Decimal DDS Signal Generator
and
Sweep Generator

User Manual

DECGEN.doc

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This manual applies to hardware as described herein and firmware DECGEN1A dated 01/04/05 and DECGEN1B dated 04/04/05.

Contents

1. Overview

This Signal Generator uses a fast ***RISC*** micro controller to generate sophisticated radio frequency signals using a number of digital signal processing ***DSP*** techniques.

The Generator is computer controlled, i.e. it has no conventional “front panel” controls. The operating frequency, the mode, sweep and other commands are all computer-controllable, using a ***KISS*** command protocol and decimal numbers. The only front panel control is an optional output amplitude control.

The Generator has four 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.

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

Manual operation (using a Terminal program on the computer) is practical and convenient, and the commands are simple and easy to learn. A bespoke computer program can be used to further enhanced performance under program control’ for example to run a test sequence.

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 audio and LF application. In particular, it allows precise and repeatable levelled carrier signals to be generated, and independent dual tones to be generated. In one version (DECGEN1A), it allows filters, antennas and receivers to be swept for correct tuning and performance. One version (DECGEN1B) has an ***RFID*** mode, capable of transmitting pseudo RFID tag data in two standard formats used for companion animal ID applications (pet “microchips”).

The Generator consists of only two or three ICs and a handful of other components. The main device is an AVR AT90S2313 micro controller, which operates at 16 MHz. An ATTINY2313 can also be used (pin and code compatible). The digital values generated by the micro are converted to analog signals by a passive 8-bit digital to analog converter. The analog output can be used in two ways – either direct, using a micro-switched attenuator arrangement (the preferred arrangement). Optionally the output can be buffered and amplified by a 1W audio device with controllable level, which is used to provide the high power output. The direct output frequency response is to 400kHz, while 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 maximum. The unit is reverse polarity protected.

The Generator has four modes:

- Sine Wave (CW) mode
- Square Wave mode
- Ramp mode
- Dual-Tone mode

In addition, there is a sweep generator function, normally used with the sine wave mode. This function is set independently of other modes, and overrides the other modes. In another version, this function is replaced by an FSK pattern generator.

There are three outputs:

- 50 OHM 1W controlled level output, 5 – 250 kHz (option)
- 1000 OHM –1dBm controlled output with 48dB step attenuator in 3dB steps
- SYNC output

The 1000 OHM output is direct from the D-A converter, and can produce 5V p-p from DC to 400kHz (0.88V RMS Sine Wave into 1000 Ohm). A 1000 Ohm stepped attenuator, controlled by the micro, provides accurate 3dB steps into 1000 Ohm. This output has the merit of being completely flat from DC to in excess of 400 kHz, and generates a 0V to 5V signal (open circuit). This output will drive about 50mV RMS into 50 Ohm, although of course the attenuators would need redesigning for 50 Ohm use.

The 50 OHM output is an optional high powered output. It is transformer coupled from the power amplifier output, and has limited frequency response; about 5 kHz to 300 kHz, or 100Hz to 5kHz, depending on the output transformer used. The amplifier is not damaged by open circuit or short circuit, but ***MUST NOT*** be coupled to an antenna without the appropriate licence. Be aware also that there is sufficient output from this amplifier to cause significant interference to other equipment if the output is coupled to an antenna. The amplifier has DC level control, and 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 SYNC output is high when the Signal Generator outputs are on, i.e. when a waveform is being generated. 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 added with the power amplifier option adjusts the output level from about 1W down to microwatts.

Sine waves are generated very accurately using a 24 bit ***DDS*** technique. The frequency resolution is 0.1 Hz, and the range is 0.1 to 400 kHz. The output is 8 bit, very clean and free of harmonics and spurious responses. The output sample rate is 1.777 MHz. The square wave and ramp waveform (positive ramp) are generated in a similar way, have 24 bit resolution, 1μs rise time and the same frequency of operation. The dual-tone mode uses a slower generation technique with 800kHz sampling rate, and each tone is 7-bit resolution. The tones are of accurate equal amplitude and independently set.

The sweep generator in DECGEN1A uses the Sine Wave 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.

The FSK mode in DECGEN1B can simulate FECAVA™ and AVID™ encrypted tags at subcarrier level. Any two frequencies can be used, although the normal frequencies used are 12.500 and 15.625kHz. A “010101” pattern option is also provided, and the user can substitute other 96-bit data patterns by loading them into EEPROM.

Two other generators in this family, “SIGGEN” and NOISE-PULSE” operate in a similar way, but providing different waveforms. SIGGEN provides Sine, Square, Triangle and Ramp to 400kHz. Noise-Pulse provides Sine, pulsed sine, pulse and pseudo-random noise to 400kHz. These two generators include simplified sweep facilities, but (unlike DECGEN) are programmed in hexadecimal.

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 numbers, 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. The micro is also reset.

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 Square Wave Generator
2 Ramp Generator
3 Dual-Tone Sine Generator

POWER Sets four general purpose outputs. Normally used to control a 3dB step attenuator.

Syntax: **P**p

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. "p" can take values from 0 – F (HEX), and the outputs are set bit-wise, with PD2 being LSB and PD5 MSB.

The normal mode of operation is to connect these outputs to relay drivers, PD2 to switch 3dB, PD3 6dB, PD4 12dB and PD5 24dB, so ***3 x p*** represents the attenuation in dB.

It is possible (although not implemented in the published design) to use this command to set the optional amplifier 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. Unfortunately the attenuation provided is this manner is neither linear or particularly repeatable. The pins can also be used as 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, not unfortunately in decimal as they would be entered.

Hexadecimal display is used for because it simplifies the software in the Generator micro (which has limited program memory space).

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. If a command remains uncompleted, the generator remains off.

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 Direct Digital Synthesis (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. In square wave and ramp modes a waveform calculation is used instead, and these modes are also carefully tailored to use nine clock cycles.

The micro operates at a clock frequency of 16 MHz, so this DDS loop is executed at a rate of 16 / 9 = 1.777 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 500 kHz, although the waveform distortion is quite visible at 400kHz. In dual-tone mode the loop is executed more slowly so that two sine waves can be constructed independently from the same table. The loop is executed in 20 clock cycles, the sample rate is 800kHz and the upper frequency limit about 250kHz.

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. Thus the smallest phase increment (and hence frequency increment) is a step of 1 in 2^{24}. The sampling rate is of course the DDS loop frequency. The actual frequency resolution can then be calculated:

Frequency Resolution = Sampling Rate / Adder Resolution

or

Frequency Resolution = $1.777 \times 10^6 / 2^{24}$ = 0.105963812934027 Hz

This Frequency Resolution sets the basis of all calculations relating to setting the Signal Generator. Looked at another way, there are about 9.437 discrete frequency steps per Hz. In order to provide easily understood frequency controls, an internal multiplication (by exactly 9.4375) is made so that the user can enter decimal numbers, have them converted to binary, and then multiplied so the DDS generator is given the correct value. 9.4375 is a convenient approximation that is easily made ($9\ ^7/_{16}$), and the crystal is calibrated slightly low (to 15.999464MHz) to compensate. In Dual mode, a further multiplication ($^{20}/_9$) is made to ensure that this mode is also direct input, although some resolution is lost.

Generator Commands

. DECIMAL or “Dot”, add offset to frequency

Syntax: **.x**

This command adds a frequency offset of “x” Frequency Resolution steps to the nominal carrier frequency, where “x” is a HEX-ASCII characters representing a value from 0 to 15. 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. This command can be considered a “decimal point” command, since each resolution step is close to 0.1Hz. For example, “.2” gives a frequency offset of 0.2118Hz. This command and the F command can be used together in a natural and logical way. For example,

F123456.7 will set the frequency very close to 123456.7Hz.

FREQUENCY Frequency Set command

Syntax: **Fxxxxxx**

This command sets the nominal carrier frequency of the Signal Generator, in all modes. The resolution is about 10 Frequency Resolution step, and the resulting frequency will be within 1Hz. The value “xxxxxx” is six numeric characters representing a number 0 to 500,000. Values that give frequencies much above 400 kHz are not useful as the waveform becomes distorted and they may exceed the Nyquist Criterion.

Setting the frequency with the **Fxxxxxx** command will cancel any existing Dot “decimal point” offset.

Simply enter the required frequency in Hz (with no separators or commas). Six characters must be entered, so use leading zeros; for example for 100Hz enter **F000100**. Setting **F000000** stops the Generator. Setting **F000000.1** will generate 0.106Hz.

MODE Waveform mode selection

Syntax: **Mx**

M0 selects sine wave, **M1** selects Square Wave, **M2** selects Ramp Wave (positive going ramp) and **M3** selects Dual Frequency Sine Wave mode. In this last mode the most recent two F commands set the two sine wave frequencies. Each waveform is 7-bit so the overall output remains 5V p-p.

The Sine waveforms are generated using a 256-step 8-bit table. The other waveforms are 8-bit and calculated on the fly. All algorithms operate at the same speed with the exception of Dual Sine.

4. FSK Generator

The FSK Generator (only in DECGEN1B) is not a “Mode” as such, since it overrides other mode settings. The FSK Generator has three settings, the two FSK frequencies and a pointer to the start of the message transmitted. The data rate is fixed at 400us per bit, the rate used for companion animal tags. 96 data bits are transmitted per telegram, and the message repeats with no delay.

In FSK Generator configuration the most recent two F commands set the two FSK sine wave frequencies.

Three messages can be generated:

Address	**Message**	**Data**
70_{HEX}	FECAVA	`55 1D 56 5A 6A 5A 99 6A 59 69 65 99`
80_{HEX}	AVID Encrypted	`5F 81 23 22 F6 D6 7F 82 D6 54 DE F2`
90_{HEX}	TEST pattern	`55 55 55 55 55 55 55 55 55 55 55 55`

Invalid patterns can be selected by using other addresses. The messages are stored in EEPROM at addresses 10_{HEX}, 20_{HEX} and 30_{HEX}, and moved into RAM at program start. Messages are selected using the **Dxx** (DATA!) command.

DATA Enable FSK mode at this address (address of tag data). Setting **D00** stops FSK mode.

Syntax: **Dnn**

Values are in hexadecimal 00 – FF. Valid values are 70_{HEX}, 80_{HEX} and 90_{HEX}. Other values will generate erroneous data. The FECAVA and AVID Encrypted data was captured from real tags, and has valid header and checksum. The test pattern does not have a valid header or checksum. By setting an address such as 68_{HEX}, or 78_{HEX}, it is possible to send telegrams with a valid header embedded, but with invalid data.

5. Sweep Generator

The Sweep Generator (only in DECGEN1A) is not a “Mode” as such, since it overrides other mode settings. The Sweep Generator has three simple settings, and defaults to a sweep with 20 discrete frequency steps in an up-frequency direction. 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 (default) 20 steps has a (default) duration of 2.5 milliseconds, so the total sweep time is 50 ms, convenient for an oscilloscope set to 5 ms/div. The default sweep speed and number of steps were chosen as the best compromise between excessive screen flicker and proper sweeping of sharply tuned devices. A wide range of other settings is permitted.

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: **Wxxxx**

Sets the frequency increment per sweep step in Hz. The value xxxx is a four-digit decimal number, 0000 to 9999. Thus the range is from zero (sweep off) to almost 10kHz per step.

Since there are typically 20 frequencies (19 steps), the maximum sweep range is 19 x 9999 = 189981 Hz.

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

A setting of **W00** 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.

COUNT Sets the number of sweep steps. The default is 14_{HEX} (20).

Syntax: **Cnn**

A hexadecimal value 01 – FF defines the number of sweep steps. Each step has the same size, and if a high value is set, it is easy for the sweep to exceed the total range of the generator.

DWELL Time spent on each step in sweep mode, in increments of 64µs.

Syntax: **Dnn**

The default value is 27HEX (2.5ms), giving a 20 step display at 5ms.div. Values are in hexadecimal 01 – FF, so the maximum DWELL is 16.32ms. For even slower sweeps simply use more steps.

6. 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), or 800kHz (Nyquist frequency 400kHz) in Dual mode. Sampling clock and alias image at 1.4 MHz -42 and –54 dBc respectively.

Dual mode outputs are amplitude, phase and frequency independent. The output levels are identical and each 3dB lower than single sine wave mode.

Operating Range
0.106 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. Approximately 1Hz – 200kHz in Dual mode.

Optional mplifier 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, 800mV RMS (-1dBV) into 1k Ohm, 84mV RMS (-38dBW, 98dBµV) into 50 Ohm.

Digital Outputs
8 bit sine data to D-A converter. Generates an 8-bit monotonic analog output 0-5V. Dual-tone sine output is 7-bit. Four digital outputs PD2 – PD5 controlled a 3dB 1000 Ohm stepped attenuator 0 – 45dB via serial command.

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

Commands
Ten immediate mode user or computer commands. EEPROM is used to store the current user settings for power-up restoration. Changes are saved manually with the **S** command.

Serial Interface
RS232, TXD and RXD only, at 9600 bps, no parity, eight bit data, one stop bit. The synthesizer stops while processing commands.

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, Square wave, Positive Ramp or Dual-tone sine wave. Swept (digitally stepped) sine wave or FSK data option depending on model.

Command Summary

.x **DECIMAL**
Decimal place frequency offset, 0 – 9 meaning 0.0 to 0.9Hz (actually 0.106Hz steps).

Cnn **COUNT**
Number of steps used in sweep mode. Default is 14_{HEX} (20). Values are in hexadecimal 01 - FF.

Dnn **DWELL**
Time spent on each step frequency in sweep mode, in increments of 64us. Default is 27_{HEX} (2.5ms). Values are in hexadecimal 01 - FF.

Fxxxxxx **FREQUENCY**
Set frequency, where xxxxxx is six digits 000000 to 999999Hz. Second frequency in DUAL mode set with same command.

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
- 1 Square Wave
- 2 Ramp Wave
- 3 Dual Sine Wave

Pn **POWER**
Sets the output signal level if the level controlled amplifier or stepped attenuator option is used. n is a hexadecimal number, "0" to "F".

R **REPORT**
Requests a message giving the current settings. Unfortunately for humans, the report is in hexadecimal, not decimal!

S **SAVE**
Saves current settings. Saves FREQUENCY (both), DECIMAL place offset, MODE, WIDTH and POWER.

Wxxxx WIDTH
Sets sweep step size in Hz, where xxxx is 0000 to 9999Hz. The sweep range is 20Hz (W0001) to 200000Hz (W9999). The start frequency for the sweep is set by the F command. There are by default 20 steps at 2.5ms intervals. Setting **W0000** turns off the sweep function.

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.
RFID	Radio Frequency Identification