General Purpose VHF Synthesizer Module

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Overview

The unit described is a generic VHF synthesizer module that can be adapted to generate any frequency within the range 20 – 170MHz; operation outside this range may also be possible. The entire module fits in a standard 35 x 51mm tinplate box and runs from a nominal 10 – 15V supply. An on-board PIC microcontroller allows the frequency and control registers in the synthesizer chip to be set to hexadecimal values using a simple serial 1200 Baud interface with ASCII text commands. Once set, the values can be stored in non-volatile memory, or changed at will using the serial interface commands. A dedicated control programme can be used to set up frequencies and control the module

The module has been designed for the experimenter, and each individual case will need to be customised to the user's own requirements, although a few examples of component values are given as a starting point for an almost plug-and-play solution to begin with. The circuit has been designed around the rather old but well proven MC145170 synthesizer chip as I have a large stock of these from an earlier project. A discrete Voltage Controlled Oscillator within the module can be adapted for any frequency within the range and for operation at the upper end of its frequency capability the existing printed inductor can be utilised. Lower frequencies will require an additional inductor to be added in series or in place of the printed one. The VCO output is double buffered and final output level is typically in the range 1 – 5dBm depending on choice of component values. An op-amp PLL filter has been included for optimum phase noise performance. The reference oscillator can be either a self-contained crystal oscillator or can come from an external master source; the PCB can be adapted for either. Photographs of two breadboard versions (with internal reference in each case) for 70MHz and 144 MHz respectively can be seen in Photo 1.

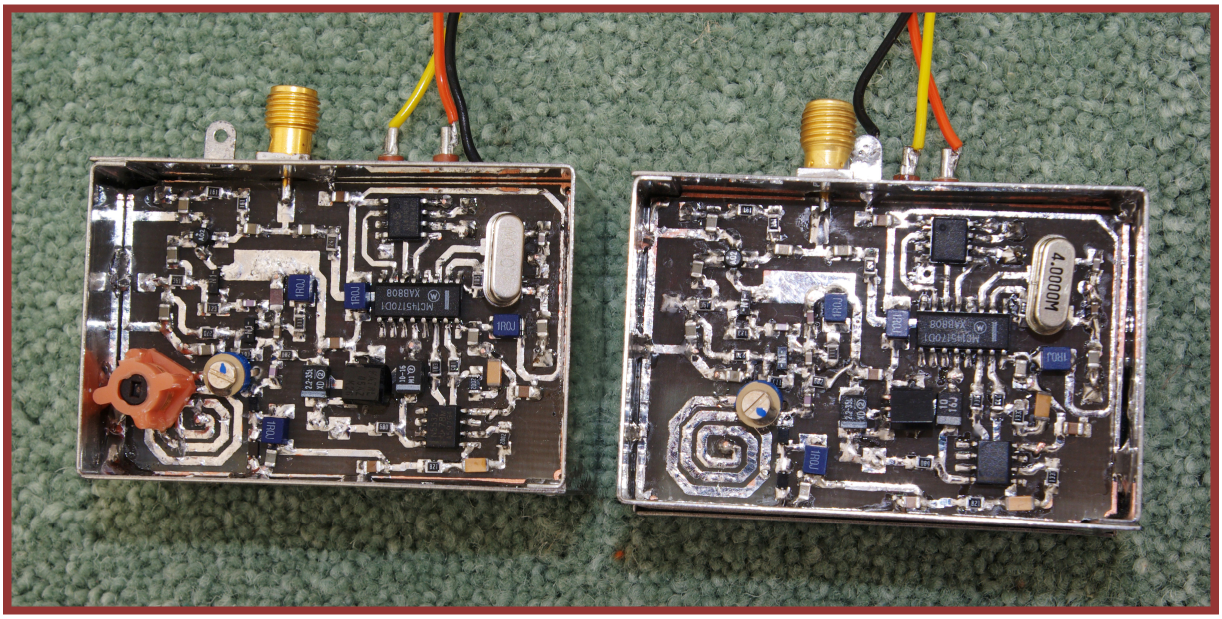


Photo 1 - Two breadboard versions of the Synthesizer module; for 70MHz and 144MHz

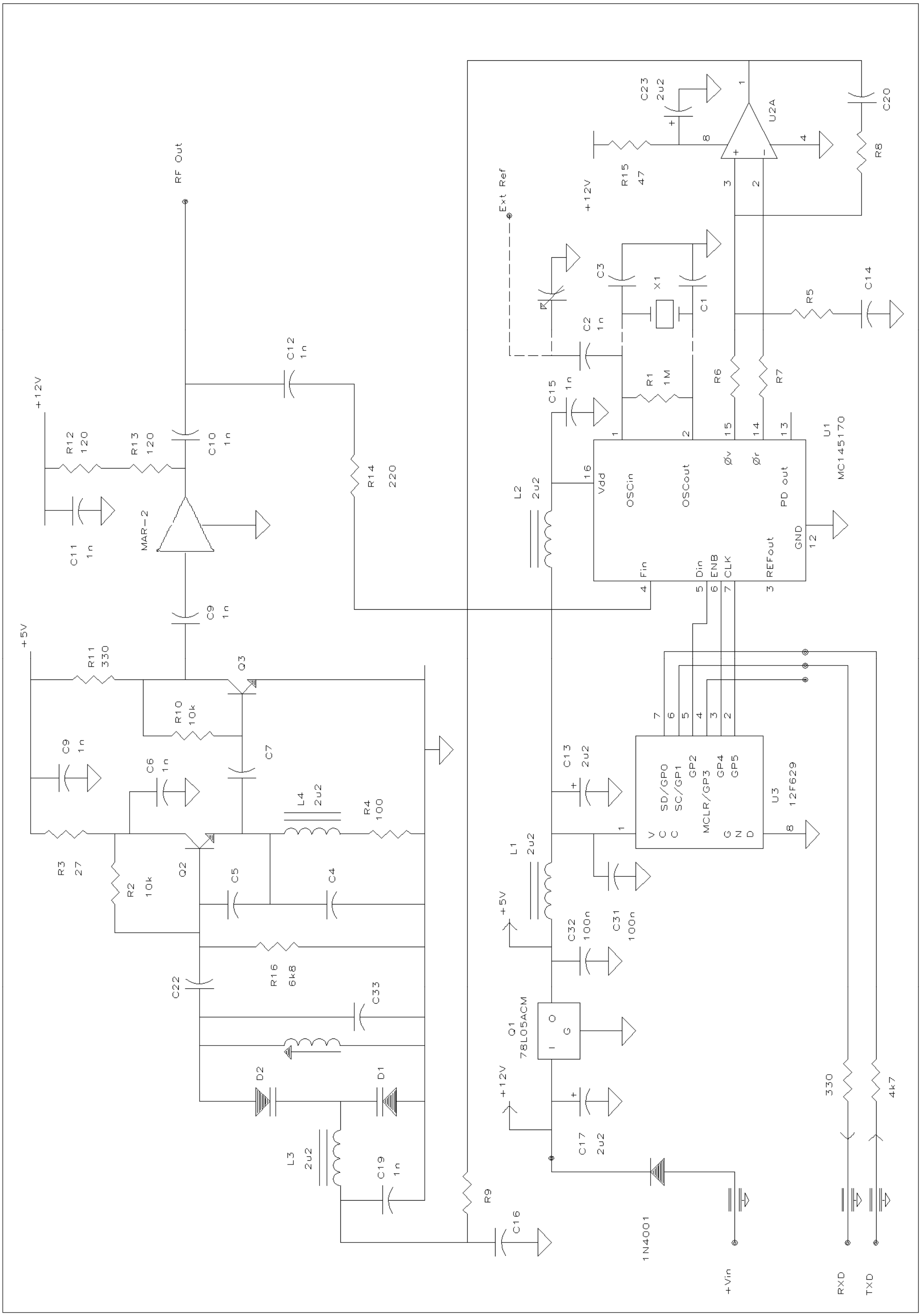


Figure 1 Circuit Diagram of the Complete Synthesizer Module

Circuit Description

The complete circuit diagram is shown in Figure 1, with component values shown where they do not have to be selected for any particular frequency range. The Colpitts VCO based around a UHF bipolar has its output lightly coupled to a second bipolar buffer followed by a MAR-2 modamp to raise the output to a useful level. A portion of the final RF is tapped off to feed the MC145170 synthesizer device. Dual back-to-back tuning diodes are used in the VCO to optimise the Q and hence improve phase noise.

There is provision on the PCB for either a crystal oscillator – which is part of the MC145170 chip – or an external reference by fitting the components appropriate in each case. Connections for either are shown by dotted lines. A trimmer for adjusting the internal reference can be installed using the pad / hole on the PCB that alternatively serves as the connection for an external reference

The two $Ø_V$ and $Ø_R$ outputs from the PLL's phase detector are taken to an op-amp filter whose component values can be determined either from the spreadsheet at [1] or from any standard PLL design literature. An extra filter element is available by choice of suitable values for the RC network between the op-amp output and the tuning diodes. The op-amp type is not shown on the diagram. An NE5532 was used for the breadboards, but most low noise types will be acceptable. The PCB layout is designed around using one side of a dual op-amp device with standard connections.

An integral 5V regulator supplies the PIC and synthesizer, and this stabilised supply is also used for the VCO and first buffer. Extensive decoupling using chip inductors is applied on each power supply delivery point. The unregulated input voltage is used for biasing the MAR-2 output amplifier and as supply to the op-amp filter. This allows the VCO tuning voltage to swing over the range typically 2 – 10V .

Some component values to start with around the VCO can be found in Appendix 1 .

PLL Design information is in Appendix 2

PCB Layout

The double sided PCB is designed to fit into a standard 37 x 55 x 30mm tinplate box such as Type No 1000112 available from G3NYK [2]. The component overlay can be seen in Figure 2 All components are surface mounted, with the majority of R and C being of 0805 size. Decoupling inductors are 0812 dimensions but there is enough leeway in pad sizes to allow other device outlines to be squeezed in. All ICs apart from the 78L05 voltage regulator are of the 1.27mm pin spacing SOIC type.

The lower side is a continuous groundplane. Pads shown as circular on the layout are connections to ground – use links on home produced PCBs. Spare pads are for connections through, and must be counterbored on the groundplane side to prevent short circuits.

A Mirrored .PDF file of the PCB at 2X scale can be found at [3]

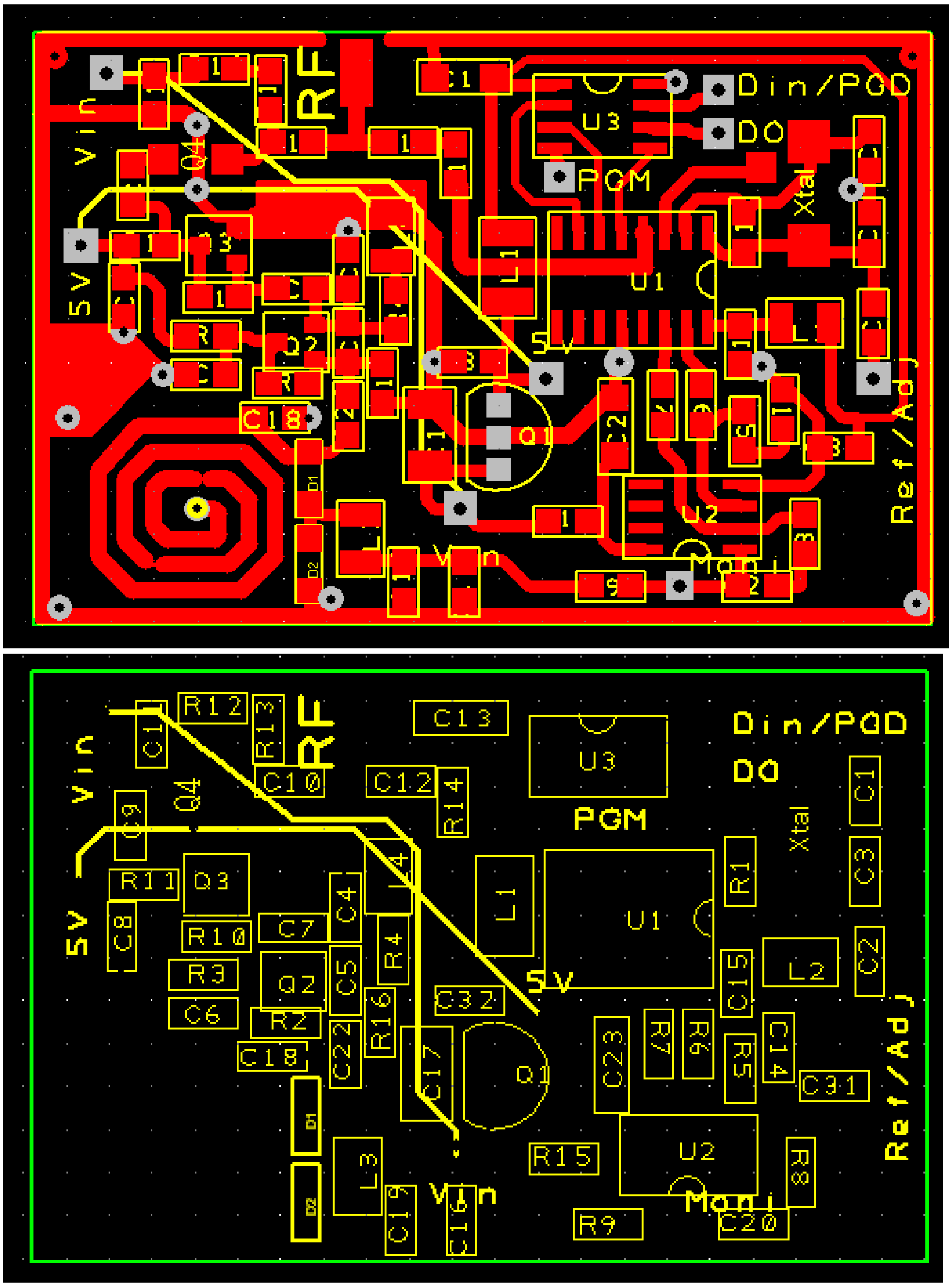
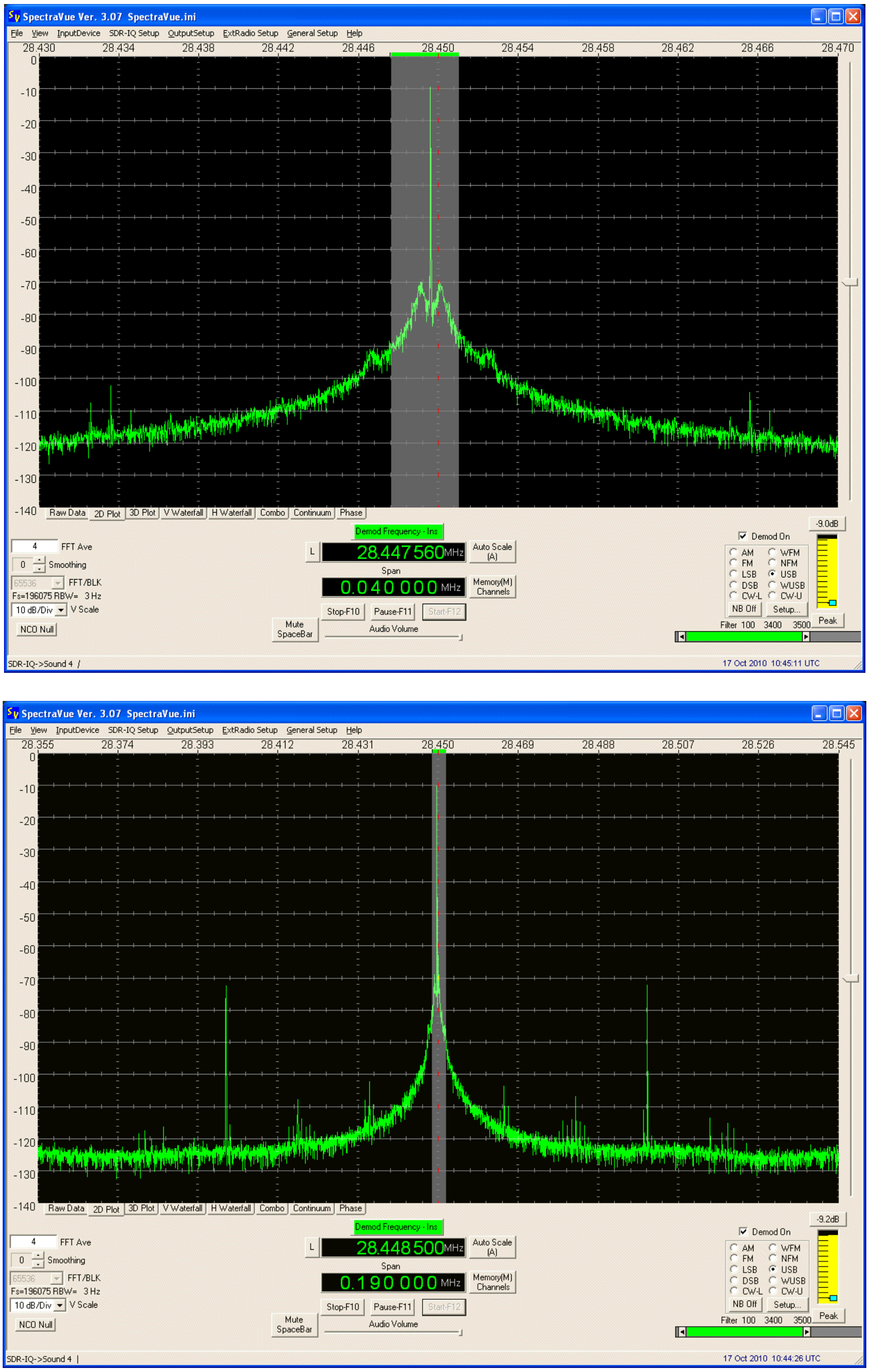


Figure 2 PCB Overlay

Performance

Measured phase noise can be seen in Figure 3 and Figure 4 respectively for the 144 and 70MHz breadboard modules. The high band unit has been programmed for a comparison frequency of 50kHz with a loop bandwidth of 5kHz. The resulting spurious of the sideband can be seen in the second photo of Figure 2 at a level of -62dBc. The low band module was set at an obscure comparison frequency around 16kHz in order to generate a precise output, and its resulting sidebands are at a very acceptable -78dBc. Loop bandwidth for this configuration was around 2kHz



SpectraVue Ver. 3.07 SpectraVue.ini
File View InputDevice SDR-IQ Setup OutputSetup ExtRadio Setup General Setup Help
28.430 28.434 28.438 28.442 28.446 28.450 28.454 28.458 28.462 28.466 28.470
0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140
Raw Data 2D Plot 3D Plot V Waterfall H Waterfall Combo Continuum Phase
Demod Frequency - Ins
L
Auto Scale (A)
Memory(M) Channels
Stop-F10 Pause-F11 Start-F12
Mute SpaceBar
Audio Volume
NCO Null
AM WFM FM NFM LSB USB DSB WUSB CW-L CW-U
NB Off Setup...
Peak
SpectraVue Ver. 3.07 SpectraVue.ini
File View InputDevice SDR-IQ Setup OutputSetup ExtRadio Setup General Setup Help
28.355 28.374 28.393 28.412 28.431 28.450 28.469 28.488 28.507 28.526 28.545
0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140
Raw Data 2D Plot 3D Plot V Waterfall H Waterfall Combo Continuum Phase
Demod Frequency - Ins
L
Auto Scale (A)
Memory(M) Channels
Stop-F10 Pause-F11 Start-F12
Mute SpaceBar
Audio Volume
NCO Null
AM WFM FM NFM LSB USB DSB WUSB CW-L CW-U
NB Off Setup...
Peak

28.447 560 MHz

Span 0.040 000 MHz

4 FFT Ave

0 Smoothing

65536 FFT/BLK

Fs=196075 RBW= 3 Hz

10 dB/Div V Scale

☑ Demod On

● USB

Filter 100 3400 3500

-9.0dB

SDR-IQ->Sound 4

17 Oct 2010 10:45:11 UTC

28.448 500 MHz

Span 0.190 000 MHz

4 FFT Ave

0 Smoothing

65536 FFT/BLK

Fs=196075 RBW= 3 Hz

10 dB/Div V Scale

☑ Demod On

● USB

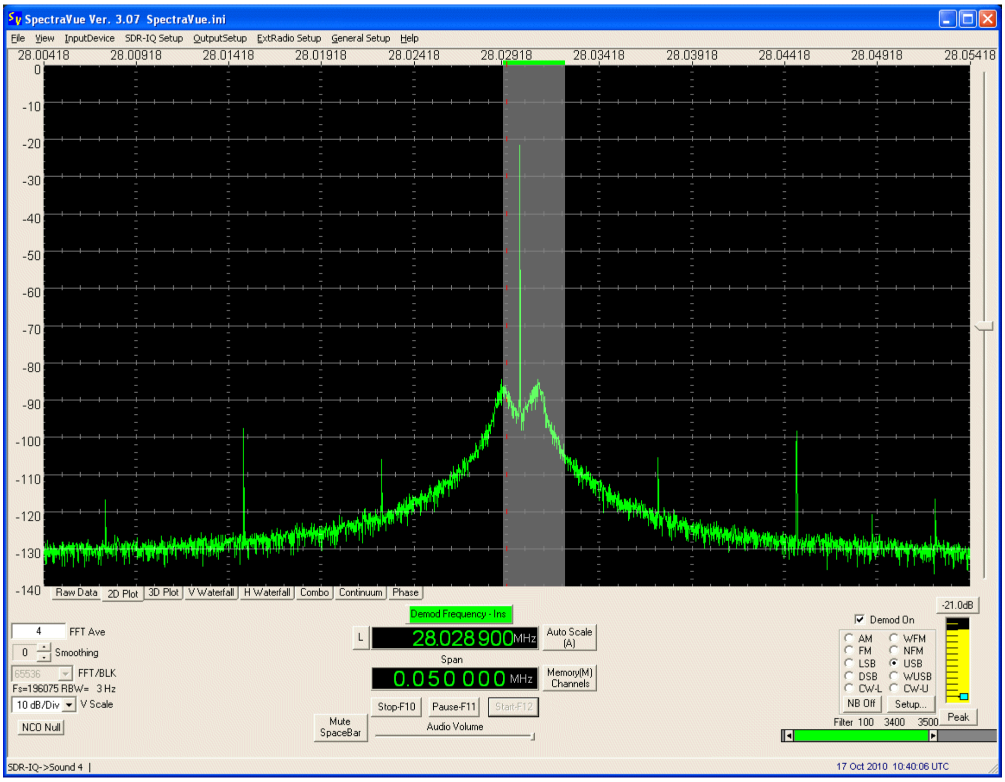
Filter 100 3400 3500

-9.2dB

SDR-IQ->Sound 4

17 Oct 2010 10:44:26 UTC

Figure 3 Measured Spurious and Phase Noise of the 144MHz Unit



FFT Ave: 4

Smoothing: 0

FFT/BLK: 65536

Fs=196075 RBW= 3 Hz

V Scale: 10 dB/Div

28.028 900 MHz

Span 0.050 000 MHz

☑ Demod On

○ AM ○ WFM
○ FM ○ NFM
○ LSB ● USB
○ DSB ○ WUSB
○ CW-L ○ CW-U

Filter 100 3400 3500

SDR-IQ->Sound 4 |

17 Oct 2010 10:40:06 UTC

Figure 4 Spurious and Phase Noise at 70MHz

In each case resolution bandwidth is 3Hz, so the dBc/Hz value can be determined by adding 5dB to the value read off at any particular offset from the curves. At 144MHz, for example, at 60kHz separation from the carrier phase noise can be seen to be at a level of around -120dBc/Hz.

Programming

The 8 pin 16F629 PIC device has three of its connections made available to pads on the PCB. The device is configured for in-circuit programming to load in new firmware. Any PIC programmer such as the *PicKit* from Microchip can be connected to the PGC/PGD/PGM (Programming Clock, Data and Program) pins for chip programming.

The PGC and PGD pads also serve as direct connection to a serial RS232 interface for controlling the chip over a 1200 baud serial interface using ASCII text based commands to send hexadecimal data for setting the register contents. These can be taken out through feed-through capacitors, but two external resistors are required. A 4.7kΩ resistor is needed in series with the serial data input from the PC to prevent possible chip damage from over current on its negative voltage excursions. On the data output to the PC, a 330Ω resistor was needed to allow in-circuit programming. If not present, the capacitance of the feed-through was sufficient to load the programmer connected directly to the pads on the PCB and prevent it from functioning. The resistor allowed adequate isolation to let the high speed programming information past.

A simple operating system is included on the PIC (in firmware named *MC145170ctl.asm*) that allows interactive setting of the registers using a terminal programme such as *Hypertrm* set to 1200 baud, 8 bit data, no parity, 1 stop bit. If the terminal / serial interface is connected when power is applied to the controller, the introductory message shown in the *Hyperterminal* screenshot below will be seen. Once connection is established, commands available for setting each of the three R, N and C registers within the MC145170 can be issued. These are :

Rxxxx, **Nxxxx**, **Cxx**, **U** and **W**.

In each case the command is terminated with a **[rtn]**

xxxx are hexadecimal characters and exactly the number shown (four or two) must be entered. They can be in upper or lower case. To see how the 8 bits (two hex characters) that make up the **C** command for setting the control register as configured see the data sheet, but for most practical purposes on this module the hex value of 33 will be suitable. This value should have been programmed into the PIC's non-volatile memory initially so there should be no need to change this unless desired.

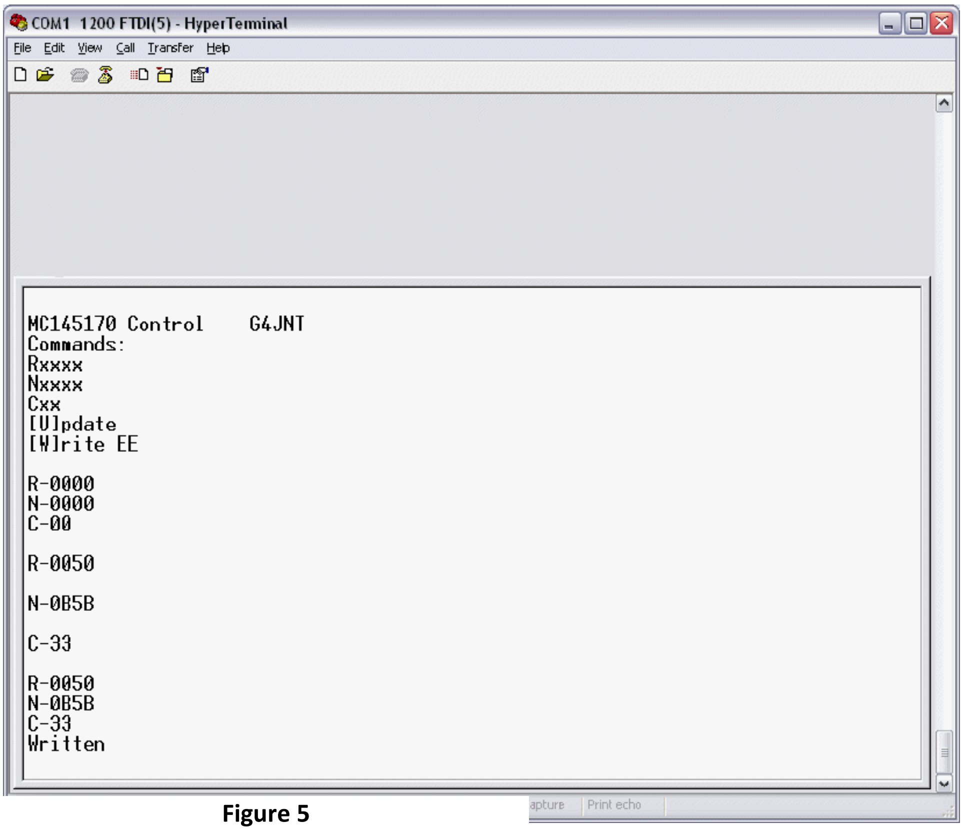
For example, using a reference oscillator of 4MHz, 50kHz comparison frequency and a wanted output of 145.35MHz first calculate the hex values needed:

R = 4MHz / 50kHz = 80 (in decimal). Convert to 4 character Hex = 0050

N = 145.35MHz / 50kHz = 2907 decimal Convert to Hex = 0B5B

Then type in the following commands in turn: **R0050 [rtn]**, **N0B5B [rtn]** (**C33 [rtn]** optional)

A screenshot from Hypertrm is illustrated in Figure 5 below.


COM1 1200 FTDI(5) - HyperTerminal
File Edit View Call Transfer Help
apture
Print echo

```
MC145170 Control     G4JNT
Commands:
Rxxxx
Nxxxx
Cxx
[U]pdate
[W]rite EE

R-0000
N-0000
C-00

R-0050

N-0B5B

C-33

R-0050
N-0B5B
C-33
Written
```

Figure 5

In each case the terminal will echo back the value entered if accepted. If no reply is seen, the command may have been try again until the response is seen.

R / N / C commands can be entered in any order.

At this point the output frequency will not yet have changed.

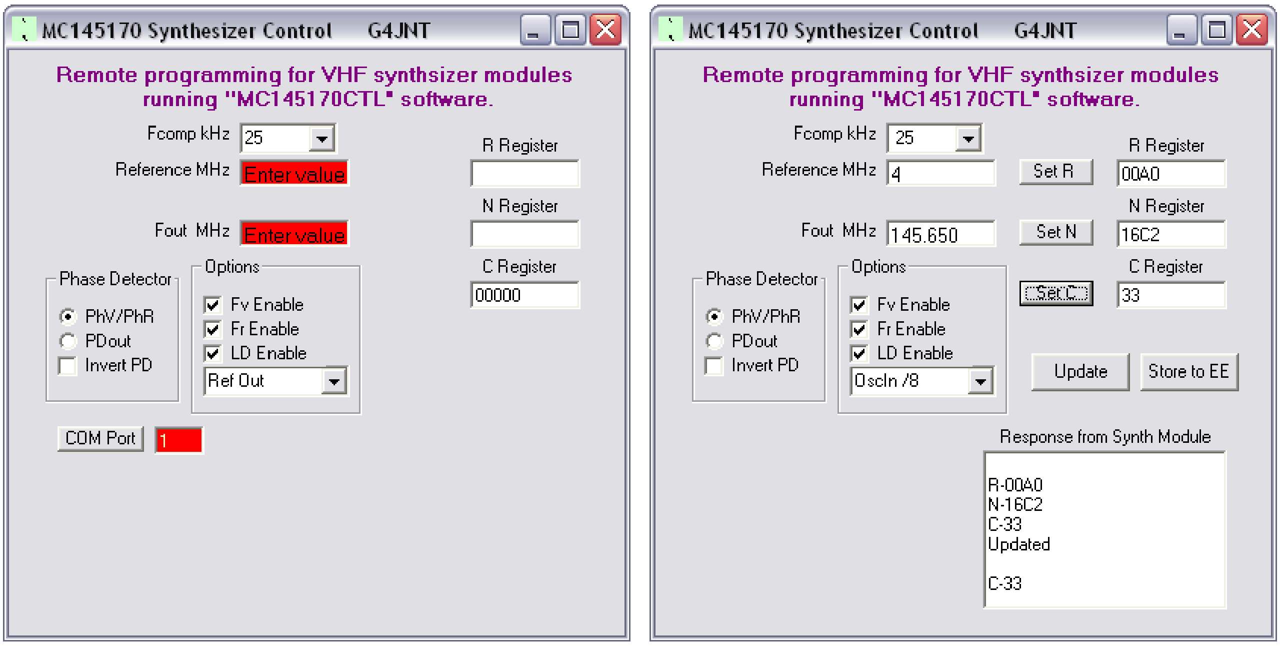
Once both R and N (and possibly C) registers have been set, then type **U [rtn]** which is the command to update the MC145170 chip itself.

To save the values permanently to EE memory, issue a **W [rtn]** command to write all three values to non-volatile memory as well as updating the chip. When accepted, the values will again be echoed back to the screen – although note that the U or W will not be shown.

Programming Utility

A stand-alone utility for setting frequencies directly can be found at [4] with screenshots from this illustrated in Figure 6.

At start up, the window will appear as shown on the left. The three red boxes must first be filled in with the reference frequency, the wanted output and the COM port to be used for communication with the module. A comparison frequency can be selected from the pull down menu, or any obscure value can be typed in instead. The individual C register functions and flags can be set by ticking or clearing the appropriate boxes – for most purposes leave these at the defaults. Then, when all the values have been entered, click the two or three buttons, *Set R* , *Set N* and *Set C* which send each of the three commands to the module in turn. The response in each case will appear in the lower right window. When complete, click the Update or WriteEE buttons.



MC145170 Synthesizer Control G4JNT

Remote programming for VHF synthsizer modules running "MC145170CTL" software.

Fcomp kHz 25

Reference MHz Enter value

Fout MHz Enter value

R Register

N Register

C Register 00000

Phase Detector

● PhV/PhR
○ PDout
□ Invert PD

Options

☑ Fv Enable
☑ Fr Enable
☑ LD Enable

Ref Out

COM Port 1

MC145170 Synthesizer Control G4JNT

Remote programming for VHF synthsizer modules running "MC145170CTL" software.

Fcomp kHz 25

Reference MHz 4

Fout MHz 145.650

R Register 00A0

N Register 16C2

C Register 33

Phase Detector

● PhV/PhR
○ PDout
□ Invert PD

Options

☑ Fv Enable
☑ Fr Enable
☑ LD Enable

OscIn /8

Response from Synth Module

```
R-00A0
N-16C2
C-33
Updated

C-33
```

Figure 2 Opening and operational screenshots of the MC145170 Programming Utility

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References

[1] PLL Design Spreadsheet PLL.XLS

[2] G3NYK http://www.alan.melia.btinternet.co.uk/componen.htm

[3] PCB Copper at 2* mirrored VHFSynthModule_PCB_TopCopper_X2_Mirrored.pdf

[4] Programming Utility 145170Ctl.EXE (rename from .EEX)

Files can be found in www.g4jnt.com/VHFSynthModule.zip

Appendix 1 Some component values to start with.

Varicap type BB149 was used here. This gives a capacitance of approximately 15 to 5pF for 2 – 10V

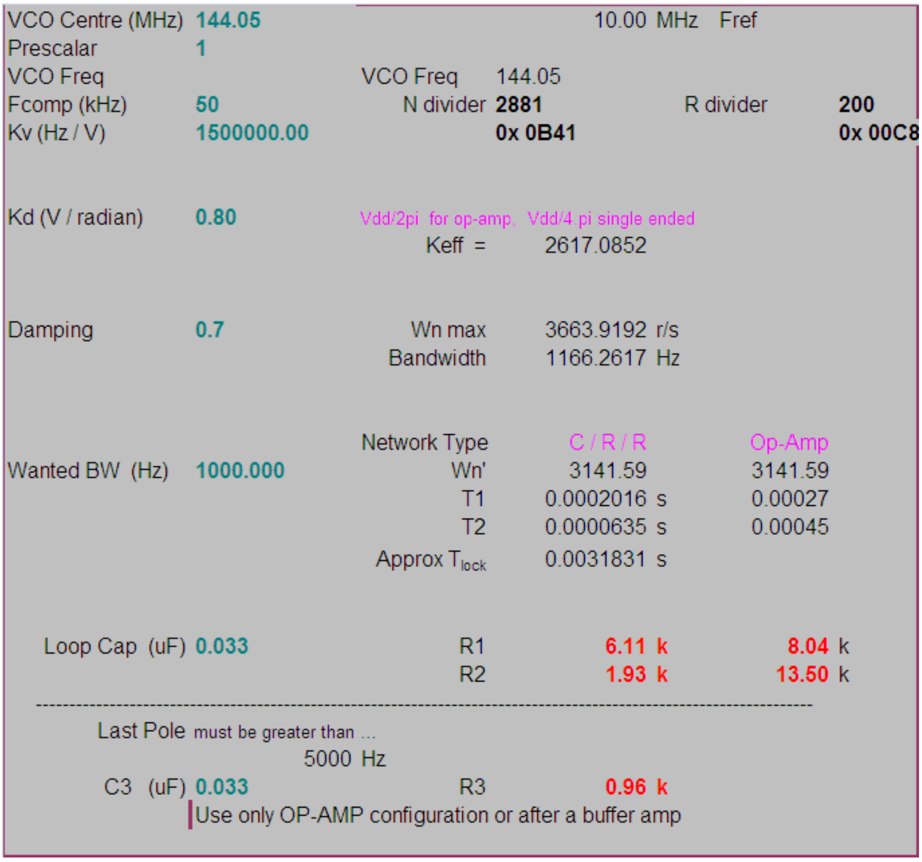
Q2 / Q3 need to be SOT-23 packaged RF transistors providing adequate gain at the frequency of interest. UHF devices such as BFR92 are eminently suitable for upper VHF use. Or almost any other UHF type.

C33 was a 20pF preset for breadboarding purposes. In a finished design this should preferably be replaced by a fixed value. A core-adjustable inductor was used for the low band version.

The printed inductor has approximately 140nH inductance.

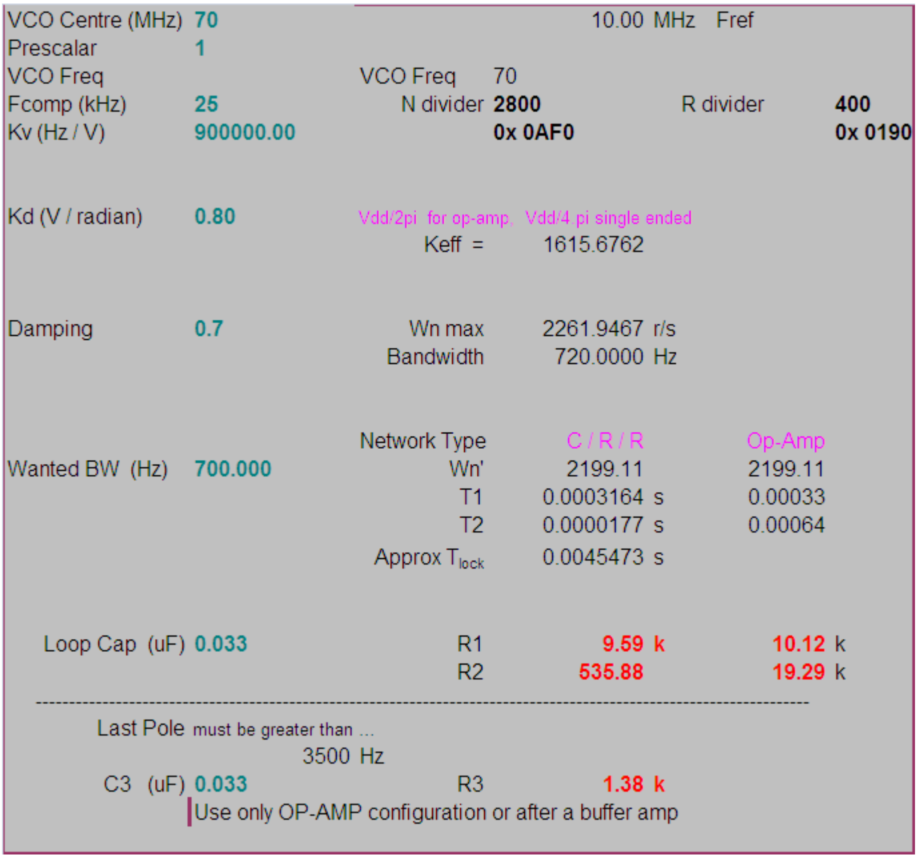
Component	High Band 145MHz	Low Band 70MHz
Tuning Inductor	Full printed ~ 140nH	Cut printed inductor and add additional 200nH in series
C22	4.7pF	6.8pF
C4	47pF	68pF
C5	22pF	33pF
C7	4.7pF	10pF
R9/C16	1k / 33nF	1.3k / 33nF
Tuning Sensitivity	1.5MHz/Volt	0.9MHz/Volt
Comparison Freq	50kHz	25kHz

Appendix 2 PLL Design



```
VCO Centre (MHz)  144.05                        10.00  MHz   Fref
Prescalar         1
VCO Freq                     VCO Freq    144.05
Fcomp (kHz)       50           N divider  2881              R divider       200
Kv (Hz / V)       1500000.00              0x 0B41                           0x 00C8

Kd (V / radian)   0.80       Vdd/2pi  for op-amp,  Vdd/4 pi single ended
                                  Keff  =      2617.0852

Damping           0.7                Wn max     3663.9192  r/s
                                   Bandwidth    1166.2617  Hz

                             Network Type       C / R / R         Op-Amp
Wanted BW  (Hz)   1000.000             Wn'      3141.59           3141.59
                                       T1       0.0002016  s      0.00027
                                       T2       0.0000635  s      0.00045
                               Approx Tlock     0.0031831  s

  Loop Cap  (uF)  0.033                R1          6.11  k          8.04  k
                                       R2          1.93  k         13.50  k
  ------------------------------------------------------------------------------
        Last Pole  must be greater than ...
                          5000  Hz
           C3   (uF)  0.033            R3          0.96  k
                  Use only OP-AMP configuration or after a buffer amp
```

R6 / R7 =	8k2
R5 / R8 =	13k
C14 / C20	33nF
R9	1k
C16	33nF



```
VCO Centre (MHz)  70                            10.00  MHz   Fref
Prescalar         1
VCO Freq                     VCO Freq    70
Fcomp (kHz)       25           N divider  2800              R divider       400
Kv (Hz / V)       900000.00               0x 0AF0                           0x 0190

Kd (V / radian)   0.80       Vdd/2pi  for op-amp,  Vdd/4 pi single ended
                                  Keff  =      1615.6762

Damping           0.7                Wn max     2261.9467  r/s
                                   Bandwidth     720.0000  Hz

                             Network Type       C / R / R         Op-Amp
Wanted BW  (Hz)   700.000              Wn'      2199.11           2199.11
                                       T1       0.0003164  s      0.00033
                                       T2       0.0000177  s      0.00064
                               Approx Tlock     0.0045473  s

  Loop Cap  (uF)  0.033                R1          9.59  k         10.12  k
                                       R2        535.88            19.29  k
  ------------------------------------------------------------------------------
        Last Pole  must be greater than ...
                          3500  Hz
           C3   (uF)  0.033            R3          1.38  k
                  Use only OP-AMP configuration or after a buffer amp
```

R6 / R7 =	10k
R5 / R8 =	20k
C14 / C20	33nF
R9	1.3k
C16	33nF