The ZL1BPU

Noise, Pulse

and

Sweep Generator

User Manual

Noise-Pulse Generator.doc

M. Greenman
20/09/02

This manual applies to hardware as described in “Sweep Generator Schematic.doc” and firmware SIGGEN2A dated 19/09/02.

Contents

1. Overview

The ZL1BPU Noise, Pulse and Sweep Generator uses a reduced instruction ***RISC*** micro controller to generate sophisticated radio frequency signals using a number of digital signal processing ***DSP*** techniques. It is very similar in concept to the ZL1BPU LF Exciter (almost identical hardware) and the ZL1BPU Signal Generator. However, the features offered are different, having both wide band noise and pulse generation capability, as well as the sine wave and sweep functions that are so useful.

The Generator is computer controlled, i.e. it has no conventional "front panel" controls. The operating frequency, the sweep, pulse, and on/off commands are all computer-controllable, using a ***KISS*** command protocol only slightly different from the other designs mentioned. The only front panel control is the output amplitude control, which can also be computer controlled if desired, although at a loss of control resolution.

The Generator has numerous modes, and operates over the frequency range from zero to about 400 kHz. The output is very precise, predictable and repeatable. The unit is controlled via a simple serial link, and is quite inexpensive to build, despite its technical performance.

The settings of the Generator are stored in internal memory, so when power is lost the Generator starts up in exactly the same condition when power is restored.

Although manual operation (using a Terminal program on the computer) is practical and convenient, the commands seem complex and some understanding of the mathematics is required. A bespoke computer program can easily alleviate this, and provide enhanced performance. A spreadsheet, DDSCALC.XLS, is available from the author to simplify these calculations.

2. Description

The purpose of this piece of precision test equipment is to provide reliable and accurate signals for a range of tests and measurements for Radio Amateur and general electronics audio and LF applications.. In particular, it allows precise and repeatable levelled carrier signals to be generated, controlled amounts of noise to be injected, antennas, antenna tuners and receivers to be swept for correct tuning and performance, power amplifiers to be tested using the pulsed ***CW*** mode. There are probably more applications than the author envisaged, simply because the design is so versatile.

The Generator consists of only three ICs and a handful of other components. The main device is an AVR AT90S2313 micro controller, which operates at 12 MHz. The digital values generated by the micro are converted to analog signals by a passive 8-bit digital to analog converter. The analog output is buffered and amplified by a 1W audio device with controllable level, which is used to provide the high power output. The amplifier has a frequency response to at least 250 kHz. The RS232 interface consists of a simple transistor design, powered by the PC serial port. A small 5V regulator powers the micro controller, and the unit operates from any 9 – 15V DC supply, typically a 12V SLA or NiCd battery pack, or a "wall wart" style DC supply. The current drawn is about 150mA. The unit is reverse polarity protected.

The Generator has four modes:

- Sine wave (CW) mode
- Noise mode
- Pulsed CW mode
- Pulsed DC mode

In addition, there is a sweep generator function, used with the sine wave mode. This function is set independently of other modes, and overrides the other modes.

There are three outputs:

- 50 OHM 1W controlled level output, 5 – 250 kHz.
- FIXED 0-5V output, high impedance
- SYNC output

The 50 OHM output is the main high powered output. It is transformer coupled from the power amplifier output, and has limited frequency response; about 5 kHz to 300 kHz. The amplifier is not damaged by open circuit or short circuit, but ***MUST NOT*** be coupled to an antenna while a transmitter is operating in the vicinity (even on another antenna). Be aware also that there is sufficient output from this amplifier to cause significant interference to other services if the output is coupled to an antenna.

The amplifier has DC level control, and the output is adjustable over greater than 60dB range. There is little leakage from the generator, and so the output can indeed be reduced to microwatts.

The FIXED output is direct from the D-A converter, and while it has no output adjustment, it has the merits of being completely flat from DC to in excess of 400 kHz, and generates a 0V to 5V signal. This output will drive about 50mV RMS into 50 Ohm.

The SYNC output is high when the Signal Generator outputs are on, i.e. when carrier or noise is being generated. It is low between pulses in pulse mode, and low when pulsed DC is at 0V. In Sweep Generator mode, this output is high only during the first step, and so provides a useful oscilloscope synchronizing signal.

There are two other connectors, the RS232 serial port for computer control, and the DC power connector. The one control knob adjusts the output level of the high power output, from about 1W down to microwatts.

Sine waves are generated very accurately using a 24 bit ***DDS*** technique. The frequency resolution is 0.08 Hz, and the range is 0.08 to 400 kHz. The output is 8 bit, very clean and free of harmonics and spurious responses. The output sample rate is 1.333 MHz.

Noise is generated using a 24 bit maximal length pseudorandom generator algorithm with four feedback terms. A table-lookup technique is used to maximize speed. The output is 8 bit, with a sample rate of 1.200 MHz, so the noise output is Gaussian in response, and useful to at least 400 kHz.

The pulsed CW mode uses the sine wave generator in tandem with a timer, which turns on and off the carrier. The sine wave always starts at zero phase angle, and the off period is at the "zero" point of the waveform (zero sine phase). The on and off time are independently controllable in 20 us steps from 20 us to 1.3 seconds.

The pulsed DC mode is similar to the pulsed CW mode, except that the output is +5V when on, and 0V when off. The on and off time are independently controllable in 20 us steps from 20 us to 1.3 seconds.

The sweep generator uses the CW set frequency as its starting frequency, and steps in 20 discrete frequencies in an increasing frequency direction. The step size is adjustable over the range 20 Hz to 5 kHz, giving a maximum sweep range of up to 100 kHz, anywhere within the operating range of the generator. Each step has a duration of 2.5 ms, so the total sweep time of 50 ms ideally suits an oscilloscope operating at 5 ms / division. The oscilloscope is triggered from the SYNC output of the generator, which is high only during the first frequency step.

General Commands

All the commands to the Generator are in a simple alphabetical format. There are 10 single letter commands. Some must be followed by hexadecimal values, which define the required setting. These commands are covered in detail under the relevant modes, and listed in the appendix.

HELP Provides a list of commands

Syntax: **H**

The list of commands is given with a terse description of their use and syntax. No other action takes place. For example:

```
H CMDS:

Axx     ADD offset
Fhhmmll FREQ set
H       HELP
Mn      MODE 0-3
Nhhll   NO pulse off
Pn      PORT
R       REPORT
T       TX ON
Wxx     WIDTH sweep
X       TX OFF
Yhhll   YES pulse on
```

MODE Sets the Generator operating mode.

Syntax: **M**n

There are four operating modes, represented by the value n, in the range 0 – 3. Other values will not be understood. The modes are:

0 Sine Wave CW Generator
1 Pseudo-random Noise Generator
2 Pulsed CW Generator
3 DC Pulse Generator

Because of the interrupt-driven nature of the software, this command executes the mode change, stores the new mode, and then resets the micro controller.

PORT Sets four general purpose outputs

Syntax: **P**n

Four general purpose outputs PD2, PD3, PD4 and PD5 are set by this command. The default value of n=0 clears (to zero) all outputs. N can take values from 0 – F (HEX), and the outputs are set bit-wise, with PD2 being LSB and PD5 MSB.

It is possible (although not implemented in the hardware) to use this command to set the carrier output power, with a four-bit R-2R network connected to the PD2 – PD5 outputs and controlling the DC volume control of the amplifier device. In this case consider this to be the "**POWER**" command. Otherwise, the pins become simple computer controlled outputs.

REPORT Reports settings

Syntax: **R**

This command causes the micro to issue a one-line report of all the current settings. For example:

```
R M2 A00 Y0010 N0020 W00 PF F030000
```

The command letter is listed before each value for easy identification. The values are in hexadecimal, just as they would be entered.

Hexadecimal commands are used for two reasons: first, it simplifies the command interpreter software in the Generator micro (which has limited program memory space); and second, it makes control of the device from a computer program easy since the command structure is simple and reliable.

It is important to note that all commands are issued during a communications interrupt, and the signal generator stops generating signals during these events. The "ON" LED also goes out.

3. Signal Generator

In order to understand how to operate the sine wave signal generator mode, it is important first to understand how the micro controller DDS technique works. The micro operates a very tight software loop (only six instructions, nine clock cycles), which looks up sine wave values from a table and places the value on a port for D-A conversion. The micro operates at a clock frequency of 12 MHz, so this loop is executed at a rate of 12 / 9 = 1.333 MHz. This is of course the sampling rate, and the Nyquist Criterion and practical low pass filter limitations set the upper limit of operation at about 1/3 of the sampling rate, or about 400 kHz.

In a DDS system, the current phase of the output samples is incremented by a fast adder, which adds a phase increment in every sample loop. In this equipment, the current phase is kept in a 24 bit register, and a single 24 bit addition is made during each loop, which. Thus the smallest phase increment (and hence frequency increment) is a step of 1 in 2^{24}. The sampling rate is of course the loop frequency. The actual frequency resolution can then be calculated:

Frequency Resolution = Sampling Rate / Adder Resolution

or

Frequency Resolution = $1.333 \times 10^6 / 2^{24}$ = 0.0794728398 Hz

This Frequency Resolution sets the basis of all calculations relating to setting the Signal Generator. Looked at another way, there are about 12.583 discrete frequency steps per Hz.

A calculator with HEX mode is indispensable for determining the values for the generator commands.

Sine wave Signal Generator mode is entered using the **M**0 command.

Generator Commands

ADD Add Offset to frequency

Syntax: **A**xx

This command adds a frequency offset of xx Frequency Resolution steps to the nominal carrier frequency, where xx is two HEX-ASCII characters representing a value from 0 to 255. The offsets are non-cumulative, i.e. issuing a second offset command will add to the nominal frequency, not the offset frequency.

Frequency offsets are positive, i.e. will increase the frequency. However, if the nominal carrier frequency is “negative”, the offset frequency will be *less negative*. This allows negative steps to be generated. See the **F** command for more detail.

The **A** command is normally used for computer controlled FSK or sweep generation, rather than manual control.

The value to use can be calculated as follows:

Value = Frequency Offset (Hz) / Frequency Resolution (Hz)

This value is then converted to 8-bit HEX. The range is 0.08 Hz to 20.26 Hz.

FREQUENCY Frequency Set command

Syntax: **F**hhmmll

This command sets the nominal carrier frequency of the Signal Generator. The resolution is one Frequency Resolution step. The value hhmmll is six HEX-ASCII characters representing a 24 bit number 0 to 16777215. Values that give frequencies much above 400 kHz are not useful (in the range **F**500000 to **F**C00000) as they exceed the Nyquist Criterion. However, values from **F**FFFFFF down to **F**DFFFFF are useful. In this case the phase adder adds a negative value, i.e. the phase steps backwards, and a “negative” frequency is generated. In CW Signal generator mode the only effect this has is that the ADD mode **A** commands subtract rather than add frequency, allowing negative steps.

Setting “negative” carrier frequencies also allows the Sweep Generator mode to sweep in the reverse (down-frequency) direction.

The value to use can be calculated as follows:

Value = carrier Frequency (Hz) / Frequency Resolution (Hz)

This value is then converted to 8-bit HEX. The useful range is 0.08 Hz to about 400 kHz. A value of zero stops the Generator.

TX ON Start Generator

Syntax: **T**

TX OFF Stop Generator

Syntax: **X**

4. Sweep Generator

The Sweep Generator is not a “Mode” as such, since it overrides other mode settings. The Sweep Generator has two simple settings, with 20 discrete frequency steps in an up-frequency direction (although see the note about “negative” frequencies in Chapter 3). The DDS technique allows incredible frequency flexibility, so it is possible to step instantaneously, and indeed phase synchronously, from one frequency to another.

Each of the 20 steps has a duration of 2.5 milliseconds, so the total sweep time is 50 ms, convenient for an oscilloscope set to 5 ms/div. The sweep speed was chosen as the best compromise between excessive screen flicker and proper sweeping of sharply tuned devices.

Sweep Commands

The sweep step size is set by the **WIDTH** command, and the starting frequency by the **FREQUENCY** command. The Sweep Generator function is entered by setting the **W** command to a non-zero value.

WIDTH Sets sweep step size

Syntax: **W**xx

Sets the frequency increment per sweep step to 256 Frequency Resolution steps per increment in value xx. The value xx is two HEX ASCII characters, expressing a value from 0 to 255. Thus the range is from zero (sweep off) to 255 x 256 = 65280 Frequency Resolution steps, or 65280 x 0.0794 = 5187.98 Hz, per step.

Since there are 20 frequencies (19 steps), the maximum sweep range is 19 x 5187.98 = 98571 Hz.

A list of suitable settings and convenient oscilloscope scales is given in the Appendix.

A setting of **W**00 turns off Sweep Generator mode. Normal operation on the previous mode may not return unless the **M**ode command is resent, or power is momentarily removed from the Generator.

5. Noise Generator

Noise Generation mode is entered using the **M**1 command. There are no controls specific to the Noise Generator.

The peak noise output is the same as the Signal Generator carrier output, but of course the energy is spread over a wide frequency range. Thus at any single frequency the level appears to be 20 dB or more lower than the carrier.

Noise is generated using a maximal length pseudo-random sequence, 24 bits long. The sampling rate is 1.2 MHz, and so the first null is 1.2 MHz. The spectrum of the noise is essentially a squared sin x/x response, so is approximately flat to about 150 kHz, then drops to about –1 dB at 300 kHz, and -6dB at 500 kHz.

The RMS noise voltage can be calculated as follows:

$$\mathbf{V_{noise} = peak\ amplitude.\sqrt{(2 / f_{clock})} \qquad (Volt/\sqrt{Hz})}$$

In our case $2/f_{clock}$ is 1.667×10^{-7} seconds, so the square root is 4.08×10^{-4} root seconds.

The peak amplitude is easily measured with an oscilloscope, being one half the p-p measurement. The noise received within a given bandwidth can then be calculated. For example, at 135 kHz, with a bandwidth of 13.5 kHz (unloaded Q of 10), the noise voltage from a 5V p-p noise signal would be $2.5 \times 4.08 \times 10^{-4}$ = **0.001 V/root Hz**.

Thus in a 2.4 kHz communications bandwidth, there would be $.001 \times \sqrt{2400}$ = 48 mV noise. (At this frequency there is no need to compensate for the frequency response of the noise envelope).

6. Pulse Modes

The Pulsed CW mode is entered using the **M**2 command, and the Pulsed DC mode with the **M**3 command. In most respects these two modes are similar, except that during the “ON” phase the Pulsed CW mode generates an RF carrier frequency (set by the **FREQ** command), while the Pulsed DC mode generates about +5V DC; during the “OFF” phase the Pulsed CW mode generates an average voltage (mid point of the sine wave), while the Pulsed DC mode generates about 0V DC.

The Pulsed CW mode always starts with a zero phase carrier, but the end of the pulse is not so easily controlled. The phase will depend on the relative frequency and on time values.

With low carrier frequencies or short on times, it is possible to generate partial sine waves! With care it is possible to adjust the carrier frequency or the on time so that there is an exact number of cycles per pulse.

The “ON” and “OFF” times are set by the two pulse commands **YES** (ON) and **NO** (OFF).

NO Sets the duration of the pulse OFF period

Syntax: **N**hhll

The off-time resolution is 21.333 microseconds, and the range is 0 to 65535 times this, or about 21 us to about 1.4 sec. The value hhll represents a number in this range expressed as four HEX-ASCII characters. To calculate an off period use the following formula:

Off (or On) value = period (seconds) x 46875 –1

For example, a period of 1 millisecond would be 0.001 x 46875 –1 = 46 (to nearest integer) or 2E (HEX). Thus the **OFF** command would be **N**002E.

YES Sets the duration of the pulse ON period

Syntax: **Y**hhll

The on-time resolution and range is identical to the off-time, and the command calculations are the same. The on-time and off-time can be set completely independently. As in the above example, an ON time of 1 millisecond would be achieved with the command **Y**002E.

7. Appendix

Specifications

Spectral Purity
Second harmonic –42 dBc, third harmonic –50 dBc (no low pass filter). All harmonics at least –50 dBc (with low pass filter). Below 20 kHz, all harmonics –60 dBc or better. Random spurii better than –60 dBc, close-in noise below –60 dBc within 1 Hz.

Sampling rate 1.33 MHz (Nyquist frequency 660 kHz). Sampling clock and alias image at 1.4 MHz -42 and –54 dBc respectively.

Noise mode sampling rate 1.2 MHz, first null is 1.2 MHz. Noise is approximately flat to about 150 kHz, then drops to about –1 dB at 300 kHz, and –6 dB at 500 kHz. At 135 kHz noise output is about –22 dBc, i.e. relative to sine wave Signal Generator mode.

Operating Range
0.08 Hz to 400 kHz, in any step size, with a resolution of 0.08 Hz. Power amplifier response drops off below 7 kHz and above 250 kHz.
500mW power bandwidth 10 kHz to 200 kHz, and depends mostly on the output transformer and coupling network.

Power Output
Amplifier: Up to 1W into 50 Ohm load. Power level adjustable over more than 60dB range using a DC control.
Direct: Output without power amplifier is 5V p-p into 1M Ohm, or 1V RMS into 1k.

Digital Outputs
8 bit sine data to D-A converter. Generates an 8-bit monotonic analog output 0-5V.
Four digital outputs PD2 – PD5 can be controlled for external use via serial command.

Power Supply
+12V DC to +15V DC at about 150mA. Supply need not be regulated. Key up 10mA, key down up to 150mA. Will operate at reduced output down to 7V. No standby power required for memory retention.

Commands
Ten immediate mode user or computer commands.

Serial Interface
RS232, TXD and RXD only, at 9600 bps, no parity, eight bit data, one stop bit.
The synthesizer stops while processing commands.
11 bytes of EEPROM are used to store the current user settings for power-up beacon or normal mode restoration. Changes are saved automatically as they are made.

Physical
Can be built on a prototype board about 100 x 75mm and will fit in box of similar size. Will operate from 0 to 70°C and will tolerate thermal and mismatch overload. Micro controller can be programmed and reprogrammed in circuit.

Modes
CW sine wave carrier, Noise, Pulsed CW, Pulsed DC, and swept sine wave.

Command Summary

Axx ADD

Add offset of xx resolution steps, where xx is "00" to "FF.

Fhhmmll FREQUENCY

Set frequency to this value times the resolution. The value hhmmll is a 24 bit binary number expressed as six hexadecimal characters, "0" to "F".

H HELP

Simple help message listing these commands.
Mn MODE
Sets the operating mode, where n is a number 0 to 3.

0 Sine wave Signal Generator
1 Noise Generator
2 CW Pulse Generator
3 DC Pulse Generator

Nhhll NO

Sets the pulse mode off-time, in steps of 21 us. hhll represents a value 0 – 65535.

Pp PORT (or POWER)

Sets Port D outputs PD2, PD3, PD4 and PD5 according to the least significant bits of value "p". These ports can be used with a 4-bit D-A to set output power.

R REPORT

Requests a message giving the current settings.

T TX ON

Turns the generator output on.

Wxx WIDTH

Sets sweep step size, where xx is "00" to "FF" in
two hexadecimal characters, in Frequency Resolution steps x 256. W00 turns off the sweep.

X TX OFF

Turns the generator output off.

Yhhll YES

Sets the pulse mode on-time, in steps of 21 us. hhll represents a value 0 – 65535.

Frequency Tables

Typical carrier or sweep-start frequencies, and sweep steps for 12.000 MHz crystal operation.

Frequencies

Freq, kHz	Setting, HEX
0	F000000
1	F003126
2	F00624D
5	F00F5C2
10	F01EB85
20	F03D70A
50	F0999999
100	F133333
120	F170A3D
125	F180000
130	F18F5C2
134.2	F19C432
140	F1AE147
150	F1CCCCC
200	F266666
250	F300000

Steps

Step size, Hz	Sweep/div, Hz	Setting, HEX
0	0	W00
100	200	W04
125	250	W06
200	400	W09
250	500	W0C
500	1000	W18
1000	2000	W31
1250	2500	W3D
2000	4000	W62
2500	5000	W7A
5000	10kHz	WF5
5200	10.4kHz	WFF

Sweep Generator Scales

The scales below are a useful and convenient way to set up the Sweep Generator. Simply print out the scales at a size to match the oscilloscope graticule markings, and slip the relevant one at the bottom of the oscilloscope screen. Then enter the commands given on the right side of the slip of paper into the Generator.

100 105	110 115	120 125	130 135	140 145	150 155	160 165	170 175	180 185	190 195

100 – 150 kHz 10kHz/div F133333 WF5

125 126	127 128	129 130	131 132	133 134	135 136	137 138	139 140	141 142	143 144

125 – 145 kHz 2kHz/div F180000 W31

130	131	132	133	134	135	136	137	138	139

130 – 140 kHz 1kHz/div F18F5C2 W18

125 127	130 132	135 137	140 142	145 147	150 152	155 157	160 162	165 167	170 172

125 – 175 kHz 5kHz/div F180000 W7A

125 127	130 132	135 137	140 142	145 147	150 152	155 157	160 162	165 167	170 172

150 – 200 kHz 10kHz/div F1CCCCC WF5

0 5	10 15	20 25	30 35	40 45	50 55	60 65	70 75	80 85	90 95

0 – 100 kHz 10kHz/div F000000 WF5

Glossary

CW	Continuous Wave. A radio term to describe a constant or keyed single carrier frequency.
DDS	Direct Digital Synthesis. A technique for generating periodic waveforms with high precision and great accuracy.
DSP	Digital Signal Processing
KISS	"Keep it Simple, Stupid"! A term commonly used to describe the simplest peripheral control protocols.
LF	Low Frequency. That part of the electromagnetic spectrum between 30 kHz and 300 kHz.
RISC	Reduced (or Rich) Instruction Set Controller. A type of micro controller which is designed for very fast processing. Typically the RISC micro uses a single memory fetch per instruction cycle and frequently just one clock cycle per instruction.