The Transatlantic on 2200 Meters

Joe Craig, VO1NA and Alan Melia, G3NYK

Longing for the days when amateurs built their own gear and DX was big news? They're back again...on the "top" top band.

There has been much excitement below our so-called top band at 1.8 MHz. At less than one-tenth this frequency, near 136 kHz, you will find many amateurs enjoying QSOs using a variety of modes. Although US and Canadian amateurs need special permission to transmit here, there is a 2200 meter amateur band in many European countries and in New Zealand. Aside from its low frequency, the most striking thing about the 135.8-138.8 kHz band is its narrow width—only 2.1 kHz, barely wide enough to admit a single SSB transmission.

Huge sources of interference are present in the band. In Greece, the Navy transmitter SXV operates on 135.8 kHz, and in Canada another Navy transmitter (CFH) is on 137.0 kHz. Just outside the band is the German station DCF39 on 138.83 kHz. These stations have effective radiated power (ERP) levels in the tens of kilowatts and can be heard on receivers thousands of miles away. At 100 kHz, there are the megawatt LORAN (long range aid to navigation) transmitters with their perpetual clatter, and above 150 kHz we have the commercial long wave band with powerful megawatt plus stations. How then can this band be of any use to the amateur experimenter?

Amateurs have traditionally overcome many obstacles in achieving their goals. When regulators restricted us to the "useless wavelengths" below 200 meters, we spanned the globe. Now that we're slowly being let above 200 meters again, we have used some modern technology and old-fashioned persistence to achieve amazing feats in this challenging environment on the long waves. We have even used the high power interference sources to our advantage.

Propagation at 136 kHz

It is generally agreed amongst the professional propagation researchers that propagation between 50 kHz and 150 kHz is different than both the bands above and below that region. The lower (VLF) frequencies are described as propagating by a waveguide mode between the ground and the ionosphere. The waveguide mode dies out mainly above 30 kHz and certainly above about 50 to 60 kHz. We believe this may due the wavelength becoming short compared with the thickness (about 30 km) of the daytime absorbing D-layer. Unlike HF frequencies, LF has a substantial groundwave service area, with the wave front being bent to follow the curvature of the Earth to some extent. In daytime, there is an absorbing ionized region, formed by photo-dissociation, which corresponds to the D-layer (50 to 90 km) and, in general, it is considered that ionospheric propagation is not an element of daytime signals

Early in 1999 an FSK signal appearing nightly in the UK at 137.00 kHz was correctly identified by Alan, G3NYK as that from the Canadian Naval station, call sign CFH, near Halifax in Nova Scotia. Rough early estimates of the path loss suggested that an amateur transatlantic crossing would just be possible with the allowed 1 W ERP. Many were dubious, but only a few weeks later Dave Bowman, GØMRF made the first one-way LF crossing to John, VE1ZJ. Then days later Peter, G3LDO managed a crossband contact. Both of these events were coincident with good received signal strength from CFH. John was located near Big Pond in north Nova Scotia. Other, regularly heard calls in the early days of tests was the well known MF station of Jack, VE1ZZ and the late Larry Kayser, VA3LK.

Daytime propagation is mainly ground wave, but at extreme range (in excess of 1500 km) there is a significant daytime ionospheric component. This has been seen on the path between CT1DRP (Porto) and DCF39, a German utility station on 138.83 kHz located near Magdeburg, and also on certain occasions on the CFH to Europe path. The peak strength usually coincides with the solar zenith at mid-path. This is at approximately 1500 UTC for the CFH to Europe path, and around 1130 UTC for the CT to DCF path. The signal enhancement under normal conditions on the 1950 km DCF to CT path is about 10 dB. This enhancement is caused by the sky-bound signal being returned by the lower region of the D-layer. Penetration of the D-layer in daytime subjects the wave to absorption, so the enhancement is not as high as seen at night. Also, the apparent reflection height is sure to be lower.

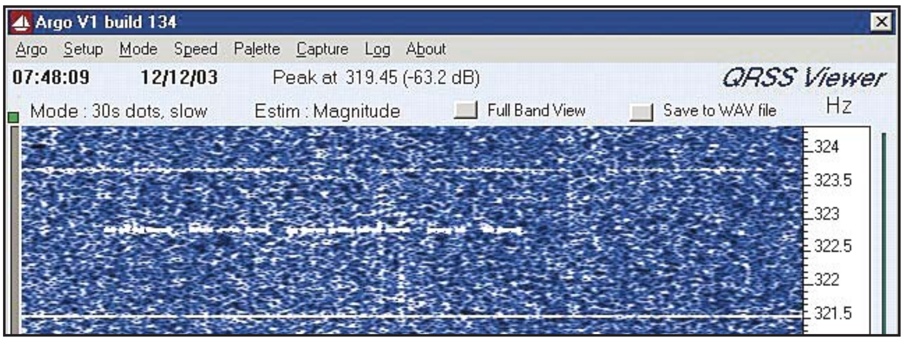

Figure 1—On December 12, the Marconi and Poldhu radio clubs commemorate Marconi's first transatlantic experiment. In 2003 they sent an LF signal from Newfoundland to England using very slow speed CW with dots 30 seconds long (QRSS30). Here is a screen capture of that signal received at G3NYK using *Argo* software. If you look carefully, you can make out white Morse characters spelling out VO1NA against the noisy blue background. *Argo* uses Fast Fourier Transforms to get very narrow effective bandwidths (fractions of a Hz) and is very popular with the LF crowd. More information on *Argo* is available on the Web at www.weaksignals.com.

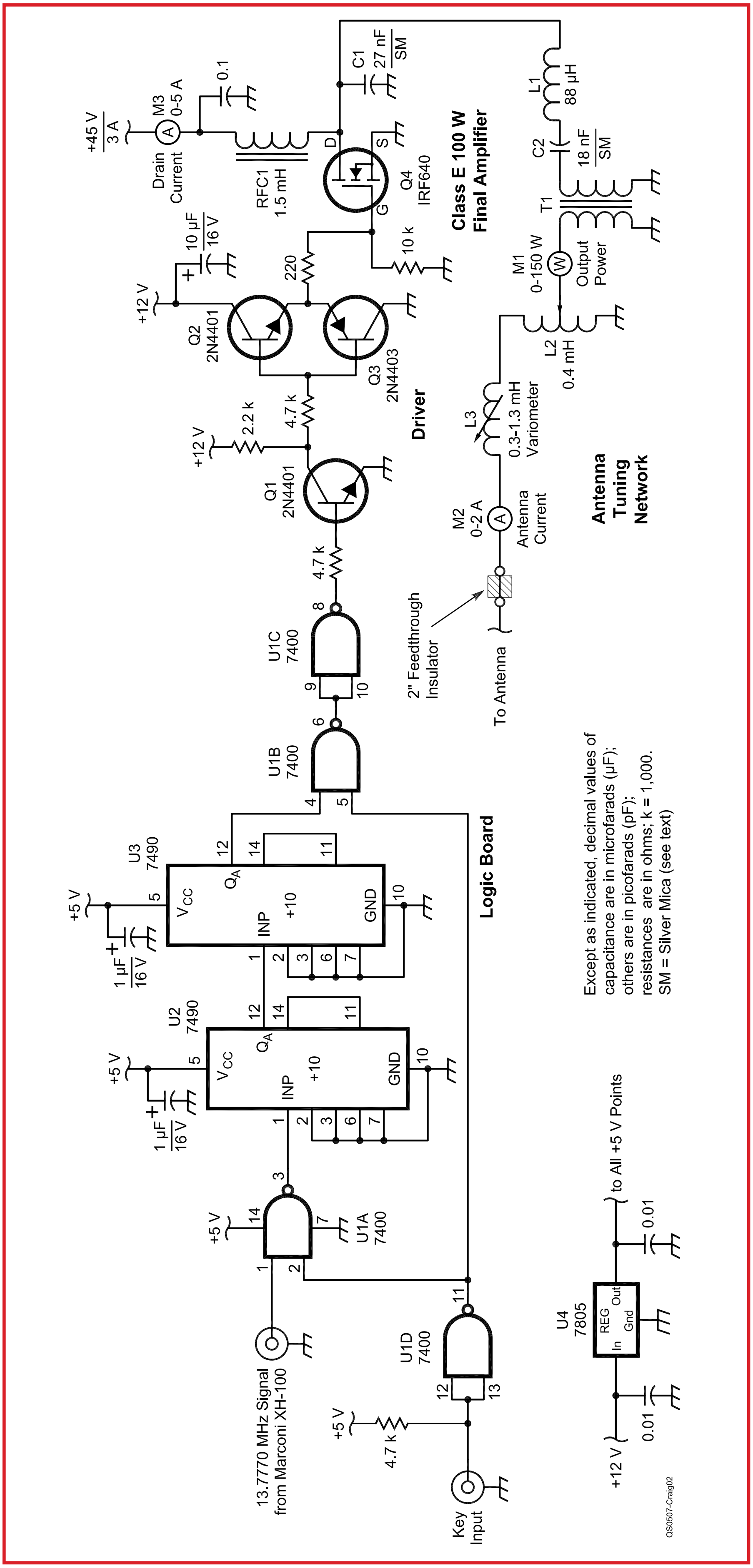

Figure 2—Schematic and parts list for VO1NA'a class E LF transmitter. As explained in the text, transmitters at this frequency tend to be unique, requiring some experimentation. This transmitter was based on design ideas of several LF experimenters and tailored for parts available from VO1NA's junk box. A very stable signal generator or TXCO may be used in place of the Marconi XH100 receiver. See the text for component details.

C1—27 nF capacitor.
C2—18 nF capacitor.
L1—88 µH air wound inductor.
L2—0.4 mH air wound inductor.
L3—0.3-1.3 mH variometer.
M1—50 Ω wattmeter.
M2—RF ammeter, 2 A full scale (see text).
M3—Drain current meter, 0-5 A dc.
Q1, Q2—NPN small signal transistor, 2N4401 or equiv.
Q3— PNP small signal transistor, 2N4403 or equiv.
Q4—International Rectifier IRF640 N-channel MOSFET.
RFC1—1.5 mH RF choke.
T1—Impedance matching transformer with 5 primary turns and 13 secondary turns on a ferrite core.
U1—7400 quad NAND gate.
U2, U3—7490 decade counter.
U4—7805 5-V regulator.

At night, the photo-dissociated electrons in the D-layer decay (or recombine) quickly, as the darkness removes the ionizing radiation. The "apparent reflection level" moves up to the base of the E-layer at around 90 to 100 km in altitude. The E-layer is a 24-hour layer, ionized, amongst other things, by high-energy cosmic rays. The atmospheric pressure is much lower than at the D-layer, so the chances of an electron encountering an atom or positive ion are much reduced and their "lifetimes" are extended. Thus, the nighttime wave has to travel through very little absorbing material. The ionospheric wave, often called the sky-wave, becomes stronger than the ground wave at distances exceeding about 800 km. Thus, all long distance contacts are due to ionospherically returned signals.

These seemingly predictable conditions are altered by the effects of Solar disturbances. The initial check of the Solar indices against known good nights drew a blank, but it was relatively easy to spot potentially poor conditions. These occurred about 2 to 3 days after a geomagnetic event that lifted the Kp index to 5 or above. This is about the same level that leads to substantial auroral effects. The conditions deteriorated more, and took longer to recover, the higher the Kp rose. It is postulated, from the signal strength plots, that Coronal Mass Ejections (CME) were responsible for injecting hot electrons into the ionosphere. After these had time to diffuse to the D-layer region (the delay), their presence was felt as long-lived absorbing material in the D-layer, reducing the nighttime signal strengths. This delay is reported in a number of professional papers on Solar disturbance to LF propagation. So the question remains: How to predict good conditions?

A more recent extensive series of DX tests have confirmed that the lesser-known index, Dst (disturbance storm time), is a fairly good indicator. Dst is determined by measuring the effect of ring of trapped ions and electrons circulating the equator in the Van Allen belt. Estimated values are published on the Internet by a number of observatories. It is thought that ions and electrons are trapped from the CME plasma clouds and are gradually exchanged with the ionosphere over a number of days. These migrate to the D-layer and form a long-lived absorbing layer. This would explain the prolonged period of poor conditions after a geomagnetic storm, even after the Kp index has returned to "quiet" conditions (< 4). Anyone interested in antennas and propagation should take a look at the vast resource of papers by Jack Belrose, VE2CV.[1] These are straightforward and very practical.

Receiving Longwave Signals

The old adage, "If you can't copy 'em you can't work 'em," is especially true on 2200 meters. Many general coverage amateur transceivers can receive down to 100 kHz and some go further, while others stop at 500 kHz. If you can tune down to 135 kHz, try it and see what you can hear. If you can hear DCF39 on 138.83 kHz after dark, you are indeed in luck. If not, then try experimenting with your antenna. A long wire sometimes works if directly connected to the antenna jack on the transceiver. In reality, a 500 foot long wire is a very short wire (less than 0.1 λ) on 2200 meters. A preferable option is to use a small loop antenna and a preamp. These loops are generally about 2 meters in diameter, and a number of designs can be found on the LF Web sites. Unlike any practical wire antenna an amateur can erect, a loop will not take up much real estate and can be made directional to reduce interference. Once you have your antenna up and can receive commercial long wave stations such as CFH and DCF39, you have sufficient receiver sensitivity and you are now well on your way to receiving amateur signals on LF.

Sensitivity is not the only issue. The others are selectivity and stability. If you want to receive amateur signals on 2200 meters, stability is essential. Modern rigs with DDS are quite adequate for this, providing the 0.1 Hz/hour or better stability required for receiving amateur LF signals. On the selectivity scale, a 500 Hz CW filter will do a good job. The remaining work, narrowing it down to 0.01 Hz, is taken care of by some highly sophisticated software that takes the audio from your receiver and splits it into tiny bands that can be displayed on a computer screen. The result is a series of Morse code dots and dashes across your computer monitor. It is an amazing marriage of modern Fast Fourier Transform (FFT) technology with 19th century Morse telegraphy. One example of this software is *Argo* by I2PHD and IK2CZL (see Figure 1).

You will probably not hear any distant amateur signals. In the words of Larry Kayser, VA3LK, the best thing you can do with your headphones is unplug them and put them in the drawer. About the only thing you will hear is static and power line noise. You have to let your eyes do the listening. Connect a patch cord between your computer and the headphone jack on your receiver and *watch* for signals using some of the excellent software that is readily available.

Building a Transmitter

Amateur LF stations are typically unique and often have a combination of homemade and commercial gear modified

[1]Notes appear on page 46.

RICK LINDQUIST N1RL

Figure 3—This rack holds the IRF640 power amplifier, power supply, antenna matching coil and variometer for VO1NA's 137-kHz transmitter. The variometer (L3) is the big red coil on the upper shelf next to the wattmeter. The matching coil (L2) is above the wattmeter. The power amplifier is on the next shelf down (with heat sink, L1, T1 and RFC1). Note that about 2000 V is present at the feedthrough insulator during transmissions.

Figure 4—The LF antenna at VO1NA used for several years (including his first transatlantic QSO) consists of two parallel wires 100 meters long, spaced 1 meter apart. The antenna is supported at the far end by a 25 meter tower, and the wires slope down toward another tower near the shack where they are connected together. The antenna is fed at this point with another 50 meters of wire for a total length of 150 meters and matched with the loading coil and variometer shown in Figure 5. The antenna has since undergone several involuntary changes as Mother Nature took down one of the wires and then in January 2005 took the remaining wire and tower during an ice storm. VO1NA is back on LF with 100 meters of wire about 10 meters off the ground. Joe was never very comfortable on the top of his tower and is most grateful he was not there at the time it collapsed. A 30-meter-tall replacement is planned.

for the purpose. Let's illustrate this with an example of a simple LF transmitter. The schematic shown in Figure 2 is based on designs of several amateurs.

A temperature controlled crystal oscillator generates a carrier at 100 times the intended frequency—in this case, 13.77770 MHz. This signal is fed into U1. Logic manipulations are performed on the carrier oscillator signal and the keying inputs to preclude a sustained positive output at the divider circuit. Such a level would destroy the final amplifier in microseconds. Additionally, it prevents any emissions while the transmitter is not keyed. This is important during receiving.

The output from U3, a square wave at 137 kHz, is fed to an inverting switch (Q1) which converts the TTL signal to a 12 V square wave. This is fed to a low-impedance-output totem pole driver circuit comprising Q2 and Q3, which switches the gate of final amplifier Q4 between 0 and 12 V. The operation of a class E amplifier is discussed in detail elsewhere and methods of final tuning are outlined.[2] It is not difficult to tune properly using a 'scope to check the waveforms and meters to monitor the input power.

The final amplifier evolved from a 15 W circuit with a P-channel MOSFET, but when efforts to increase the power to 100 W at 12 V resulted only in fried FETs and frustration, a new strategy was sought. The next step was to try a higher voltage device, an N channel IRF640.

Using G3NYK's spreadsheet program to get approximate values for the tuning components simplifies the design considerably. The process entails selecting a power output and voltage within the specifications of the MOSFET you wish to use. C1 is calculated based on the required power output. The values of the remaining components, L1 and C2, are provided by the spreadsheet, but will usually require a small bit of adjustment to achieve optimal efficiency. The output transformer, T1, can be adjusted by changing the turns ratio to get the desired output impedance, usually 50 Ω. The transmitter signal then goes through a wattmeter and on to the antenna tuning network (L2, L3).

High quality capacitors should be used for C1 and C2. Parallel combinations of silver mica or pulse rated metalized polyethylene capacitors are recommended. RFC1 and T1 are both wound on 2.75 inch square ferrite cores such as those used in flyback transformers. RFC1 is 28 turns for about 1.5 mH of inductance. The number of turns depends on the core material, which should be selected to avoid saturation and excessive heating. L1 was constructed using two concentric air wound inductors. The inner one is 2.75 inches diameter by 6.25 inches long. The outer one is 3.125 inches diameter by 2 inches long. You can adjust the inductance by taking taps and fine tune it by sliding the coils. L1 conducts large amounts of current and should be built accordingly with wire no smaller than no. 16.

Figure 5—After almost two years of tuning the antenna from inside the shack, in January 2005 VO1NA moved the loading coil and variometer outside to the tower. A smaller variometer, about 60-250 µH, was used in series with a tapped loading coil. This moves the RF and high voltages away from the house. A standard 50 Ω coaxial cable runs back to the transmitter in the shack.

The finished transmitter is shown in Figure 3. Increasing the voltage made it much easier to get high efficiency. Within a short time 100 W at about 80% efficiency was achieved and there seemed little point in further tinkering. It was very gratifying to see that the only hot thing on the bench (besides the soldering iron!) was the dummy antenna. The MOSFET, mounted on a heatsink about 3 × 3 × 4 inches, was barely warm after several minutes of steady carrier. For those interested in even higher power, a 700 W transmitter has been described in *QEX*.[3]

Some form of filtering may be needed at the transmitter output to reduce the harmonic content of the signal, but it is worth noting that a properly tuned class-E stage has less distortion (and harmonics) than a class-C or class-D stage. Amplifiers are discussed in Peter Dodd's excellent *Low Frequency Experimenter's Handbook*.[4]

The Antenna and Tuning Networks

Because ¼ λ is more than 500 meters at 136 kHz, it is not likely that you will have the good fortune to be able to erect a resonant antenna. A large amount of capacitive reactance and a very small radiation resistance are the facts of life for any practical LF antenna.

The first step in tuning the antenna is to cancel the capacitive reactance by inserting a large amount of inductance, often several millihenrys, in series with the antenna. This is simplified by using a variometer (L3), which allows a continuous variation of inductance. Next, the remaining resistive component has to be transformed to the output impedance of the transmitter, which is normally 50 Ω. This is usually achieved by using an autotransformer (L2) to step up the resistance, or if you are fortunate, to step it down. The ultimate goal is to get the efficiency of the transmitter and the antenna current as high as possible at the same time. It's a little more challenging than erecting an antenna and running coax from it to the rig as we do so easily on the wavelengths below 200 meters.

The inductance needed to achieve resonance is obtained from

$$L = \frac{1}{(2\pi f)^2 C} \qquad \text{[Eq 1]}$$

where C is the antenna capacitance, which can be roughly estimated as 5 pF per meter of antenna length. For example, if your antenna is 100 meters long, its capacitance will be about 500 pF and the total inductance needed is about 2.7 mH. Fine tuning is done by adjusting the variometer and matching transformer for maximum antenna current.

The LF antenna that VO1NA used for the transatlantic experiments is shown in Figure 4. The antenna is about 150 meters long, including 100 meters of horizontal wire and another 50 meters of wire between the shack and feed point acting as a feed line. The use of two parallel wires increases the antenna capacitance and efficiency.

To match VO1NA's parallel-wire antenna, L2 is air wound, with 100 space-wound turns for a total inductance of about 0.4 mH. It is tapped for the best resistive match.

L3 is the tuning variometer with an inductance range of about 0.3 to 1.3 mH. The variometer is wound with 12 gauge insulated copper wire. The insulation is used as a convenient means of spacing the turns to reduce losses.

A good ground connection is very important and this will take some experimentation. The ground resistance can be estimated from

$$R_g = \frac{P}{I^2} \qquad \text{[Eq 2]}$$

where P is the power of the transmitter and I is the antenna current. At VO1NA it is about 40 Ω.

Danger: High Voltage! Please note that there are very dangerous voltages present on the antenna end of the tuning coil and the antenna itself. Special precautions are necessary to prevent electric shocks and burns, as well as arcing. Low frequency RF can be deadly lethal when it uses your body as the ground lead.

Getting the Message Out on the Long Waves

Keying the transmitter can be done in several ways. For slow speed CW (0.04 WPM) one has to be very persistent for manual operation. Most of us aren't that patient so we use a diode matrix identifier or program a computer to do the job. A matrix (or EPROM/PIC) is very convenient for beacon operation, but a computer offers more versatility for making slow speed QSOs. VO1NA's IDer is a CMOS version of the circuit published by Tom McMullen, W1SL, many years ago.[5]

A variety of modes is used on LF, but by far the most popular are FSK or slow speed CW (QRSS) in which the dots are sent on one frequency and the dashes on a slightly higher frequency. For long distance work, dots are 30 to 60 seconds long, so the QSOs do not involve the exchange of a lot of details other than the call signs and the signal reports.

Transatlantic Experiments on Long Wave

VO1NA's initial transmissions were with a 5 W transmitter used for long wave experiments on 180 kHz in 1992. He retuned it for 136.269 kHz and coupled it to a 30 meter wire antenna. Signals were heard 7 km away. Next he built a 15 W class E transmitter using a P-channel MOSFET. Contacts were had with several members of the Marconi Radio Club of Newfoundland including VO1FB, VO1HD, VO1HP and VO1XP.

Signals were finally radiated outside the country when the 150 meter wire antenna shown in Figure 4 was raised and signals were detected by John Andrews, W1TAG in Holden, Massachusetts, about 1600 km away. This success encouraged the attempt to span the Atlantic, and the 100 W transmitter described earlier was built from parts in the old junk box.

Arrangements were made between G3NYK and VO1NA based on Alan's predictions of conditions. After a few tries, signals were finally copied and the Atlantic spanned for the first time from VO land. Alan used an indoor 1.25 meter loop made out of 16 turns of 25-pair telephone cable, tuned and amplified with the simple preamp shown on his Web site.

On June 12, 2003, 101½ years after Marconi spanned the Atlantic, a two-way QSO was completed with Jim Moritz, MØBMU, near London—more than 3700 km away. Jim used a 2 meter loop to receive Joe's very slow CW signals on 137.777 kHz.

Other transatlantic contacts have been completed, including a couple with G3LDO. To date, the best DX from VO1NA has been RN6BN at 6600 km. We've copied each other's signals and are still hoping for a two-way QSO. A long wave listener, Hartmut Wolff in Germany has copied VO1NA's 137 kHz signals a number of times, as well as his QRP (5 W) beacon on 189.81 kHz. Closer to home, and at even higher CW speeds Frank Davis, VO1HP, while operating the Marconi Radio Club station VO1MRC, completed the first two-way conventional CW QSO in Canada by working VO1NA at 20 WPM. With a recent reception by Hartmut of a 10 W signal, transatlantic experimentation promises to be very interesting and gratifying for upcoming winter seasons. More information on our experiments appeared in *The Canadian Amateur*.[6]

Web Pages for the LF Experimenter

These Web pages offer a wealth of additional information about Amateur Radio LF experiments, hardware, software and propagation.

Argo Software
www.weaksignals.com

CT1DRP Web site
homepage.esoterica.pt/~brian/

G3YXM LF News
www.wireless.org.uk

G3NYK Web site
www.alan.melia.btinternet.co.uk

KL1X Web site
myweb.cableone.net/flow/

Long Wave Club of America
www.lwca.org

NOAA Space Environment Center
www.sec.noaa.gov

ON7YD Web site **www.qsl.net/~on7yd/**

VE7SL Web site **imagenisp.ca/jsm/INDEX.html**

W1TAG Web site **www.w1tag.com**

W3EEE Web site **www.w3eee.com**

W4DEX Web site **www.w4dex.com**

Conclusion

Before transmitting on the 2200 meter band, please note that Canadian amateurs are required to obtain a Letter of Authorization (LOA) from Industry Canada. This can be done through Radio Amateurs of Canada. American amateurs are required to obtain an experimental license under Part 5 of the FCC Regulations. We hope that this band will be allocated to the amateur service on a worldwide basis.

Amateurs who seek technical challenges and new excitement have a fascinating new frontier at 2200 m. With the aid of the Internet, you can become part of a growing fraternity with some very competent and knowledgeable fellow amateurs. State-of-the-art software has been developed and made readily available for all to use. New developments are surfacing all the time.

Acknowledgments

We wish to acknowledge the support of members of LF community, Radio Amateurs of Canada, the Marconi Radio Club of Newfoundland and the Radio Society of Great Britain for their LF Internet reflector.

Notes

[1]J.S. Belrose, W.L. Hatton, C.A. McKerrow and R.S. Thain, "The Engineering of Communications Systems for Low Radio Frequencies," *Proc. IRE*, Vol 47, No 5, May 1959, pp 661-680.

[2]N. Sokal, "Class E Power Amplifiers," *QEX*, Jan/Feb 2001, pp 9-20.

[3]A. Talbot, "A 700 W Switch-Mode Transmitter for 137 kHz," *QEX*, Nov/Dec 2002, pp 16-26.

[4]P. Dodd, *The Low Frequency Experimenter's Handbook* (Radio Society of Great Britain, 2000).

[5]T. McMullen, "A Low Cost CW Identifier," *QST*, Apr 1975, pp 34-36.

[6]J. Craig, R. Dodge and R. Peet, "LF In Newfoundland and Labrador," *The Canadian Amateur*, Sep/Oct 2004, p 39.

Photos by Joe Craig, VO1NA, unless otherwise noted.

Joe Craig, VO1NA, was first licensed in 1976. He is the son of VO1FB, husband of VO1RL, and father of Julia. Joe completed his Bachelors and Masters degrees at Memorial University of Newfoundland and works with the Government of Canada as a physicist. He has lectured at the University and at conferences in radio and physical science and has authored dozens of technical and research papers as well as several publications in the primary literature. Joe is a member of the Baccalieu and Poldhu Amateur Radio Clubs, the Marconi Radio Club of Newfoundland, Radio Amateurs of Canada and a life member of the Quarter Century Wireless Association. He has both CW and 160 meter DXCC. Joe also enjoys swimming and fitness, music, traveling, photography and astronomy. He can be contacted at **jcraig@mun.ca**.

Alan Melia became interested in Amateur Radio at school about 1955 and obtained his license, G3NYK, while at Liverpool University in 1960. He graduated with a BSc (Hons) in Physics in 1961 and joined the then Post Office Research Department (later British Telecom Research Labs) where he worked for 30 years on transistor and IC test and reliability. He then joined a small local two-way radio company, retiring 5 years ago. He started on 160 m, and has become addicted to LF, particularly propagation effects. He is a member of the RSGB Propagation Studies Committee, and still holds membership in the Institute of Physics as a Chartered Physicist. He can be contacted at 67A Deben Ave, Martlesham, Heath, Ipswich IP5 7QR, UK or **alan.melia@btinternet.com**.