in a very narrow bandwidth. This is illustrated in Figure 5, which shows a narrow (just 100 Hz-wide) slice of the Loran spectrum at 100 kHz, the Loran centre frequency. The spectrum analyser bandwidth is at the narrowest setting available, 3 Hz.

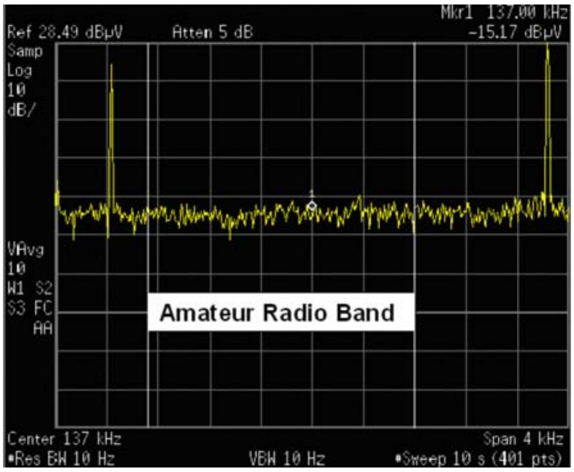

Figure 5: Spectrum from 135kHz-139kHz at 33km from Anthorn

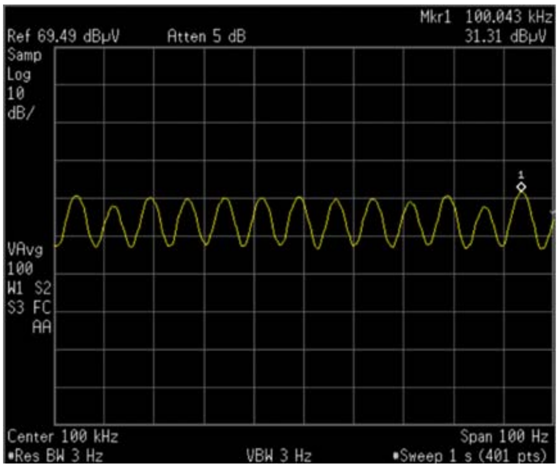

Figure 6: 100Hz-wide spectrum around 100kHz at 33km from Anthorn

The Loran spectrum, part of which we see here, is made up of thousands of spectral lines. They are spaced at intervals of:

$$F_{GRI} = \frac{1}{2 \times GRI \times 10^{-5}}$$

For the GRI of Anthorn, 6731, this becomes (approximately):

$$F_{GRI} = \frac{1}{2 \times GRI} = \frac{1}{2 \times 6731 \times 10^{-5}} = 7.4Hz$$

So, the Loran spectrum consists of a large number of components, spaced 7.42832 Hz apart. As one would expect, we see 13 of them in this 100 Hz slice. These spectral lines, of course, are continuous unmodulated carriers of zero bandwidth, delta functions in the frequency domain. Their apparent width in Figure 5 is simply a representation of the 3Hz filter bandwidth of the spectrum analyser.

Because the Loran transmission is complex, the components seen here are of slightly different strengths. The analyser has picked out the strongest and assessed its amplitude as 31.31 dBµV, a measure of the strength of the Anthorn transmission at 100kHz.

Figure 6 shows the same measurement, now carried out to show the 100 Hz section of the spectrum centred on 136 kHz. Again we see 13 spectral lines; this is undoubtedly Loran energy in the amateur radio band. The analyser measures the amplitude of the strongest spectral line as –13.97 dBµV. So, the Loran spectrum here is just over 45dB weaker than at 100kHz.

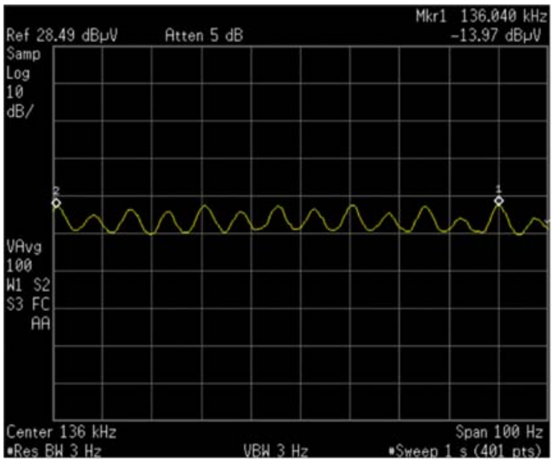

Figure 7: 100Hz-wide spectrum around 136kHz at 33km from Anthorn

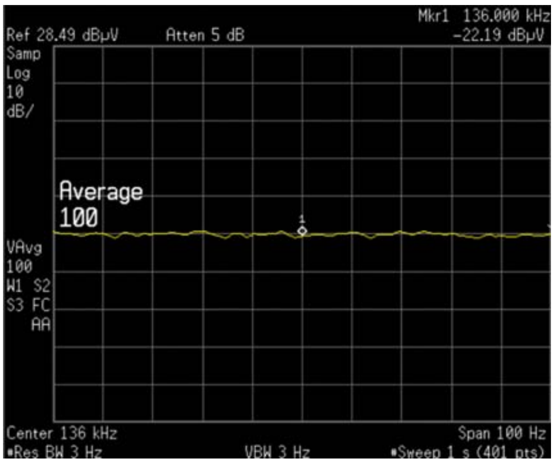

Figure 8: 100Hz-wide spectrum around 136kHz at 33km from Anthorn, with loop antenna nulling out Anthorn signal

To confirm that this Loran energy is from Anthorn, and not from another Loran station, the loop antenna that had been pointing at Anthorn was rotated by 90 degrees, so that it nulled out the Anthorn signal. The result is shown in Figure 7. The background noise at this peaceful rural site is approximately –22 dBμV.

Power radiated from Anthorn

The spectrum measurement at 136 kHz shown in Figure 6 gives us the possibility of calculating what power Anthorn is transmitting in each spectral line there. The spectrum analyser and its loop antenna have been calibrated so that the field strengths of the individual lines can be measured.
By reference to the groundwave propagation curves of the International Telecommunication Union (ITU) shown in Figure 8, these field strengths at a known range of 33km can be translated into transmitter radiated power [2]. This measurement technique and calculations were checked using the 60 kHz MSF transmission from Anthorn. The resulting measured radiated power, 16 kW, was within 1 dB of the independently-calibrated radiated power of the MSF transmission.

From Figure 6, and taking into account the antenna factor (+21.5dB), we assess the average strength of the individual Loran spectral lines around 136 kHz at our test site as +6 dBμV/m. To produce that field strength at a range of 33km, Anthorn must be radiating a power of 50 μW. If we add up the total power of all 284 Loran spectral lines that fall in the amateur radio band, it is 14 mW. The radiated power density is 6.8 mW per kilohertz of bandwidth.

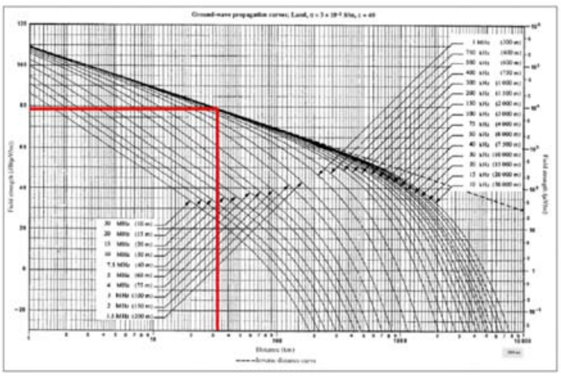

Figure 9: Groundwave propagation curves (from [2])

So Anthorn, with its peak power of 200 kW, is transmitting just 14 milliwatts in the amateur radio band. This is an extremely low level of out-of-band emission. Yet in the region around Anthorn those tiny unwanted components of the Loran signal may still be sufficient to exceed the strengths of amateur radio signals arriving from very distant stations.

Co-existence

Radio amateurs who use the 136 kHz band have co-existed there with Loran-C for many years and have worked out innovative solutions to the problems of interference from Loran stations. When Rugby first came on the air in 2005, there were already more than 70 Loran stations worldwide. In Europe alone, 13 of them were transmitting when, in 1998, British radio amateurs were first granted permission to use the band, on a secondary basis with the proviso of non-interference to other services. Of these Loran stations, Lessay (northern France), Sylt (northern Germany) and Ejde (Faeroe Islands) had delivered strong signals into adjacent regions of the United Kingdom for many years.

What makes amateur radio co-existence with Loran possible is the extraordinary way in which long-range amateur communications are conducted in this band. Because even the entire band is too narrow for a single speech channel, they employ data transmissions for short distances, and slow Morse code for long-range communications. For transatlantic operation, this can be exceptionally slow Morse, in which the duration of a single dot is between 3 and 30 seconds, and a dash between 9 and 90 seconds! The dominant noise at these low frequencies is atmospheric. Such very slow Morse requires only an extremely narrow receiver bandwidth, which admits very little such noise. Indeed, a single Hertz is more than sufficient.

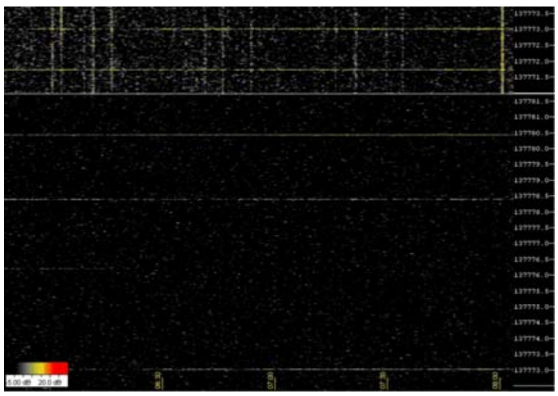

Figure 10: Waterfall diagram (from [3])

This very slow Morse is intended to be seen and not heard: at the receiving station it is read using a so-called “waterfall diagram”, as shown in Figure 9 [3]. Here, the vertical axis is frequency: note the half-Hertz major divisions. The horizontal axis is time, in hours! An extremely weak transatlantic Morse signal can be seen at 137778.4 Hz.

Many radio amateurs successfully avoid Loran spectral lines. Figure 10 shows a waterfall diagram recorded in the north-western United States [4]. Clearly visible are individual Loran spectral lines: a pair from the North Central (8290) chain, and one each from the Canadian and US West Coast chains. Many slow Morse transmissions could squeeze into the gaps between those spectral lines.

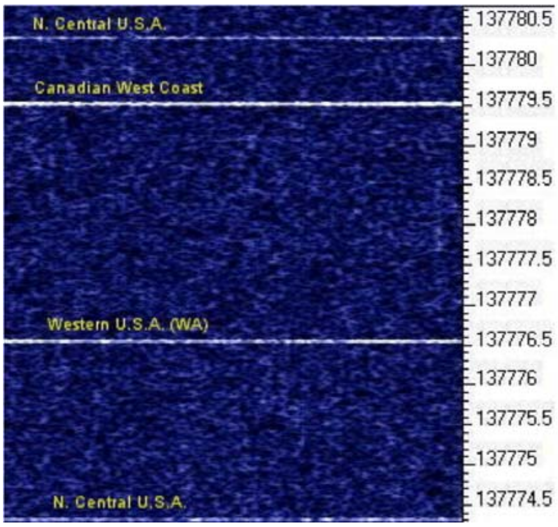

Figure 11: US Loran spectral lines (from [4])

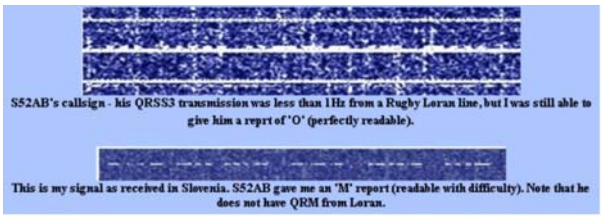

Figure 12: Reception less than 1Hz from a Rugby Loran spectral line (from [5])

Indeed, Figure 11 shows a British radio amateur, communicating with a Slovenian, less than 1 Hz from one of Rugby’s Loran spectral lines [5]. Radio amateurs actually list the Loran lines as frequency markers - of atomic precision [6]!

Radio amateurs have also devised a battery of techniques (examples in Figure 12) to combat Loran interference: loop antennas to null out the nearest Loran station; pairs of phased antennas with steerable nulls; and noise-cancelling circuits [7,8].

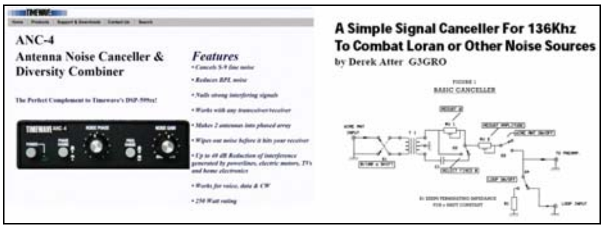

Figure 13: Techniques for combating Loran! (from [7,8])

Nevertheless, the General Lighthouse Authorities and VT Communications Ltd., the operators of the Anthorn station, are actively exploring the feasibility of filtering out the remaining milliwatts of power around 136 kHz from the Anthorn transmission. There has even been discussion of a technical proposal that a notch could be created in the transmitted spectrum at 136 kHz by judicious selection of Eurofix signal coding [9]!

Summary

The measurements set out in this paper have shown that Anthorn’s signal is as a Loran signal should be. There are no spurious emissions in the amateur radio band, only the normal sideband energy of a Loran station. In the 136 kHz amateur radio band, Anthorn radiates a miniscule 50 μW per spectral line, 14 mW in total across the 2.1 kHz-wide band with a density of 6.8 kHz per kiloHertz. The Loran stations at Lessay, Ejde and Sylt all pre-date Anthorn. They also pre-date the amateur radio band. Happily, radio amateurs themselves have developed effective receiving techniques to remove Loran sideband interference. But, as good neighbours, the GLAs and VT Communications Ltd. are exploring the feasibility of notching out the tiny amount of remaining energy at 136 kHz from Anthorn, something that would be unique among the many Loran stations worldwide.

References

[1] ITU Radio Regulations, Volume 1, Chapter 1, ‘Terminology and Technical Characteristics’, 2004.

[2] ITU Recommendation ITU-R 368-7, ‘Ground-Wave Propagation Curves for Frequencies between 10kHz and 30MHz’.

[3]http://jpmere.online.fr/Grabber/Grabber.htm.

[4]http://www.imagenisp.ca/jsm/136.html

[5]http://homepage.ntlworld.com/mike.denniso n/index/lf/gallery/s52ab.htm m

[6]http://www.lwca.org/library/reference/LORA N/loran_lines.ht

[7]http://www.timewave.com/support/ANC-4/anc4.html

[8]http://www.carc.org.uk/assets/Downloads/vlf filter.pdf

[9]Peterson, B., Peterson Integrated Geopositioning Inc, private communication to Williams.