HF low distortion sinewave signal generator, 3 to 30MHz

1. Introduction

The popular QRP Labs VFO/SigGen kit is a controller for the Si5351A Synth module kit. It has rotary encoder tuning of the main Clk0 output, and one fixed (configurable) output that may be used as a BFO for example, in a superhet radio. The output frequency range is from 3.5kHz to almost 300MHz. A GPS module can be connected to achieve GPS discipline to better than 0.1ppm. There are many configurable features such as presets, IF Offset, and configurable on-screen display.

The outputs of the VFO/SigGen kit are squarewave outputs directly from the Si5351A Synth kit, with an amplitude of 3.3V Peak-peak. For those applications where a sinewave output is required, a Low Pass Filter can be connected at the output of the Si5351A and will attenuate the harmonics, converting the squarewave into a beautiful sinewave. The simple addition of a Low Pass Filter in this way produces a sinewave but is applicable only to a relatively narrow band of frequencies. Coverage of a wider range requires changing the Low Pass Filter.

Starting in VFO/SigGen firmware s1.03, there is a configurable facility for controlling up to 6 external relays, depending on output frequency. This is intended to be used with the QRP Labs 6-band LPF switching kit. With suitable selection of Low Pass Filters, a clean sinewave can be generated across a wide bandwidth. This application note describes a low distortion sinewave signal generator using this system, covering at least the range 3 to 30MHz and with all spurii at least 45dB below the fundamental sinewave output.

2. Module interconnections

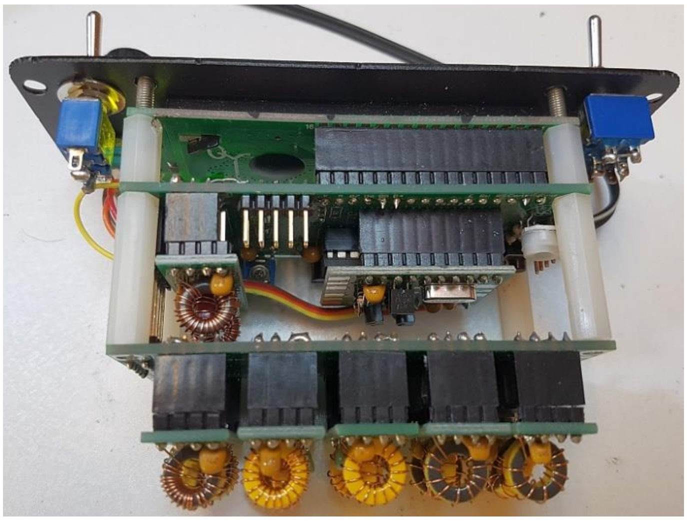
This project uses the following QRP Labs modules:

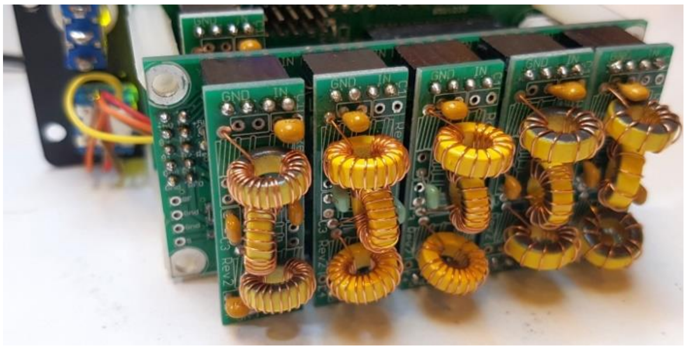
- VFO/SigGen kit with firmware version at least s1.03
- 6-band relays-switched LPF kit
- 60m Low Pass Filter kit
- 40m Low Pass Filter kit
- 30m Low Pass Filter kit
- 20m Low Pass Filter kit
- 15m Low Pass Filter kit
- 10m Low Pass Filter kit

Optionally you may wish to add:

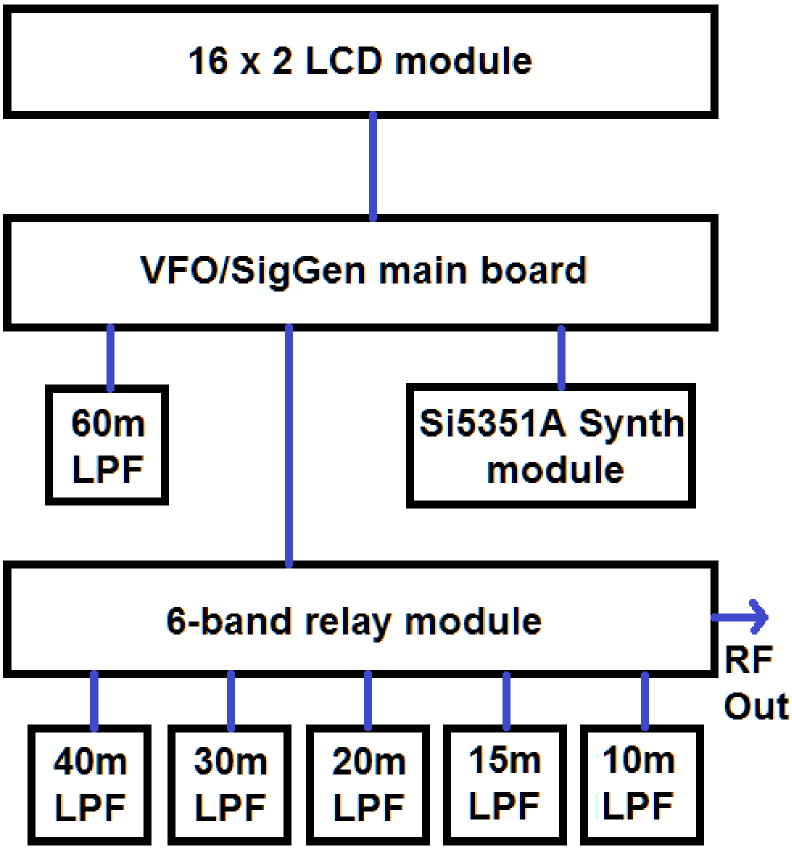
- QLG1 GPS Receiver kit for GPS discipline
- VFO Enclosure kit for a nice enclosure and switch/button/connectors/hardware accessories

These photographs show the module assembly used for the measurements in this App Note. It consists of the modules listed above, with some substitutions as it was put together from leftovers available in the lab. An “Ultimate3 QRSS/WSPR” enclosure front panel is used for convenience. Note the substituted steel screws to hold the front panel to the LCD module – the real enclosure kit includes black screws for this purpose, as well as 6mm spacers and other mounting hardware, connectors, switches etc. The green backlight LCD module is also non-standard – the VFO/SigGen kit is supplied with a blue backlit module!





The 60m band LPF filter is plugged into the socket on the main VFO/SigGen board; the other LPFs 40, 30, 20, 15 and 10m are plugged into the relay board. The display is configured simply with the frequency on the top row, and the LPF band slot displayed in the bottom left, using the #LP tag. Here it shows filter 4, which is the position of the 30m LPF used for the displayed 10MHz output frequency.

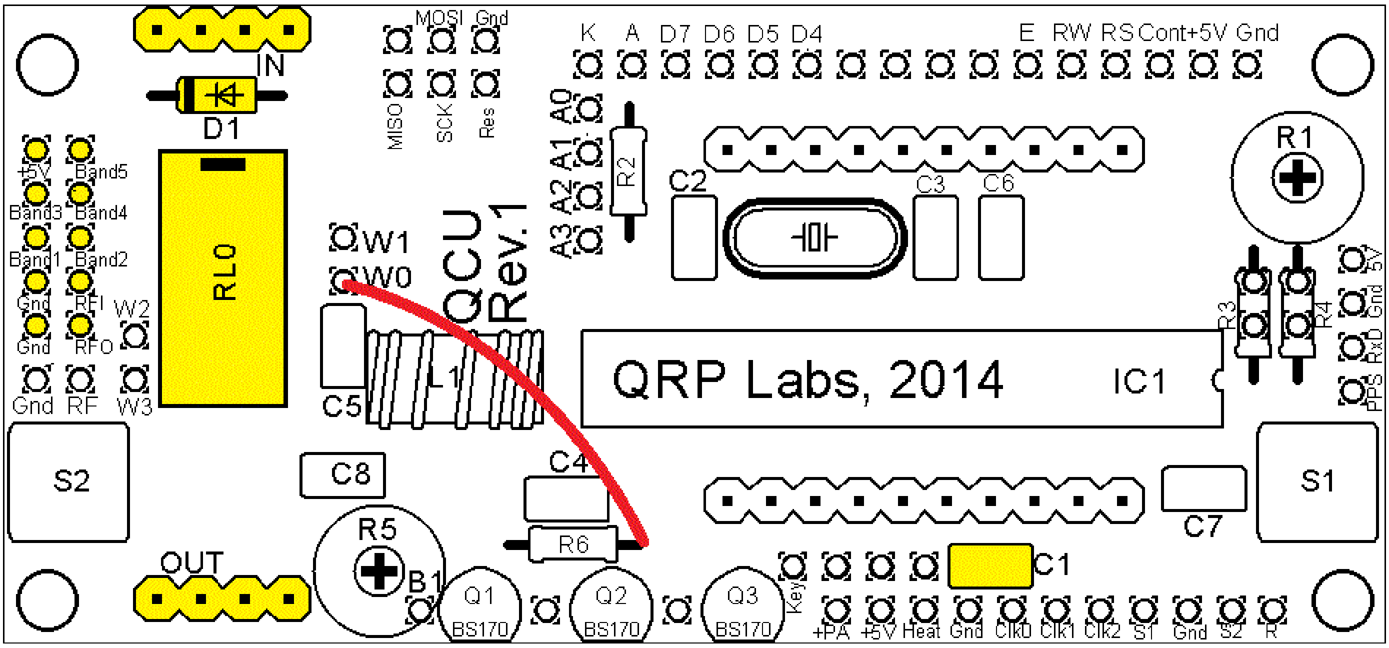


The block diagram (right) shows the module assembly. The positions of the Low Pass Filter modules ARE somewhat important. In particular, the lowest frequency should go on the main VFO/SigGen board. The highest frequency (10m band LPF) must go in slot 1, closest to the RF output from the relay board. If you have at least Rev 5 of the relay PCB, the highest frequency LPF is always in circuit. This provides improved attenuation of VHF harmonics.

3. VFO/SigGen assembly

The assembly of the VFO/SigGen kit requires some additions to the assembly instructions, in order to accommodate the relay board and Low Pass Filter kits, and to route the Clk0 signal through the filters.

This layout diagram shows the changes and parts that need to be installed on the main VFO/SigGen PCB, in **addition** to the components specified in the VFO/SigGen assembly instructions.



Build the VFO/SigGen kit following the assembly instructions, build the relay-switched LPF kit following the assembly instructions, and also the six LPF kits.

Undertake changes as follows:

- Install 0.1uF capacitor (code “104”) in position C1 (supplied with VFO/SigGen kit).
- Connect an additional wire from the right hand side of R6, to pad W0. This routes the Clk0 RF signal to the relay, bypassing the PA components which are not installed in the VFO/SigGen kit (they are used in the Ultimate3S QRSS/WSPR kit).
- Install 1N4148 diode D1 (supplied with 6-band relay switching kit).
- Install TX2-5V relay RL0 (supplied with 6-band relay switching kit).
- Install two 4-pin header sockets at “IN” and “OUT” locations (supplied with VFO/SigGen kit)
- Install the 2 x 5-pin tall male header (supplied in the relay-switched LPF kit) to the left edge of the VFO/SigGen board, to connect with the 2 x 5-pin female socket on the relay-switched LPF PCB

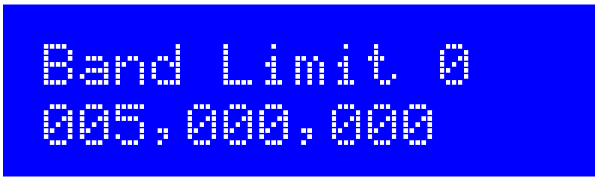
Once these components have been installed, and the rest of the VFO/SigGen kit assembly instructions completed, the kit is ready for assembly with the other modules – the relay-switched LPF kit and six LPF kits. The RF output should be taken from the SMA connector pads end of the relay-switched LPF board.

Plug the 60m LPF into the main VFO/SigGen PCB (relay 0). Populate relay positions 1 to 5 with LPFs 10, 15, 20, 30 and 40m. This ordering is IMPORTANT!

4. VFO/SigGen Configuration

A reminder: Firmware version s1.03 or above is necessary for controlling the relay board.

Now it is necessary to configure the band limit configuration settings of the VFO/SigGen kit. These are the six settings labelled “Band Limit 0” to “Band Limit 5”.



Edit these configurations as follows:

Band Limit 0	005,000,000	(60m LPF)
Band Limit 1	050,000,000	(above 10m LPF, see note below)
Band Limit 2	021,000,000	(15m LPF)
Band Limit 3	014,000,000	(20m LPF)
Band Limit 4	010,000,000	(30m LPF)
Band Limit 5	007,000,000	(40m LPF)

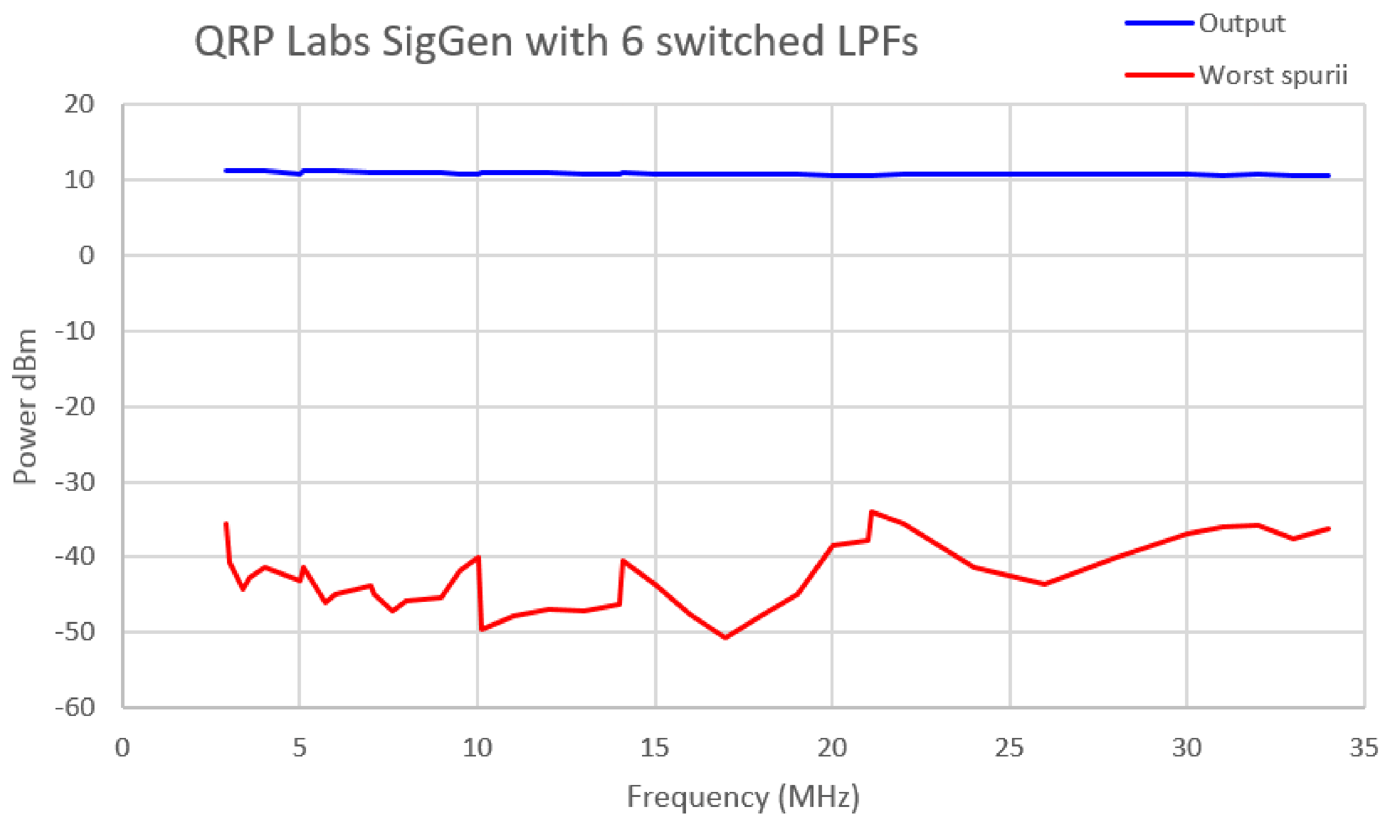
The VFO firmware selects the lowest frequency relay which it can, according to this table of band limits. The relay which is activated is the LOWEST one with limit frequency less than or equal to the VFO operating frequency.

Note that “Band Limit 1” is the highest frequency. The 10m Low Pass Filter is in this relay position (slot 1). The cut-off of that filter is something near, but above, 30MHz. If you set Band Limit 1 to 30,000,000, then at any operating frequency higher than 30MHz, NONE of the relays will be activated. Practically speaking, you may prefer to have some output at a reduced performance, than none at all. So you can set Band Limit 1 to something somewhat higher than 30MHz. In these tests it was configured to 50MHz.

5. Performance measurements

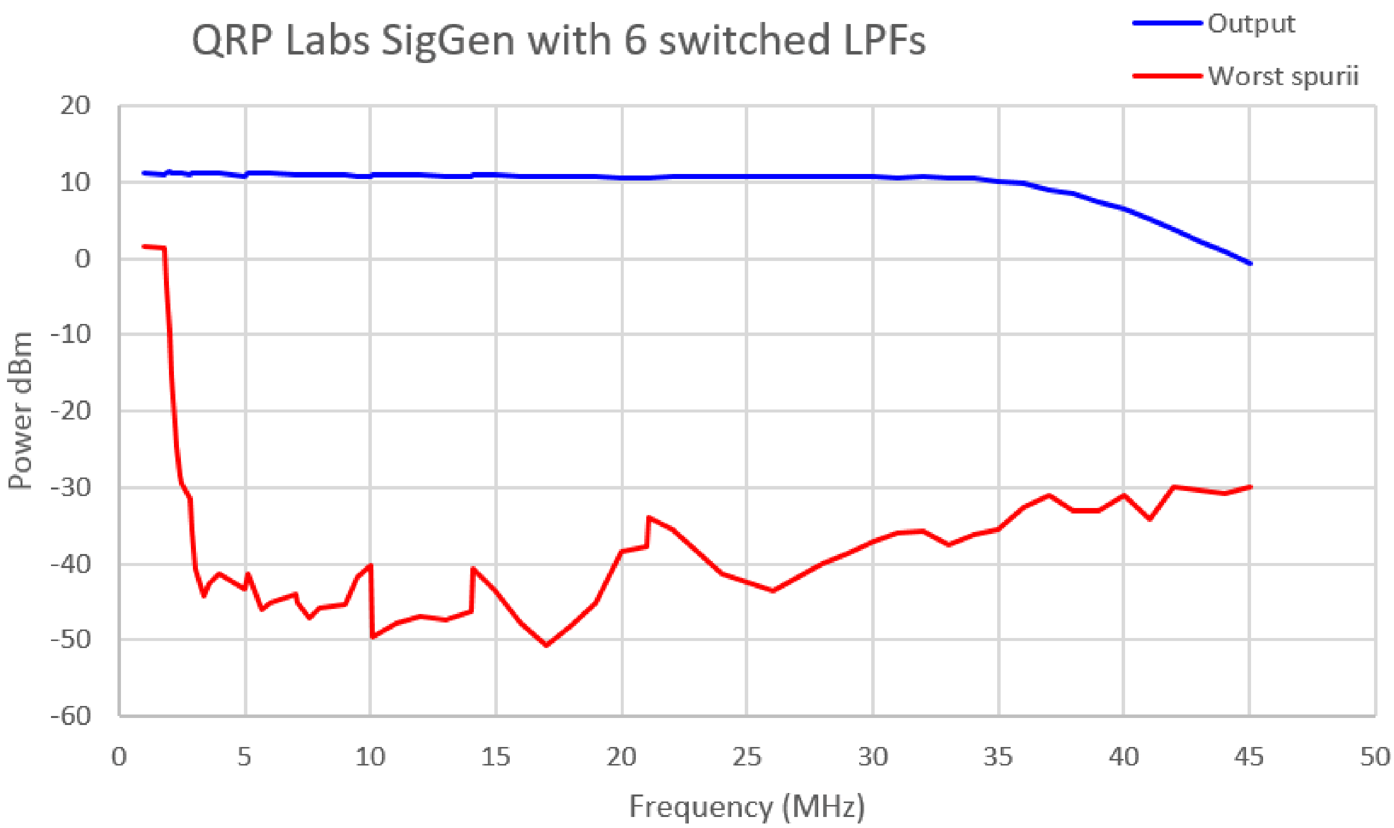
The pictured VFO/SigGen with Relay-switched LPF kit and six LPFs (60, 40, 30, 20, 15 and 10m) were tested into an Advantest R3361C Spectrum Analyser with 50-ohm input via about 1m RG58 coaxial cable.

Measured output was flat across the range 2.9MHz to 34MHz: 10.8dBm into 50 ohms, +/- 0.4dBm. The worst spurri was at -34dBm, which is -45dBc (45dB below the fundamental output). See chart below.



The chart below has a wider range, covering 1MHz to 45MHz output.

At the lower end, below 2.9MHz the spurious output level worsens. This is due to the 2nd harmonic which stops being attenuated by the lowest frequency LPF (60m band, 5MHz). At the upper end, beyond 34MHz the fundamental starts to be attenuated by the highest frequency LPF, the 10m band LPF which is always in circuit.



Overall the results are very satisfying for such a simple and inexpensive piece of equipment. The Low Pass Filters were all constructed without measurement (e.g. without measuring inductance on an L-C meter). Simply by counting toroid turns according to the LPF kit assembly instructions. There was no measurement of filter performance to determine cut-off frequencies – the entered frequencies 5, 7, 10, 14 and 21MHz are therefore just an approximation of the real cut-off of the filters. There was no shielding of the unit or enclosure in a metal box etc.

These measurements therefore represent the minimum of what should be achievable by an average constructor without access to measurement equipment, simply by counting turns winding the toroids according to the manuals, and with approximate configuration. A more advanced constructor may no doubt optimise the LPF construction and fine tune the signal generator filter thresholds for optimum performance.

6. Discussion of design compromises

The first measurements with this relay-switched LPF filtered sinewave output VFO/SigGen were made using a set of six filters with more widely spaced in ratios 2:1. For example, 160m, 80m, 40m, 20m, 10m, 6m etc. The result is that a wider frequency range can be covered, such as 1MHz to 50MHz.

The penalty paid for this wider frequency range is worse spurious content in the sinewave output. Specifically, the 2nd harmonic of the operating frequency is always most troublesome. Imagine an operating frequency of 7.001MHz. This assumes the frequency switching threshold of the 40m filter installed is 7.000MHz. So the operating frequency is just above the threshold for the 40m filter. Therefore the active filter in this case is the 20m filter, with a cut-off something above 14MHz. The 2nd harmonic of the operating frequency is at 14.002MHz and will pass through the 20m LPF with negligible attenuation.

The worst harmonic attenuation performance is therefore at operating frequencies just above the defined thresholds. With 2:1 ratio filter cut-off frequencies, the 2nd harmonic cannot be attenuated at these operating frequencies. In my tests, I found that the worst 2nd harmonic levels were at -23dBc. This is a significant deterioration in harmonic attenuation compared to the design presented earlier in this document; but, the frequency range is wider. So – everything is a design trade-off, as usual. You can have a wider frequency range, but at the price of a less clean sinewave. You must decide what is best for your intended application!

With the chosen filters of 60, 40, 30, 20, 15 and 10m, the ratio of filter cut-off frequencies between adjacent filters is 3:2 or 4:3 in every case. Therefore there is some "overlap" in coverage, so that the 2nd harmonic is always somewhat attenuated at any operating frequency, resulting in the clean sinewave output, with worst case -45dBc harmonic content.

Attenuation of the 2nd harmonic can also be improved by adjusting the band frequency thresholds. For example, instead of entering 7.000MHz for the 40m filter, enter 8.000MHz. This is possible because the actual cut-off frequency of the filter is somewhat higher than the 40m amateur band. This means that at an operating frequency of 7.001MHz the 40m filter is still being used. By the time the system switches to use of the 30m filter, at 8.001MHz, the 2nd harmonic is at 16.002MHz and is more heavily attenuated by the 30m filter, than the 7.001MHz 2nd harmonic would have been.

However – now consider what is meant by "cut-off frequency" of a LPF. It is the frequency where the signal is attenuated by 3dB. If the real cut-off frequency is measured on a spectrum analyser, and is entered exactly as the filter switching threshold, then the fundamental output frequency will be 3dB attenuated. The consequence is that the output flatness (I measured 10.8dBm +/- 0.4dBm from 2.9 to 34MHz) will be impaired! Now the variation will be larger, as the signal is attenuated by 3dB as the frequency approaches the cut-off frequency. So again it is a trade-off, this time between harmonic content and flatness of the wanted sinewave output level.

7. Sinewave SigGen kit set

A set of kits is available to order at the QRP Labs shop for this sinewave signal generator project, which includes VFO kit, Relay-switched LPF kit and six LPF kits. Please see http://shop.qrp-labs.com/sinesiggen

8. Resources

- VFO/SigGen kit assembly and operating instructions: http://qrp-labs.com/vfo
- 6-band Relay-switched LPF kit assembly instructions: http://qrp-labs.com/ultimatelpf
- LPF kit assembly instructions: http://qrp-labs.com/lpfkit
- Optional QLG1 GPS Receiver for GPS discipline http://qrp-labs.com/qlg1
- Optional enclosure/accessories kit http://qrp-labs.com/vfobox
- For any questions regarding the kit assembly discussed in this document, please join the QRP Labs group, see http://qrp-labs.com/group for details

9. Document Revision history

1.0 First version, 23-Feb-2017

1.01 01-Mar-2017: correct confusion in the assembly notes section in section 3, about which of the 2 x 5-pin male/female connectors to install on which board.