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Design and construction of the 5MHz beacons GB3RAL, GB3WES and GB3ORK part one

The 5MHz beacon project has now been running for some months, and many UK readers will by now have heard the transmissions on 5.29MHz [1]. The beacons are intended, and have been designed, for propagation monitoring, and so transmit several types of modulation to assist reception by as wide an audience as possible. In part one of his two-part article, G4JNT looks at the design history of the project, beginning with GB3RAL, and continuing with the initial work on GB3WES and GB3ORK, which will be concluded next month

Three transmitters make up the system, GB3RAL in Oxfordshire, GB3WES in Cumbria and GB3ORK in the Orkney Islands; each transmits for one minute in every 15. They are timed such that GB3RAL transmits exactly on the hour then at 15, 30 and 45 minutes past, GB3WES one minute after that, with GB3ORK sending its sequence at 02, 17, 32 and 47 minutes. Timing is controlled by a GPS receiver at each station and is accurate to within 1 microsecond. Software has been written by Peter Martinez, G3PLX, to allow automatic unattended monitoring of these beacons. The first panel gives more details of this.

AUTOMATIC BEACON MONITORING

Peter Martinez, G3PLX, has written a piece of software for automated monitoring of these beacons. The audio output from a receiver is connected to a computer's soundcard input; the software digitises the audio, then uses the resulting data to derive the signal-to-noise ratio for each of the three beacons by measuring signal strength and background noise in a 1Hz effective bandwidth. The computer's internal clock is used to differentiate between the three beacons, and to identify the 25- to 30-second period when full carrier is being transmitted. Any drift in the computer clock is tracked and taken into account, as is any frequency or tuning error to within ±20Hz

Measured data for all three beacons are shown on screen for the previous 40 hours, and can be automatically logged to a file in a format suitable for direct inputting to the 5MHz Working Group's monitoring database. A screen plot from this software is shown in **Fig 1**.

The software can be downloaded from [1]; look for the compressed file 5mhzbcns.zip.

Each beacon transmits a (nearly) identical sequence, shown graphically in **Fig 2.**

The first 7s are taken up by the callsign, followed by a short period of plain carrier at full power.

From 7s to 15s, the power is reduced in steps of 6dB per second, to a final level of -48dB. This final level corresponds to transmitted power level of just 160µW. A 100ms gap at the beginning of each new power level setting makes the individual steps easier to detect by ear. The power steps are designed to aid aural estimation of signal-to-noise ratio by counting (and logging) the number of steps that can be heard before the lower-power steps have disappeared into the noise.

The power steps are repeated for the interval 16s to 24s.

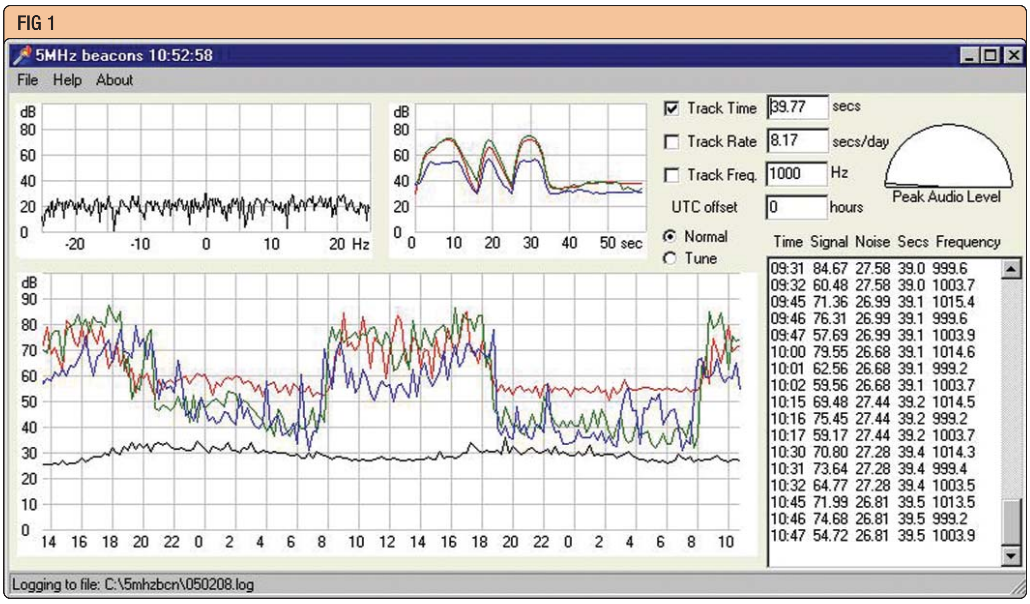
From 25s to 30s, a period of full-power carrier allows automatic logging software to measure the received signal.

The remaining 30s are taken up with a sequence consisting of precisely timed 500µs-wide pulses, at full power, with a 40Hz repetition rate. This part of the waveform sounds like a low pitched buzz and is designed for ionospheric sounding experiments, enabling measurements of delay and multipath propagation to be undertaken.

GB3RAL – THE FIRST 5MHz BEACON

The first beacon to form part of the chain was GB3RAL at the Rutherford Appleton Laboratory near Didcot, Oxfordshire, which went on air in the middle of 2003. The hardware for this was put together by Mike Willis, G0MJW, who used an off-the-shelf synthesiser as the frequency source, followed by a 100W broadband power amplifier, then later an amplifier that, because of its obsolescence, had been made available to the project by Yaesu (UK). The Yaesu PA just needed a couple of simple modifications to hardwire it for single-band operation, and would be operated well backed off at 10W output, giving good linearity. The power steps were generated by a commercially-made stepped attenuator – a piece of laboratory equipment (sometimes seen on the surplus equipment stands) and controlled from 0/5V logic level signals. This had six stages of attenuation giving 0 to 63dB of attenuation in binary steps of 1dB. Mike made up a custom PIN

FIG 1



☑ Track Time 39.77 secs
☐ Track Rate 8.17 secs/day
☐ Track Freq. 1000 Hz
UTC offset 0 hours
● Normal
○ Tune

```
Time  Signal Noise Secs Frequency
09:31 84.67 27.58 39.0 999.6
09:32 60.48 27.58 39.0 1003.7
09:45 71.36 26.99 39.1 1015.4
09:46 76.31 26.99 39.1 999.6
09:47 57.69 26.99 39.1 1003.9
10:00 79.55 26.68 39.1 1014.6
10:01 62.56 26.68 39.1 999.2
10:02 59.56 26.68 39.1 1003.7
10:15 69.48 27.44 39.2 1014.5
10:16 75.45 27.44 39.2 999.2
10:17 59.17 27.44 39.2 1003.7
10:30 70.80 27.28 39.4 1014.3
10:31 73.64 27.28 39.4 999.4
10:32 64.77 27.28 39.4 1003.5
10:45 71.99 26.81 39.5 1013.5
10:46 74.68 26.81 39.5 999.2
10:47 54.72 26.81 39.5 1003.9
```

Logging to file: C:\5mhzbcn\050208.log

FIG 2

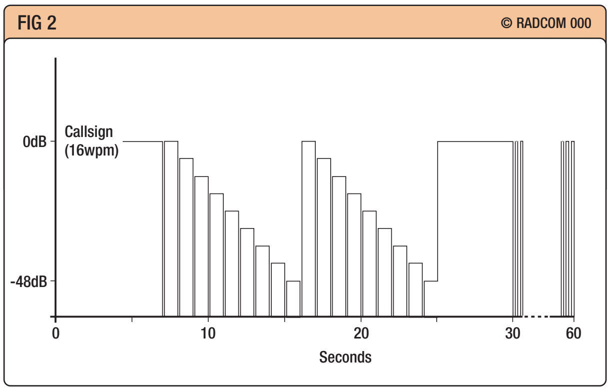


Fig 1
Screen display of automatic monitoring program.

Fig 2
Beacon keying sequence.

diode keyer that could allow the RF to be switched on/off fast enough to transmit the sounder sequence and the CW keying. It achieved 80dB of on-off isolation, but needed a negative supply to achieve this. A Garmin GPS receiver module was to hand to supply timing pulses; a 23A power supply had been donated by SMC, and the only remaining item was the hardware needed to control all this lot!

CONTROLLER DESIGN

I was approached to design a microcontroller (PIC)-based unit for the project. Initially, we planned to use the GPS timing to deliver just a one pulse per second (1pps) signal to the controller, which could then count these seconds pulses to determine the correct 15-minute starting point, and issue the appropriate signals to the keyer and attenuator; a separate signal to activate the power amplifier was also required.

Manual setting of the correct start time would be necessary for this timing method, and it was realised that a nicer automatic time setting scheme is possible when using GPS receivers. As well as the logic level 1pps timing signal, the GPS receiver outputs the time and date together with navigation information and receiver and satellite status. The data is sent as a simple textual string on a serial interface using stop-start, or RS-232-type signalling once per second (immediately *after* the one second pulse to which the data refers). The data format is shown in the second panel.

So now, the microcontroller no longer has to keep track of time itself, since it can read this data from the serial interface and set itself to the correct time. As the data are sent after the 1pps to which it refers, this has to be taken into account in the software.

The PIC software was written and a small PCB produced that allowed all the input / output lines from the PIC chip to be sent off to their destinations. Mike wired this into the rest of the hardware and initially put the assembly on air from his home as an attended personal beacon, sending its sequence every 15 minutes. When the licence for GB3RAL came through, the beacon was transferred to its proper location, the callsign re-programmed and (after solving a few EMC problems with the installation) the whole lot went on air permanently.

GB3WES AND GB3ORK

After the successful launch of GB3RAL, the RSGB 5MHz Working Group applied for, and received, licences for two more beacons in the chain, GB3WES and GB3ORK.

DATA FORMAT FROM GPS MODULES

All off-the-shelf GPS modules give a binary data output on a serial interface. As supplied, this is usually in some proprietary binary format, and software has to be customised to each different manufacturer's module to be able to understand it. However, most modules can also be programmed to give their data in a standard, text based, manner. The format has been standardised by the National Marine Electronics Association and is applicable to all maritime navigation equipment, not just GPS. The format is referred to as NMEA-0183 and data are supplied in a variety of text-based 'sentences', these differing in type depending on what information is contained and the uses for which they are intended. The data rate is defined as 4800-baud, 8-bit stop-start signalling and is compatible with the RS-232 (more properly IEA-232) format as used on all computers' serial ports. Some level shifting and polarity conversion is usually required, as the GPS modules usually output 0/5V logic signals - usually solved with a single chip such as the MAX232.

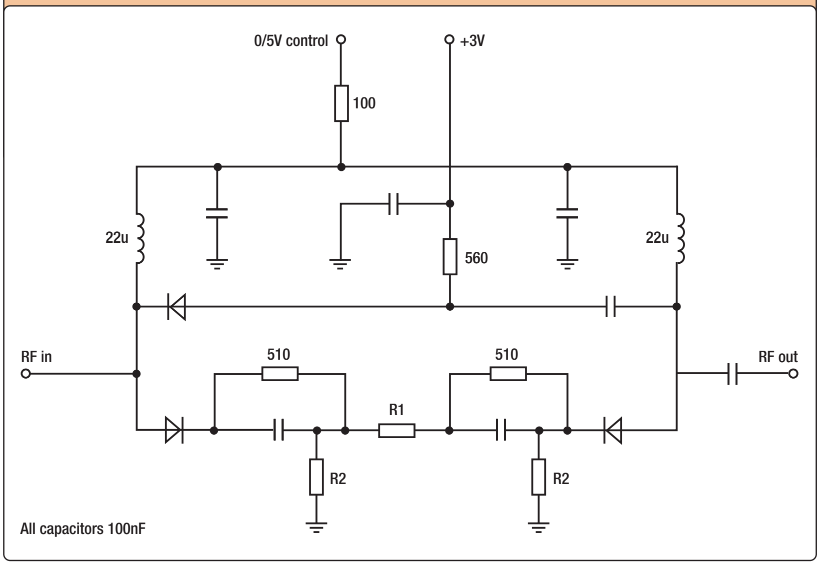
A typical string of data as sent from the Garmin GPS25 module, once per second, looks like this.

```
$GPRMC,212132,A,5054.5876,N,00117.4041,W,000.0,000.0,141202,003.5,W*7B
$GPGSA,A,3,,11,14,,28,31,,,,,,,3.7,2.4,2.7*38
$GPGSV,2,1,06,03,23,146,,11,64,276,40,14,33,083,44,20,21,215,36*74
```

For our purposes, the first sentence beginning '$GPRMC' is the most useful; this is the NMEA Recommended Minimum Specific GPS (RMC) sentence. The other sentences shown here include space vehicle status data and satellite visibility Data items of the RMC sentence are separated by commas as follows.

The first item is the time, here 21:21:32 – this refers to the seconds pulse that has just happened.
The 'A' indicates a valid position and time fix; if not present, the data may be in error.
The longitude, in the format DDMM.MMMM, with leading zeros suppressed, here 50° 54.5876' N.
The latitude, in the same format, here 1° 17.4041' W.
Speed over ground, knots (zero).
Course over ground, degrees.
Date, in the form DDMMYY, here 14/12/2002.
Magnetic variation, here 3.5° W.
* indicates the end of the data, followed by a checksum in hexadecimal, and terminated with a carriage return / linefeed pair, [CR][LF].

FIG 3 © RADCOM 000



All capacitors 100nF

FIG 4 © RADCOM 000

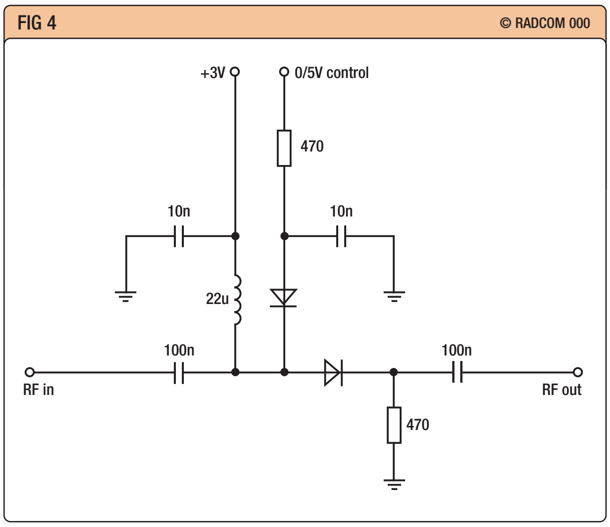


Fig 3
Circuit diagram of attenuator stage.

Fig 4
Circuit diagram of keyer.

Thanks should go to both the RSGB and Ofcom for the swift processing of these licences, which only took a few weeks from initial submissions to receipt. Beacon keepers were identified who would be prepared to host the beacons at their homes, so all that remained were two completely new sets of beacon hardware to be built.

I already had most of the hardware to hand. The controller already existed, the RF source could be adapted from a standard DDS module [2] and a second Yaesu power amplifier had already been donated. By a piece of timely serendipity, I just happened to have a third identical PA to make up the complement! This was all that remained from a scrapped FT-747 transceiver of some years ago.

We would have liked to include a high-stability GPS-locked frequency standard. There is an excellent GPS Disciplined Oscillator [3] that makes use of the 1pps signal from a GPS receiver to lock a high-stability reference oscillator. However it, and the oscillator/oven needed, would have proved too costly, so a simple temperature-compensated oscillator (TCXO) was used on its own to drive the DDS reference clock. These can usually achieve a frequency stability within 2ppm, so ought to keep the beacons within 10Hz of nominal. There is a GPS receiver module, the Connexant/Navman Jupiter-T model, which includes a 10kHz output intended for straightforward locking of oscillators – and would have proved absolutely perfect here. However, the Jupiter-T is difficult to program to give NMEA data outputs and, when it can be persuaded to do so, these are typically one or two seconds late. As timing is so important here, this otherwise-ideal module couldn't be used.

All that remained to be built was a keyer circuit and a programmable attenuator. We contemplated buying a suitable attenuator from Minicircuits but, at over £50 each (and two would have been needed in each beacon for the complete 48dB power step range), decided this was too extravagant. So a programmable attenuator had to be built from scratch.

ATTENUATOR AND KEYER DESIGN

Several hundred surplus and obsolete PIN diodes suitable for switching HF were sitting in my loft looking for a good home, so this was the obvious route to go. As we wanted 6dB power steps and I was going with a custom attenuator design, it seemed pointless staying with the 1/2/4/8/16/32dB steps of the original lab attenuator. Instead, a four-stage attenuator was built with steps of 6/12/12/24dB. This would allow all attenuation values from 0 to 54 dB in 6dB steps to be selected by switching in selected stages. The circuit diagram of one of the four attenuator stages is shown in **Fig 3**. A π resistor network is switched into circuit by a pair of PIN diodes; when that stage is not needed these are switched off and a third PIN diode activated to bypass the resistor network. As PIN diodes need to be reverse-biased to turn them off properly, a 3V reference line derived from a Zener diode goes to each attenuator stage to facilitate proper forward / reverse biasing with just 0/5V logic drive levels. The values of resistors R1 and R2 for each attenuation setting are shown in **Table 1**.

The four cascaded stages gave measured attenuations, for each setting, from 0 to 54 dB, that were accurate to within 1dB, and the final design using surface mount construction worked satisfactorily from 3.5MHz up to 200MHz. Initially, it had been hoped that the attenuator could also perform the keyer function, switching in 54 or 0 dB for off/on, respectively. However, in order to achieve the accurate attenuation settings, considerable decoupling is required on the PCB, and two 0.1µF capacitors shunt each control signal line coming from the PIC. These meant that extra high-current buffering would be needed if the attenuator was to be driven at the sounder pulse repetition rate. Even the CW keying would tax the PIC output driver stages unpleasantly. The solution was either to install high-current drivers on each logic line, or to build a separate keyer. As PIN diodes were plentiful, the latter solution was taken and the keyer circuit can be seen in **Fig 4**. One PIN diode on its own could be persuaded to give a little over 30dB attenuation, but it is always nicer to do a job properly and the final version shown, using a pair of diodes, achieved over 50dB on/off ratio with no trouble. It could be driven with 500µs-wide pulses, reliably, directly from the PIC.

NEXT MONTH

The project concludes with a description of the GPS module, the new PA, the overall assembly and considers the lessons learned from the venture.◆

Table 1: π-attenuator resistor values.
\|\| means 'in parallel with'. Values in ohms.

Attenuation dB	R1 (series)	R2 (shunt)
6	37.5 (75 || 75)	150
12	93.8 (120 || 430)	82
24	399 (430 || 5600)	56

REFERENCES

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[3] GPS Disciplined Oscillator
Brooks Sheera, W5OJM, *QST*, July 1998