Si5351A VFO/Signal Generator

s1.02

1. Introduction

This is the operation manual for the VFO/Signal Generator kit. Please read it in conjunction with the assembly manuals for building the kit:

- VFO/Signal generator assembly manual (the controller PCB, rotary encoder, buttons and LCD)

- Si5351A Synth assembly manual, or OCXO/Si5351A assembly manual if you use the OCXO

- QLG1 GPS assembly manual, if using the QRP Labs QLG1 GPS to discipline the oscillator

Note that the output of the Si5351A are squarewaves at 3.3V peak-peak. Please read the Si5351A datasheet, linked from http://www.qrp-labs.com/synth . If you require a sinewave output, then you could fit a QRP Labs Low Pass Filter kit http://www.qrp-labs.com/lpfkit to the main PCB, to filter away the squarewave harmonics. This would be effective over only a limited band of frequencies but may suit your application.

The LCD may be configured to show not just VFO frequency, but also your callsign or other text, and if you have a GPS connected (for disciplining the oscillator) you may display GPS parameters such as date, time, latitude, longitude, altitude, satellite reception status, and Maidenhead locator.

2. Operating instructions

When you have just built the kit and have not yet configured it, upon power-up the kit will enter "Diagnostic Mode". If you can see this message on the screen, all is well. Press the Left button to continue. If you do not see this message or any writing on the LCD, please refer to the troubleshooting web page.

On power up (and after leaving the diagnostic mode, if any), the LCD displays the firmware name and version number for a few seconds, then loads Preset 0, and enters VFO tuning mode.

2.1 Modes of operation

There are four modes of operation. The usual running mode is the VFO tuning mode, in which the Clk0 frequency is displayed on the screen, and the rotary encoder tunes it.

- VFO tuning mode (default at start up)

- Select preset mode

- Select tuning rate mode

- Configuration menu editing mode

2.2 VFO tuning mode
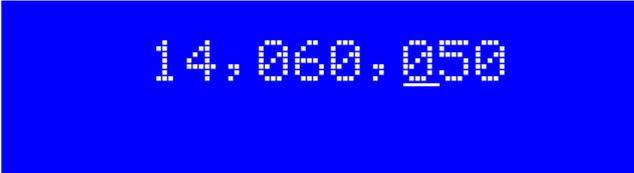
```
14,060,050
```

The rotary encoder tunes the Clk0 output frequency. The tuning rate is indicated by the underlined digit of the frequency display. In the above example the frequency is 14.060050MHz and the tuning step is 100Hz.

Note that the lower frequency limit of the Si5351A synthesiser chip when using the supplied 27MHz reference crystal, is 3.515kHz. The upper frequency limit has been found to be approximately 292MHz. The register configuration allows higher frequencies to be set but the chip refuses to output any frequency above 292MHz. The Si5351A datasheet specifies an upper frequency limit of 200MHz. The practical upper limit may be lower depending on your application, since at such high frequencies the spectral purity of the output is degraded; furthermore the minimum tuning step becomes wider than the 1Hz resolution of the tuning control.

Control functions:

Rotary Encoder: Tunes the frequency in steps indicated by the underlined digit
Left button: Enter "Select preset" mode
Right button: A brief press enters the "Configuration menu editing" mode
Right button hold: Press and hold, to enter "Select tuning rate" mode

2.3 Select preset mode
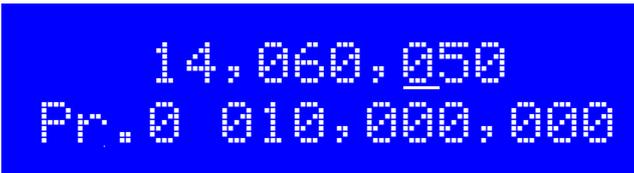
```
14,060,050
Pr.0  010,000,000
```

Use the rotary encoder to cycle through the presets which you have set up, in the configuration menu. To choose a preset to load into the VFO, press the right button. To cancel preset selection mode and return to VFO tuning mode, press the left button.

Control functions:

Rotary Encoder: Scroll up and down through the list of configured presets
Left button: Cancel "Select preset" mode and return to VFO tuning mode
Right button: Load the selected preset into the VFO, and return to VFO tuning mode

2.4 Select tuning rate mode

```
14,060,050
```

Use the rotary encoder to move the cursor underlining the tuned digit, to the left and right. The select tuning rate mode is active only while pressing the right button. Remember that the internal button in the rotary encode is in parallel with the right button. Therefore changing the tuning step is a matter of pressing in the rotary encoder, holding it pushed in, and turning it to alter the tuning rate.

The available tuning rates are 10MHz, 1MHz, 100kHz, 10kHz, 1kHz, 100Hz, 10Hz and 1Hz. The default at power up is 100Hz.

Control functions:

Rotary Encoder: Move the tuning rate cursor left and right
Left button: No effect, in tuning rate mode
Right button: Right button must be held pressed, to keep in select tuning rate mode. Releasing the right button returns to the VFO Tuning mode.

2.5 Configuration menu editing mode
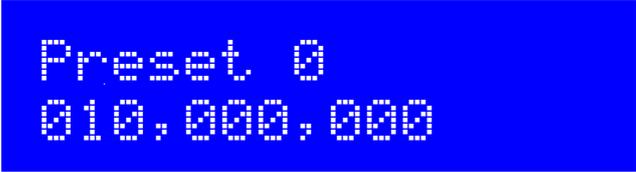
```
Preset 0
010,000,000
```

This is the mode for editing all the configuration parameters. The configuration items are stored in the processors EEPROM memory, and are preserved when the power is switched off. Enter the menu editing mode from the VFO tuning mode, by pressing the right button briefly.

Control functions:

Rotary Encoder: Moves the display up and down through the list of configuration menu items
Left button: Press to start editing the currently displayed configuration item
Right button: Leave the menu editing mode and return to the VFO Tuning mode.

More details on the actual editing process are in the next section.

2.6 Editing a configuration menu item

The user interface consists of the 16-character 2-row LCD, rotary encoder, and two push-buttons. A number of user-configurable settings available, to set up the frequency presets, GPS behaviour, IF Offset, Multiplier, and other settings. The menu system allows all of the settings to be edited.

The menu is a list of items and the rotary encoder is used to scroll through this list. When you see the item which you want to edit, press the LEFT button to start editing it. To return to the VFO Tuning mode, press the RIGHT button.

There are two types of menu item: alphanumeric (e.g. display format specification), and numeric (e.g. preset frequencies). Editing a configuration is slightly different depending on the type. When scrolling through the list of menu items using the rotary encoder, you enter editing mode by pressing the LEFT button.

2.6.1 Number editing

When editing a numeric setting, the rotary encoder is used to cycle through the numbers 0..9 until you find the number you want. The LEFT button moves rightwards one position to the next character to be edited. The current character being edited flashes. When the final (rightmost) digit has been chosen, a LEFT button press saves the setting into memory and returns you to the menu list.

2.6.2 Alphanumeric editing

The most complex editing is alphanumeric, which also includes certain punctuation. The principle is the same as for Number editing: the LEFT button moves the cursor one character to the right, and the rotary encoder cycles through the letters, punctuation and digits. However facilities are also provided to insert/modify/delete one character, or the whole message.

The order of the letters, punctuation and numbers is as follows:

The following characters/symbols have special function:

Delimiter: This character is used to delimit sub-text inside the text entry.

Insert: Use this symbol to insert a character in the text. Find this character using the RIGHT button, then press the LEFT button to activate it. All the characters to the right of the cursor position are shifted right one position, including the character which was originally in the current position.

Backspace (delete): If you select this character as the current flashing character using the RIGHT button, then when you press the LEFT button, the current character is deleted and the flashing cursor moves back left one position.

Delete all: If selected as the current character, pressing the LEFT button has the effect of deleting the entire message, starting again at the left of the screen. There is no "undo", so use with caution!

Enter (finished): If selected as the current flashing character, pressing the LEFT button is used to finish editing the setting. The setting is saved, and you return to the main menu list. Note that

the text that is saved is only the text to the left of the Enter symbol. If you select this symbol and press the LEFT button when you are not at the furthest right position of the message, then everything right of your position is deleted.

Enter Right (finished): The behaviour of this symbol is the same as Enter, except that it preserves all the text, including the text to the right of the cursor. It simply saves the whole line.

2.7 Menu configuration settings

The following sections explain each configuration menu item in detail.
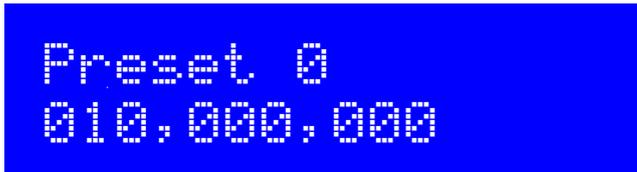
```
Preset 0
010,000,000
```

10 presets are available, labelled 0 to 9. Preset 0 has a factory default value of 10,000,000 and is loaded into the VFO at power up. The other presets are defaulted to 0.

```
Clk 1
009,002,000
```

The Clk 1 parameter allows you to set up the Si5351A Synth on a frequency of your choice, on its Clk1 output. Clk1 may be set anywhere in the permissible frequency range of the Si5351A. Here it is shown set to 9.002MHz for example. If Clk 1 is set to 0 (the default value), then the Clk 1 output is switched off.

The Clk 1 output could be useful for example as the BFO in a receiver, with the Clk 0 output as the VFO. Note however that some degree of crosstalk does occur between the outputs, this is an unavoidable limitation and may be an issue in some applications where high performance is required.

```
IF Offset
+009,000,000
```

IF Offset allows you to use this signal generator as a VFO in a superhet radio, and set this value to your Intermediate Frequency (IF) offset. The actual output frequency is the displayed frequency plus the IF Offset. The default value is 0. In this example it is set to 9.0MHz. Both positive and negative offsets can be used.

Note that the resulting Clk0 frequency must still satisfy the range requirements of the Si5351A. In the case of a frequency error, an error flag is set. This causes an "E" to be displayed at the top right of the display, in the default display configuration. It is cleared by tuning to a valid frequency that is within the Si5351A's range.

The value entered here is the IF frequency itself. The actual output frequency of the VFO kit is computed from the displayed frequency and the IF frequency as follows:

Positive offset: actual output frequency = IF + displayed frequency

Negative offset: actual output frequency = IF − displayed frequency

As an example, consider the popular BITX40 40m band SSB transceiver, using this VFO kit as the oscillator. The IF of the BITX40 is 12MHz. The analogue VFO in the BITX40 runs at 5MHz and therefore tunes "in reverse" – so 7.000MHz needs a VFO at 5.000MHz, and 7.100MHz needs a VFO at 4.900MHz. When replacing the analogue oscillator in the BITX40 with this VFO kit, set this IF Offset configuration to -012,000,000. The "negative" sign will cause the output frequency to be 12MHz minus the displayed frequency – which is exactly what is needed for a BITX40 VFO.

```
Multiplier
1
```

Multiplier allows you to use this signal generator as a VFO in radios where a Quadrature Sampling Detector (for example) is required, that is clocked by a VFO signal at 4x the receive signal. The Clk0 frequency is the displayed frequency + offset, multiplied by the multiplier.

Note that the resulting Clk0 frequency must still satisfy the range requirements of the Si5351A. In the case of a frequency error, an error flag is set. This causes an "E" to be displayed at the top right of the display, in the default display configuration. It is cleared by tuning to a valid frequency that is within the Si5351A's range.

```
GPS (Mode Baud)
0 009,600
```

The first setting is the GPS mode. This controls how and whether GPS is used. If set to a non-zero value, and a GPS module is connected and producing a valid 1pps signal, then the accurate time pulses from the GPS unit will be used to discipline the output frequency(s) of the VFO/Signal Generator.

When GPS is enabled (non-zero mode parameter), the Si5351's Clk2 output is set to ¼ the 27MHz crystal reference frequency. This signal is routed to the ATmega328's Timer1 input, and the GPS

1pps gate is used to implement a frequency counter that measures the ¼ reference oscillator value. The measured value is fed into the computation of the register values to achieve the desired output frequency.

The GPS discipline mechanism uses a two-stage process to achieve an accurate output frequency quickly but with minimum "jitter" once done. The first stage is a coarse adjustment to get close to the required final value. The subsequent fine-tuning adjustment varies the measured 27MHz value retained internally, in steps of 0.01Hz so that the jitter from one second to the next is minimised.

Additionally the coarse value is stored in EEPROM so that the next time the kit is switched on, the output frequency will already be near its correct value, and lock will be faster.

The baud rate setting specifies the speed of the serial data coming from the GPS. At the moment this serial data is not used by the VFO/Signal Generator kit.

GPS Mode settings:

0   GPS is not used at all. The kit is in free-running mode. The 27MHz oscillator won't be measured and disciplined (compensated) by the GPS.

1   The kit triggers on the falling (negative) edge of the 1pps signal.

2   The kit triggers on the rising (positive) edge of the 1pps signal. This is appropriate for most GPS modules, where the pulse width is 100ms for example.

Baud Rate setting (default 9,600 baud):

This second setting on the GPS screen determines the baud rate for receiving serial data input from the GPS module. It must be set to match the data output from the GPS module otherwise no data can be decoded. You will need to refer to your GPS module documentation to determine the correct speed.

Any baud rate can be entered here. 9,600 is most common and is the default. The kit should be able to support 115kbps but higher than this may be subject to inaccuracies and may not function properly.

The kit uses no parity, 1 stop bit, and 8-bit data. I have never encountered a GPS module that does not use the same settings, which appear to be very standard.
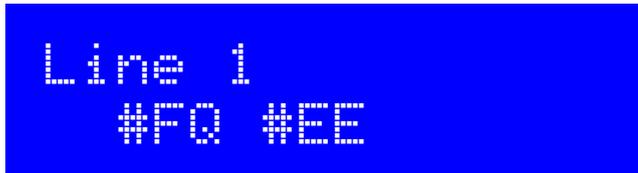
The Line 1, Line 2, Line 3 and Line 4 configuration settings determine the display format. Line 1 is the top row of the LCD, Line 4 is the bottom row. Configuration parameters for lines 3 and 4 are only visible if you have set the LCD Rows parameter to 4 (see later section). The kit is supplied with a 2-row, 16-column LCD. However you can connect a larger (4 row) HD44780-compatible display. You can enter free fixed text (for example, your callsign). You can also include #tags. Each tag is a #

character followed by a two-character identifier. Valid tags are replaced dynamically. Obviously the most useful tag to include is the #FQ tag, which displays the frequency on the display.

If you connect a GPS receiver to discipline the oscillator, you can also display a variety of information from the GPS, including date, time, latitude, longitude, altitude, ground speed, and 4- or 6-character Maidenhead locator (converted from latitude and longitude).

The default setting for Line 1 is as above. It shows the frequency centred on the top line of the display. At the top right corner the #EE tag causes an "E" to be displayed in the event of a frequency range error in either the Clk0 or Clk1 outputs. The error can be cleared by tuning to a valid within-range frequency. The range of the Si5351A output is approximately 3.5kHz to 292MHz. The default setting for Lines 2..4 is just blank. You can edit it for your own fixed display or include valid #tags as described below, to dynamically update display data with GPS information such as time, date etc.

The following table lists the available tags:

Tag	Example:	Explanation:
#FQ	10,000,000	VFO Frequency (note Clk1 frequency includes IF Offset and Multiplier)
#C1	45,000,000	Clk1 output frequency
#RF	27,003,968	Measured 27MHz reference oscillator frequency
#EE	E	Single character error flag. Blank if there is no error. E if there is an error.
#ER	ERR	Three character error flag. Blank if there is no error. ERR if there is an error.
#TR	100 kHz	Current tuning rate, occupies 7 characters. 1Hz (min) to 10MHz (max)
#HH	10	UT hours (24-hour format, from GPS data)
#MM	43	UT minutes
#SS	58	UT seconds
#LH	01	Local time hours (24-hour format, converted from GPS data)
#LM	43	Local time minutes
#H2	10	Local time hours (12-hour format)
#AP	AM	Local time AM/PM indicator
#GV	A	GPS validity flag ("A" = valid, "V" = invalid, "-" = no GPS data)
#GG	3D	GPS fix status ("3D" = 3D fix, "2D" = 2D fix, "No" = no fix, "--" = no GPS data)
#GF	08	Number of satellites used in solution computation ("--" = no GPS data)
#GT	12	Number of satellites being tracked ("--" = no GPS data)
#GS	31	Average signal to noise ratio of tracked satellites ("--" = no GPS data)
#DD	06	Day of UT date ("--" = GPS data invalid)
#DM	Apr	Month of UT date (3 letters format; "--" = GPS data invalid)
#DY	15	Year of UT date (2 numbers format; "--" = GPS data invalid)
#HB	[Note 1]	1pps heartbeat (see Note 1 below)
#M4	IO90	4-character Maidenhead locator ("----" = GPS data invalid)
#M6	IO91CG	6-character Maidenhead locator ("------") = GPS data invalid)
#LT	22°32`1799N	Latitude (blank if no GPS data)
#LN	114°01`1823E	Longitude (blank if no GPS data)
#AT	84.0	Altitude (blank if no GPS data)

Note 1: The heartbeat is a single-character heartbeat symbol, it beats in time with the received 1pps signal, if a GPS receiver module is being used.

Note 2: The VFO kit does not contain a real time clock of its own. The clock display functionality is only available if a GPS receiver is connected with decodable data and has a satellite lock.

Note 3: The table also indicates the behaviour when no GPS data has been received yet, or when the GPS data validity flag is set to "V" (invalid data). This typically occurs for a few seconds after power up until the GPS has scanned the satellites and received enough for a fix computation.

Many of these tags are derived from data sent by the optionally connected GPS receiver module. This information is updated with freshly decoded data from the GPS every second. It comes from the following NMEA sentences.

$GPRMC: Latitude, Longitude, Validity flag, Date, Time
$GPGSA: Type of fix, None, 2D, 3D
$GPGGA: Number of satellites in fix, Altitude
$GPGSV: Number of satellites being tracked, signal strength

Scrolling display data

You can also display multiple pieces of information sequentially on each line. Each line display is delimited by the delimiter character ▌ (the inverted space character). The display will then loop around all the displays configured, displaying each in turn.

For example, if you enter Line 2 as: "#GV #GG F#GF T#GT S#GS▌Long: #LN▌Lat: #LT▌Alt: #AT", then you have specified four separate displays, each delimited by the ▌ character. The bottom line will cycle through the four items:

i) Satellite information display (#GV #GG F#GF T#GT S#GS)
ii) Longitude display (Long: #LN)
iii) Latitude display (Lat: #LT)
iv) Altitude display (Alt: #AT)

The time each of these sub-lines is displayed is also configurable! See next section.
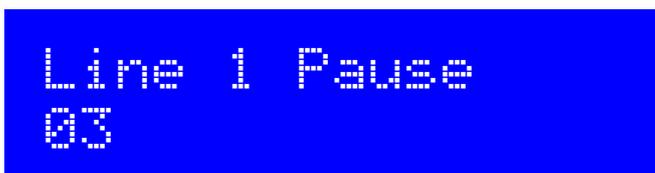
The number of seconds the sub-lines are displayed for, on Line1. This is only relevant if you have configured multiple sub-lines for the display to cycle through, using the ▌ delimiter character (see previous section). The default is 3 seconds.

An identical setting is available for Line 2, Line 3 and Line 4. So that each line could, if you wish, have different cycle display times.

Note that the configuration settings for lines 3 and 4 are only visible if you have configured the "LCD Rows" parameter to 4 rows (see later section).

```
Local Offset
+0.120
```

This setting specifies the offset of local time to UT. The time displayed by the #HH, #MM tags is always UT (straight from the GPS, if connected). The #LH, #LM, #H2 tags display local time, offset by the number of minutes in this setting. Positive and negative offsets can be chosen, for time zones ahead of UT or behind UT.

```
Corr. threshold
050
```

This parameter specifies a correction threshold, which is applied when using a GPS to discipline the oscillator. The 1 pulse per second (1pps) from the GPS continuously acts on the reference oscillator. But the VFO frequency (and Clk1 frequency, if configured) is re-calculated using the new 27MHz reference frequency and updated only when

a) The rotary encoder is turned, to adjust the frequency

b) The menu system is entered and exited

c) The 27MHz reference frequency differs by more than this specified correction threshold, from the value last used to update the VFO.

The default is 50Hz. This parameter is useful because when the VFO is re-calculated it can cause small glitches in the output frequency, which can be audible on a receiver. It can be annoying if that happens once every second – depending on your intended application for this kit. So this parameter allows you to specify this tolerance threshold, so that updates are infrequent.

```
Ref. Frq.
27,000,000
```

This is the value of the 27Mhz crystal reference frequency. If you are using a GPS to discipline the oscillator (non-zero GPS mode parameter, and valid 1pps GPS signal available), this value is updated automatically during the GPS discipline process. If you are not using a GPS (GPS Mode = 0) then you can edit this parameter manually to calibrate your VFO/Signal Generator kit.
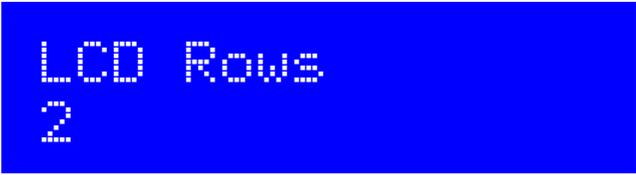
```
LCD Rows
2
```

This kit can be used with any similar HD47780-compatible display having 2 or 4 rows. The supplied LCD has 2 rows and this is the default for this parameter. If you wish to use a larger display, you can edit this parameter to access rows 3 and 4. When set to 2 rows, the Line 3, Line 4, Line 3 Pause and Line 4 pause parameters are hidden in the menu system.
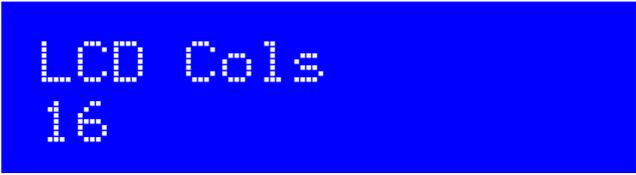
```
LCD Cols
16
```

This kit can be used with any similar HD47780-compatible display having 16, 20, 24 or 40 characters per row (columns). The supplied LCD has 16 columns and this is the default for this parameter. If you wish to use a larger display, you can edit this parameter.

```
Backlight
9
```

This setting allows the LCD screen's blue LED backlight brightness to be adjusted, IF you fitted the A0-A3 jumper wire when building the kit. The default value is 9 (maximum brightness). 0 corresponds to minimum brightness – the backlight is switched off.

You should also note that the backlight brightness control is achieved by 8-bit pulse width modulation of the LED voltage. The frequency is 610Hz and the duty cycle is varied. Pulsing the 30mA LED could introduce noise onto the power supply so if you are also using a receiver you should check that interference is not caused.

3. Factory Reset

On powering up the kit, a message is shown for a few seconds on the LCD, which indicates the version number. If the Right button is pressed during the display of this splash screen message, then a confirmation message appears saying "Reset? Sure? Press left btn". Now if you press the left button, the chip EEPROM contents are erased and returned to the original factory settings.

The effect of this feature is to entirely return the microcontroller chip to its original settings, it is the same as buying a new chip and inserting it. All calibration settings are erased and returned to the default settings.

4. Resources

Please see the kit page http://www.qrp-labs.com/vfo for information on latest updates and issues.

Please join the Yahoo group http://groups.yahoo.com/group/qrplabs/ for new kit announcements, to discuss any problems with the kit, enhancements you've made, or just to tell everyone how much fun you're having.

5. Version History

1   19-Jan-2016

- Initial version, for firmware version s1.00

2   04-Apr-2016

- Firmware version s1.01 – only change is to remove the 10MHz limit on IF offset

- Clarification of operation without GPS, in the GPS settings description, top of page 7

3   11-Nov-2016

- Firmware version s1.02

- Add negative IF offset capability

- Added a long list of new #-tags to display data from the GPS module, when the serial data line is connected.

- Added multiple scrolling customisable display feature, with configurable pause on each item (Line 1 Pause, Line 2 Pause etc. parameters)

- If the #RF tag is in the display (reference frequency) and GPS discipline is used, it is updated every 1 second with the new value

- Add the #HB tag to display the heartbeat in the display, which beats in time with the GPS 1pps

- Changed "Cont. correction" parameter to "Corr. threshold", it now allows recalculates the VFO when the reference frequency has changed by the specified amount. Continuous correction can be achieved by setting 0.

- Improvement to the GPS discipline at power-up. The calibration starts off in "fine" mode, only moving to "coarse mode" if necessary after 10 seconds. This avoids a large frequency jump at power up.

- Extended display support to 2- or 4-rows, and 16, 20, 24 or 40 columns (defined via new configuration parameters "LCD Rows" and "LCD Cols")

- Bug fix: memory corruption when editing Line1 and Line2 could cause unexpected behaviour

- Bug fix: It was impossible to edit display configuration lines e.g. "Line 1" parameter when they overflowed the 16 char display area

4   11-Nov-2016

- Added example and further detail on the use of the negative IF offset, which had caused some confusion.