RF Generation for Superhets

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Introduction

RF generation using Direct Digital Synthesis has been available to commercial radio manufacturers and amateur home-brewers for decades [1]. The DDS devices conveniently are operated under the supervision of a microcontroller, which also provides means to support a user interface. In a recent article [2], mØxpd argued that the introduction of simple "physical computing" platforms such as the Arduino and the appearance of DDS devices on inexpensive modules have transformed these methods from the preserve of specialists to a technology which is i) accessible to all G-QRP members and ii) attractive in terms of price, functionality, performance and simplicity. That argument was presented in the context of direct conversion radios for CW. The present article extends the argument to address applications in a superheterodyne architecture for SSB phone use.

A Practical RF Generation Scheme

A superhet radio involves two signal generators; one to mix the incoming radio signal to an "Intermediate" frequency and a second to mix this to audio baseband. The former generator we shall call the VFO and the latter the BFO. The VFO needs to be capable of frequency change to effect tuning (and, at a coarser scale, band change), whilst the BFO is essentially fixed, changing only to switch between upper and lower sideband operation. In conventional practice, this has seen the BFO implemented as a crystal oscillator, with two crystals providing the LSB and USB frequencies. The system proposed in this article takes the (apparently) extravagant approach of using Direct Digital Synthesis to generate both VFO and BFO signals. The very low price of current DDS modules (e.g. those based on the AD9850 device) makes what once would have been profligacy a rational choice – the second DDS module may easily cost less than a pair of sideband crystals and the resulting system will be very much more flexible.

Consider the system of Figure 1, in which an ordinary superhet receiver is provided with VFO and BFO signals from two DDS modules.

Signals from the antenna are selectively amplified before being passed to a mixer, where they are modulated by the VFO to produce a copy of the desired signal at intermediate frequency. The signal can be processed at this intermediate frequency – typically by a narrow filter, wide enough to pass only one sideband of narrow-band speech. Finally, the processed signal is applied to a second mixer, where the BFO modulates it down to audio frequency. Note that the transmitter uses the same architecture but with the signal flow reversed - literally, in the case of the BITX described below.

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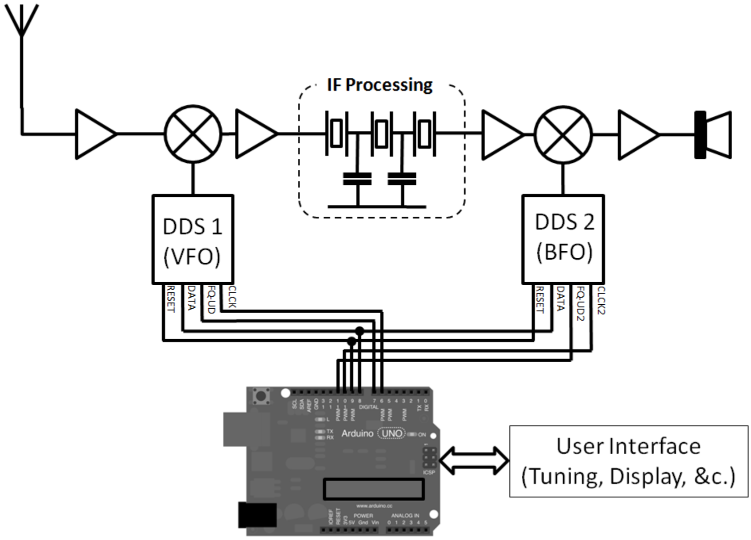


Figure 1 **RF Generator Scheme applied to Conventional Superhet Rx**

The two DDS devices required to perform this task can be controlled by a simple microcontroller – in the case described here the "Arduino" platform is used (although any other microcontroller family could be substituted at the builder's discretion, if s/he is able to develop the necessary code). The DDS devices have a serial interface, in which serial data on one "DATA" line is defined at the instants of the transitions on a second "CLOCK" line, but there are two further control lines (a data latch command and a reset). Of these four lines, it is possible to share the DATA and RESET between the VFO and BFO, whilst the other two remain unique to allow each DDS to be individually "addressed" by the microcontroller. Thus, a total of six lines from the microcontroller are used to control the two DDS modules, as shown in Figure 1.

Operation of the pair of RF synthesizers is summarised by a single equation, relating VFO and BFO frequencies to what we might call "dial frequency"; that frequency displayed on the tuning indicator.

$$\textit{Dial frequency} = \textit{BFO frequency} + \textit{VFO frequency} \qquad (1)$$

BFO frequency is usefully interpreted as a constant, determined by a combination of band and mode. [In practice, for phone operation, it is only determined by band as LSB is used below 10 MHz by convention whilst USB is used above this frequency]. This means that the VFO expresses the variable component of the dial frequency, as is implied in the name <u>Variable</u> Frequency Oscillator. In use, the BFO is set only on band- or mode-change, whereas the VFO is adjusted every time a tuning change is made. It is seen that digital control traffic to the VFO has higher density than that to the BFO.

When the IF is at lower frequency than the carrier of the signal which the radio is intended to receive, equation 1 is interpreted without confusion. When, however, the IF is above this “target” frequency, equation 1 implies a negative VFO frequency. Although this has meaning as a mathematical abstraction, the DDS module cannot accept a negative frequency input – so the code replaces equation 1 with a pair:

$$\textit{Dial frequency} = \textit{BFO frequency} + \textit{VFO frequency}\ \Big|_{\text{Dial frequency} > \text{BFO frequency}} \qquad (2a)$$
$$\textit{Dial frequency} = \textit{BFO frequency} - \textit{VFO frequency}\ \Big|_{\text{Dial frequency} < \text{BFO frequency}} \qquad (2b)$$

The code compares the Dial and BFO frequencies (amounting to considering which band is in use) and selects one of equations 2a and 2b, with the result that the VFO always is instructed to generate positive frequencies!

Advantages

The benefits accompanying use of DDS in the VFO have long been recognised. Most importantly, the radio will offer a level of stability which is hard to achieve with analog VFOs. It will deliver this stability – at high resolution – from below VLF to above HF, which is very hard to achieve with a single analog VFO. There are, however, interesting collateral benefits of DDS available to the home-brewer, especially when using SSB. It will be found that many amateur stations transmit at integer multiples of 1 kHz – due to the digital RF generators in their commercial rigs. Tuning to these stations is suddenly quick and easy when the home-brewer also enjoys digital frequency synthesis and control in their VFO, though the ability to tune continuously between the kiloHertz points remains. The authors note (and, to some extent, share) the reaction of some readers in seeing this “channelisation” as something to lament, rather than as a benefit!

The benefits accompanying use of DDS in the BFO are less familiar; this article’s digital, programmable BFO is itself something of a novelty. The ability to tune the BFO will be found of great benefit in the alignment phase of the development of a new scratch-built rig (which usually will feature a homebrewed crystal IF filter of uncertain passband). It allows the BFO frequency to be precisely optimised for the filter and leaves the builder totally free to set IF frequency to any value suggested by available crystals etc.. It even is simple to arrange BFO support for multiple IF frequencies to suit different bands / modes. The benefits available to the home-brew “scratchbuilder” are matched by those which can be accessed by the builder who retro-fits the RF generator scheme here described into an existing rig.

Implementation

Code has been produced to allow readers to experiment with the “Double DDS” RF generation scheme described in these notes. The code, which takes the form of Arduino “sketches”, implements both a basic control example and a more elaborated example with conventional “VFO” features (multi-band, RIT, etc).

The overall RF Generator hardware can be assembled using DDS shields, but it is almost as easy to work directly with the DDS modules themselves. The code has been tested on various Arduino boards and more experienced users can easily run the code in a stand-alone AVR microcontroller chip. The code and schematics for various hardware configurations are available by following the links on http://www.gqrp.com/sprat.htm .

The authors' experiments with this RF generation scheme have been reported on their respective websites / blogs [3, 4], but key application examples from the contexts of scratch-building and retro-fitting are presented below.

Application: Using the RF Generator in a Scratch-built Rig

mØxpd has been using the RF generator scheme in an SSB rig following the popular "BITX" design [5], allowing multi-band and multi-mode operation. The DDS module produces approximately 1V pk-pk output from 100 Ohms source impedance. This is inadequate to drive the two diode balanced modulator used as detector (Rx) / modulator (Tx) in the original BITX, although the DDS output has been found sufficient to drive the diode ring mixer, which has a driver stage.

mØxpd uses a single buffer / driver to couple the output of the DDS BFO source to the detector/modulator, as shown in Figure 2.

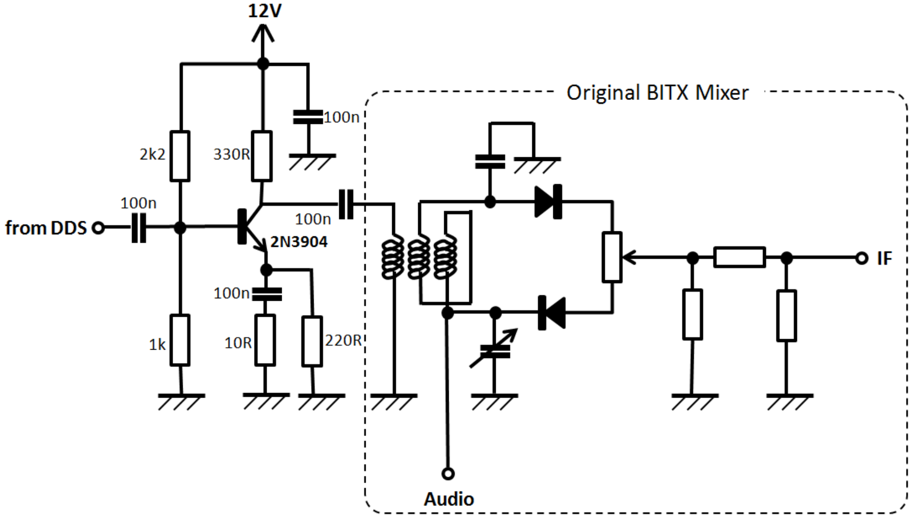


Figure 2 mØxpd's interface between DDS and the BITX detector / modulator

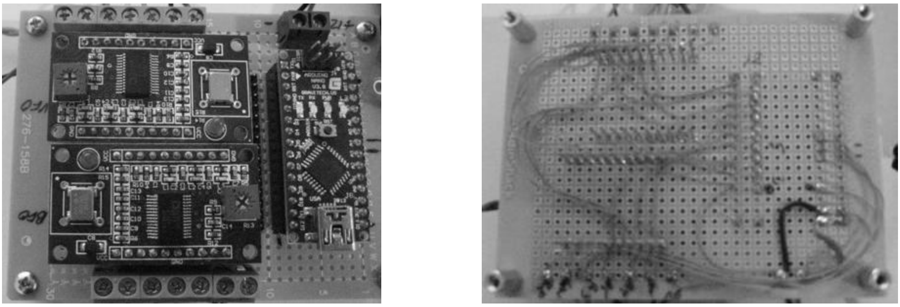
Application: Retrofitting the RF Generator to Existing Rigs

At n6qw there are many homebrew radios and some suffer the general weakness of the lack of an accurate, stable signal source for the LO. With mØxpd's design that is no longer a concern, as several of these radios have been tested with the Arduino/Dual DDS combo and it is like coming out of the dark ages. The first retrofit "proof of concept" application was for the single DDS in a 20m QRP SSB transceiver shown below in Figure 3.

Figure 3 20m SSB Transceiver with Single DDS VFO

The IF is at 9.0 MHz using the GQRP Crystal Filter and two bilateral amps from G4GXO [6]. The Tx and Rx mixer stage is a TUF-1. (Some cosmetics need to be added to front panel as the 20X4 LCD is larger than the original cut-out.) For good measure I followed the RF generator with a LPF that has a 30 MHz Fc. I do note that the drive is a wee bit shy to the TUF-1 which is a 7 dBm device where you need 1.414 Volts Peak to Peak. As mØxpd noted, the output of the DDS is about 1 Volt pk-pk. A suitable "booster amp" is described below.

This same radio was been tested with the dual DDS RF Generator which is being controlled by an Arduino "Nano". Truly it is a compact package and the underside wiring is done using wire wrap technique, as seen in Figures 4. What a treat to swing down to 40m and automatically be on LSB. Previously, with only the USB crystal available for this radio, going to 40m would be problematic.



Figures 4 RF Generator implemented using wire wrapping and the Arduino "Nano"

Figure 5 is gain adjustable amp which can be used with a TUF-1 or AE1-L (the latter is a 4dBm device (1.0 V pk-pk)). The BFO requires a similar amplifier.

Another homebrew radio of mine which I dubbed JABOM (Just A Bunch Of Modules) [7] originally used a 4 pole 4.9152 MHz homebrew filter which was replaced by the GQRP 9.0 MHz filter. The JABOM was tested using the dual DDS unit and is a future candidate for a permanent dual system installation for operation on 40 and 20m. Again, the lack of a LSB crystal previously had limited this radio to USB. The total cost, including the Arduino Nano, two DDS modules and 20X4 LCD was under $35, making the price point highly cost effective.

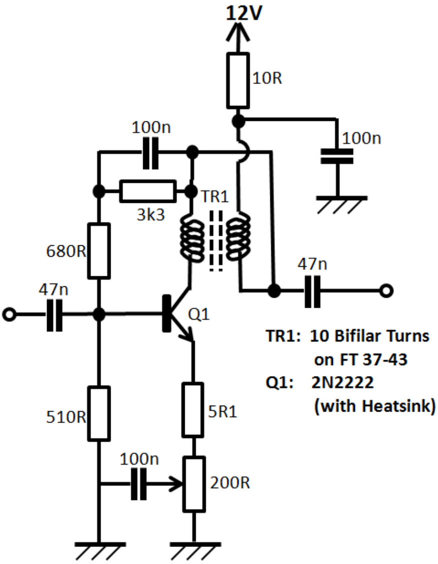


Figure 5 Gain-adjustable amplifier
(*after a circuit on the* ei9gq *website***)**

One dual unit is slated for installation in a radio that is yet to be built but will use a 3.180 MHz filter from of an early Yaesu FT-101 for which I do not have the matching crystals. Frequently the FT-101 crystal oscillator board is listed on one of the auction sites at a price exceeding the cost of a dual DDS system. Based on the capability of the Dual DDS, I recently bought a FT-101SSB filter for $7.50 USD and now I am ready to proceed with that project.

The dual unit adds a whole new dimension of what is possible with many commercial and homebrew filters. A very exciting opportunity for the dual system is the installation in the boat anchor commercial radios that aside from drifting and the lack of a digital display are otherwise really great sounding radios (valves you know). The dual system also solves another problem frequently encountered with the older radios; their USB and LSB crystals have drifted with age and are no longer useable. The bonus of the dual system is not only a RF generator but the generation of the BFO/CIO frequencies to match the filter.

Using the RF generator in tube type radios must be done with care. A booster amp is definitely needed as is some isolation between the DDS and the radio. I also built an isolated power supply which is fed from the filament string, shown in Figure 6. Avoid powering the Arduino from the plug-in type switching regulators ("wall warts") as the hash generated is noticeable.

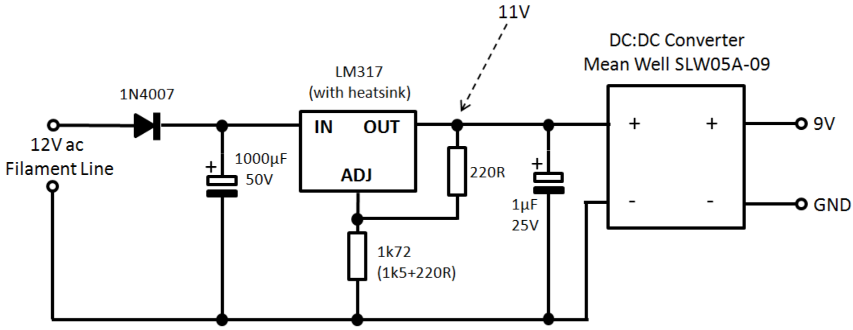


Figure 6 Isolated PSU for Powering the Arduino from a filament string

The other isolation is the LO RF signal is fed via a ferrite transformer of about 12 turns on the winding to the radio and 4 turns on the DDS side. A FT-50-43 core is used for the windings to better match the radio/DDS. On the radio side one end of the 12 turn winding is grounded and the other end injects the signal through a 10 nF 500 VDC cap. The side of the transformer connected to the DDS is not grounded but acts much like link coupling.

One valve radio used as a test bed was a 1960’s Heathkit 40m Single Band SSB transceiver which uses a 2.305 MHz four pole crystal filter in the IF. The Arduino/Dual DDS essentially replaces two valves.

The Heathkit uses a low frequency VFO just above the broadcast band and mixes that signal with an 11.190 MHz fixed crystal oscillator. The resultant difference frequency is now in the 9.5 to 9.8 MHz beating against an incoming signal frequency of 7.0 to 7.3 MHz. Thus the sidebands are reversed but I designated the offsets to accommodate this arrangement. [The IF is 2.305 MHz, the BFO is on 2.303300 MHz and the ‘VFO’ tunes in the 9 MHz range.] The point of insertion of the VFO was done essentially where the plate of the mixer valve would be connected. The 10nF 500 VDC cap is needed to prevent shorting the LV supply to ground.

The n6qw homebrew radios/commercial radio modifications use a variety of filter frequencies. A few seconds at the computer and these various filters and their offsets can be easily programmed into the Dual DDS code and that is a capability previously unavailable. But that also addresses an issue of how to manage the interfaces and that is the reason for my using the small terminal blocks shown in Figure 2 so that insertion into any project is not a monumental task. Figure 7 shows the Dual DDS Board “al fresco” on the work bench.

Closing remarks

Generation of stable, flexible RF signals for a superhet system can be achieved using DDS modules under the control of computing platforms such as the Arduino. The microcontroller retains the capacity to perform other tasks, such as switching band-specific filters and managing other modes (both of which are planned developments for the code).

Recent “open-source” radio platforms (such as the TenTec “Rebel”) attest to the flexibility of and contemporary interest in these methods. We have sought to demonstrate how simple digital methods bring formerly unavailable flexibility to modify our radios literally on the fly. This flexibility is applicable to older “boat anchors” – every bit as much as to modern platforms. The cost of the DDS modules, the accessibility of the microcontroller systems and the performance and flexibility of the resulting system make this technique an attractive choice for those building or retro-fitting radio systems, extending the “Occam’s Microcontroller” thesis to phone applications.

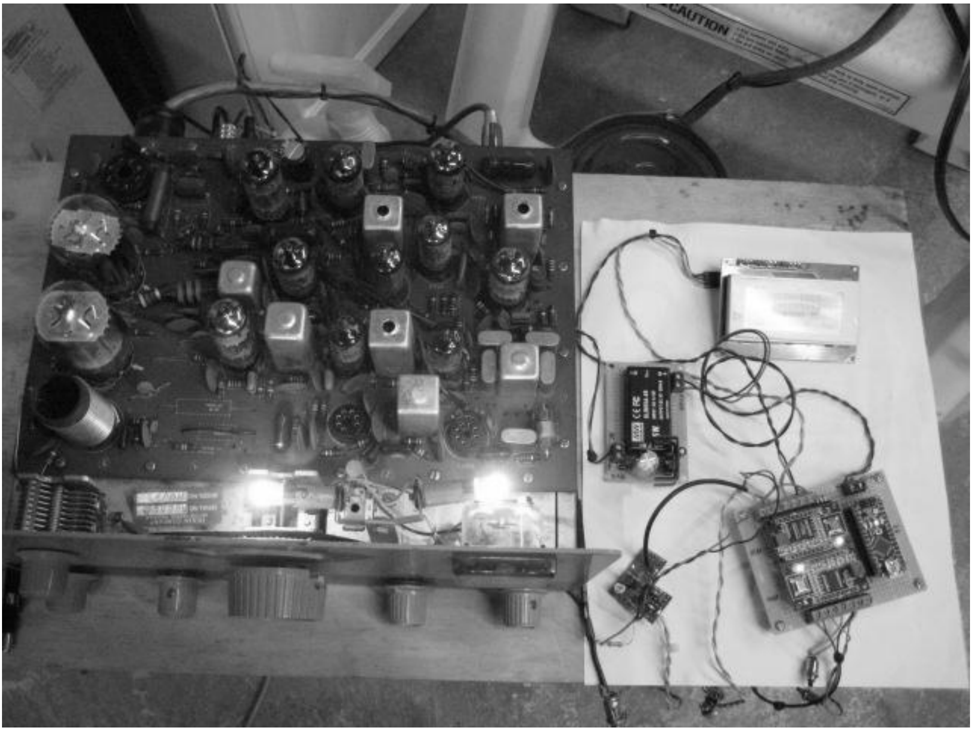


Figure 7 **HW-22 & the Dual DDS RF Generator**

References

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[2] "Occam's Microcontroller", P. Darlington, mØxpd, SPRAT 156, p13, Autumn 2013

[3] see mØxpd's blog "Shack Nasties" at m0xpd.blogspot.co.uk

[4] see n6qw's website at www.jessystems.com

[5] "BITX - An easy to build 6 watts SSB transceiver for 14MHz", A. Farhan, vu2ese, downloaded from: http://kambing.ui.ac.id/onnopurbo/orari-diklat/teknik/homebrew/bitx20/bitx.htm

[6] "A 19dB Bi-Lateral Amplifier with 37dB Gain Control Range", R. Taylor, g4gxo, SPRAT 128, p 6, Autumn 2006

[7] "JABOM – A 17m SSB QRP Transceiver", P. Juliano, n6qw, QRP Quarterly, Fall 2011, p 40