DESIGN AND BUILDING OF THE 5MHz BEACONS, GB3RAL, GB3WES and GB3ORK

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Introduction

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. Full details can be found in Reference 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. Three transmitters make up the system, GB3RAL in Oxfordshire, GB3WES in Cumbria (Westmorland) and GB3ORK in the Orkney Islands; each transmitting 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. Annex 1 gives more details of this.

Each beacon transmits a (nearly) identical sequence, shown graphically in Figure 1

> The first 7 seconds are taken up by the callsign followed by a short period of plain carrier at full power.
>
> From 7 to 15 seconds, the power is reduced in steps of 6dB each second, to a final level of –48dB. This final level corresponds to transmitted power level of just 160 microwatts. 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.
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> The power steps are repeated for the interval 16 to 24 seconds
>
> From 25 to 30 seconds a period of full-power carrier allows automatic logging software to measure the received signal.
>
> The remaining 30 seconds are taken up with a sequence consisting of precisely timed 500us 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, 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 100 Watt 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 10 Watts 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 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 23 amp 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 just deliver 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 RS232 type signalling once per second (immediately *after* the one second pulse to which the data refers). The data format is shown in Annex 2. 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 is sent after the 1PPS it refers to, this has to be taken into account in the software.

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 QTH 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. 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 was 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 (Reference 2) and a second Yaesu power amplifier had already been donated. By a piece of lucky serendipity, I just happened to have a third identical PA to make up the complement! This was all that remained from a scrapped FT747 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 (Reference 3) that makes use of the 1 PPS signal from a GPS receiver to lock a high stability reference oscillator. However, it, and the ovenned oscillator needed, would have proved too costly, and a simple Temperature Compensated Oscillator (TCXO) was used on its own to drive the DDS reference clock. These can achieve usually within 2 parts-per-million frequency stability 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 programme 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 1/2/4/8/16/32 dB steps of the original lab attenuator. Instead, a four stage attenuator was built with steps of 6/12/12/24 dB. This would allow all attenuation values from 0 to 54 dB in 6dB steps to be selected by switching in selected stages. This circuit diagram of one of the four attenuator stages is shown in Figure 2 A PI 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 biassed 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 the table below. (|| means in parallel with)

PI Attenuator resistor values

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

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 0.1uF 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 can be seen in Figure 3 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 500us wide pulses, reliably, directly from the PIC.

GPS Module

All the PIC code for GB3RAL had been written for NMEA data supplied from a Garmin GPS25 module (which I had often used before, and was also what Mike had available) so the controller supplied to him worked straightaway. For the later beacons I intended using a surplus Motorola Oncore unit that was sitting on the shelf, then purchase another more modern version of this one for the third beacon. At first sight the NMEA data appeared to be identical to that of the GPS25, so no software changes should be needed. On integrating the Oncore module with my existing PIC controller, however, there was no way the combination could be persuaded to work at all. It just dumbly sat there doing nothing! I could see the NMEA data by directly reading it on a PC, but the PIC software, which worked perfectly with the Garmin, just refused to take any notice whatsoever.

After much head scratching and peering at long strings of letters and numbers, I noticed that whereas the Garmin had output its hours, minutes and seconds in the format …,HHMMSS,…. the Motorola module was supplying …,HHMMSS.SSSS,… with decimals of seconds in the data string. Previously the PIC software counted the commas as they arrived, then extracted the time by counting *backwards* from the second comma, having saved the last few items of previous data in memory. This was clearly now failing to give the correct time as the decimals of seconds and the dot were appearing where the hours and minutes ought to have been. The solution was to modify the software to detect the first comma, then store the *next* six characters to give the time.

The new, more modern, Oncore M12 module needed a 3 Volt supply rather than the 5V of the original, so a separate power regulator had to be provided, also a separate chip to interface the 3V logic levels to the 5V required on the PIC. Once this interface was constructed, both GPS modules now communicated successfully with the PIC controller. The controller PCB, attenuator / keyer assembly built on another PCB, and the GPS module, were built into a single screened diecast box to give a standalone unit that was a complete beacon source - supplying a few milliwatts with the correct timing and power step sequence , albeit at only a few milliwatts. A photograph of the completed driver hardware showing the three modules can be seen in Figure 4

New Power Amplifier

Unfortunately, when it was tested the second donated Yaesu power amplifier was found to be faulty: two driver transistors had failed. There were no more spare PA units available, the driver transistors were obsolete and difficult to obtain, so my spare PA module was pressed into service and integrated to make up the first complete beacon assembly. The whole lot was mounted in a surplus 19” rack mount and put onto extended soak test, running on-air continuously as an attended beacon, signing G4JNT. The transmission sequence started immediately GB3RAL had completed its transmission. (Initially the beacon went on air signing G8IMR, my alternative callsign, until it was gently pointed out that G8IMR did not hold an NoV for 5MHz!)

There now remained the problem of what to do for a second power amplifier. A bodged repair job on the faulty one, using a different type of driver transistor, was just not the done-thing for high reliability electronics targeted at 24 hour per day operation, so the Yaesu amp was deemed to be beyond repair and another solution was needed. I had several surplus TMOS power FETs of the MRF134/5/6/7 family, and previously had built a broadband 8 watt amplifier covering 20 to 80MHz for a non-amateur related project using a MRF136. This had been straightforward to get going, so the design was lifted, the inductors modified for the lower frequency and a bit more feedback included to tame the increased gain at low frequencies. The circuit is shown in Figure 5. A single MRF137 device will supply approaching 20 Watts when used in this circuit, operating from a 24 Volt supply. At the 10 Watt output level, it was comfortably linear, running at less than 0.2dB of gain compression so would amplify the power step sequence correctly.

The only snag is that now a 24V power supply was needed. The logic circuitry had its own internal regulator down to 5 (and 3) Volts. Supplying the driver from the full 24V would lead to excessive dissipation in the driver unit, so an additional power resistor was added external to the driver to drop the voltage supplied to a more acceptable level to feed the regulators.

The Final Assemblies

The new PA was built into a second rack mount and integrated with its driver unit to form the final beacon hardware. It only required 24V at 2 Amps which could be delivered from a surplus PSU found at a rally.

As there was going to be plenty of 12 Volt power available at the site of GB3WES, the first beacon that had been built using the Yaesu PA became that one. This went on air in October 2004. GB3ORK was shipped up to the Orkneys along with the PSU, and came on air in December. Apart from a few teething and installation / shack decoration glitches and power cuts, both have operated continuously from then.

Some details of GB3WES can be found on the Web site of G3WGV given in Reference 4.

A Few Lessons Learned

The switched attenuator and keyer turned out to be the most complicated part of this project but, fortunately, a large number of surplus PIN diodes that were ideally suited to this task just happened to be available. These devices, especially in the quantities needed here, would otherwise have been quite expensive – typically they cost one to two pounds each. Discrete FET switches were tried, but failed to achieve the isolation needed for the higher stages of attenuation. An alternative would be to use packaged FET switches designed for RF routing – these are available from companies such as Minicircuits, and may have a slightly lower cost as many devices are included within one chip. However, isolation still couldn't be guaranteed and the final cost could begin to approach a that of a ready made attenuator module.

BUT, in retrospect, there was a much simpler solution – just use a different DDS chip. The Analog Devices AD9852 device includes on-chip programmable control of the output amplitude to 12 bits of resolution which allows the output power to be varied over a range of 70dB. Now, both power steps and keyer could be made by directly programming the DDS chip from the PIC controller, without any need for more RF hardware. The RF chain could now just simply be DDS chip and Power amplifier / filter. This device will form the basis of any future beacon projects undertaken.

Much time was wasted getting the PIC software to read NMEA data from a different GPS module. Instead, the proprietary binary format should have been used and the old NMEA compatible code jettisoned. It even appears out that the Oncore binary format has become an 'unofficial' standard that other GPS receiver manufacturers have incorporated into their products. For example, the Jupiter-T GPS module defaults to this format at switch on. Furthermore, these are quite reasonably priced, (I even had at least one spare!) and would have allowed for simple frequency locking circuitry with its 10kHz output.

The Future

As designed, the beacons can be used directly on 3.5 and 7 MHz, just by changing the PIC Code in the DDS controller. (In fact, new driver software in the DDS modules used does now allow up to four pre-programmed frequencies to be selected in the range DC to 12MHz). The timing controller PIC could easily be programmed to change frequency bands as well as generate the power / keying sequence. By adopting the AD9852 based concept described above, a completely integrated, single board, multi-band beacon driver could be produced. With the addition of a broadband PA, a complete multi-band propagation monitoring beacon becomes feasible, complementing those of the International Beacon Project on the higher bands.

Furthermore, the AD9852 can directly generate frequencies up to 80MHz, making its use in VHF and UHF beacons feasible. The ability to change the frequency in steps of minute fractions of a Hertz, together with the high resolution setting of amplitude and phase of the DDS output, means that a host of data modulation schemes could be incorporated into a new generation of modern beacon designs. At the other end of the spectrum, GB3SCX on 10GHz already uses an AD9851 DDS device to generate RTTY keying.

References

Ref 1 RSGB 5MHz group http://www.rsgb-spectrumforum.org.uk/beacon_reporting.htm
Ref 2 AD9850 DDS Module, G4JNT, RadCom November 2000
Ref 3 GPS Disciplined Oscillator, Brooks Sheera, W5OJM, QST July 1998
Ref 4 Details of GB3WES http://g3wgv.com/gb3wes.htm

Annex 1

Automatic Beacon monitoring Software

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 is 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 Figure 6

The software can be downloaded from Reference 1 ; look for the compressed file *5MHZBCNS.ZIP*

Annex 2

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 manufacturers' 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 is supplied in a variety of text based 'sentences', these differing in type depending on what information is contained and for where they are intended. The data rate is defined as 4800 baud, 8 bit stop-start signalling and is compatible with the RS232 (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:

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$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
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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 deg, 54.5876 min. N
The latitude in the same format, here 1 deg, 17.4041' W
Speed over ground, knots (zero)
Course over ground in degrees
Date in the form DDMMYY, here 14 / 12 / 2002.
Magnetic variation (3.5 degrees W)
* indicates the end of the data.
Followed by a checksum in hexadecimal, and terminated with a carriage return / linefeed pair, [CR][LF].