

Some Comments on “Performance of the IQPro DDS VFO and Evaluation of Wideband Op-Amps,” by Gary Johnson, WB9JPS.

Wes Hayward, w7zoi, July 6, 2006

Roger sent this document over to me, noting that he didn't have time on his plate to dive into it right away. Besides, I was the one with the driving interest in the phase noise and spur issues. The IQPro DDS VFO was a design by Craig Johnson, AA0ZZ, that appeared in the May/June issue of QEX and used a AD9854 synthesizer chip with quadrature outputs. As such, it has caught the imagination of several experimenters interested in wide tuning range phasing type direct conversion receivers such as Rick's R2Pro.

I did a rather quick read of the piece and found it to be quite useful. Gary bought a spectrum analyzer just to do this job, but I bet that he is not about to sell it now. He got an HP-8568B, which back in the late 1970s and early 1980s was the premier lab spectrum analyzer that HP sold covering the DC to 1.5 GHz region. They also offered the 8569, which was a band switched box that went into the microwave spectrum.

I'm sure that another read of the piece will produce more observations, but I wanted to document these while they are fresh in my mind. (Besides, we are headed out of town for a few days and I don't want to forget the details.)

I gather from the write-up that Gary is a very experienced analog designer. He is clearly very comfortable with high speed op-amps including those that he evaluated for this application. I suspect that these experiments may have been more of an introduction for him to the RF world, at least in his home ham activities.

Spurs

The first thing he did was to measure the output of a single channel (I or Q) with the spectrum analyzer with a goal of examining the spurious outputs. The initial measurements were directly from the transformer output port from the DDS chip, without an amplifier connected. He immediately found that the spurs were down far enough that they could not be easily seen within the dynamic range of his analyzer. So he implemented a notch filter, referencing the LC circuit that I used for spectrum analyzer harmonic distortion measurements in Ch 7, EMRFD. One point that should have been emphasized is that there should be a pad (10 dB is good) between the synthesizer being evaluated and the notch filter. The circuit being measured “wants” a wideband termination. This was probably there. He picked up 24 dB with this notch filter, enough to easily move the spurs on screen along with the desired output. He did major measurements at 7 and 28 MHz. The 7 MHz results looked really good, with only a finite number of spurs present, and all over 80 dB below the carrier. This is a far cry from the compromised spectrum that we saw with the AD9850. The AD9854 uses a faster clock and more bits in the DAC.

There were no close in results. It would have been interesting to see what the spurs were like within a few kHz of the carrier. This was not possible with the LC notch filter that Gary used. It would, however, be possible with a crystal notch filter like the one that I have planned on building for this same measurement. You do have to tune the synthesizer to the filter frequency, which is a limitation. But it is still simpler than other measurement schemes. Note that virtually all of the systems we use for phase noise and oscillator spur measurements are just schemes to attenuate the strong carrier.

The 28 MHz results were not as good as those at 7. Part of the problem may have come from the lack of a notch filter for this experiment. But the data were well within the dynamic range of the HP8568B, so there should not have been a major measurement problem.

Gary did a measurement at a carrier output of 25 MHz, which was interesting because it was an integer sub-multiple of the 125 MHz clock used in the synthesizer. This was a “sweet spot” in that there were generally few spurs. However, those that did occur, other than harmonics, were close to the carrier.

One of the measurements was of the wideband spurious output with the analyzer spanning from DC to 500 MHz. Gary suggested an external low pass filter, but then waxed about the problems of doing a good one with leaded parts compared with a SMT design. This is but another example of a general fear of using SMT for ham projects. While I can see a hesitation to “do it all with SMT,” a low pass filter is such a dramatic example of a place where surface mounted parts really do make a difference that I would push for a hybrid approach. (Yea, I know – it’s a soap box that I love to climb upon.)

Phase Noise

From here, Gary moved on to the measurement of phase noise. He started with a sweep of a 28 MHz signal over a narrow span (about 30 kHz total) with a 10 Hz resolution bandwidth. This was probably a RBW that was too narrow. Generally, when measuring phase noise, you want to use a wider bandwidth, for it makes the noise louder while leaving the carrier unchanged, which puts the two into the dynamic window of the analyzer. No matter though. He essentially just measured the noise performance of his spectrum analyzer, which is what usually happens with any synthesizer that is interesting.

In an attempt to get a better measurement, he adopted the scheme that Linley Gumm used with his high level differential-pair oscillator that was first in SSD, and then in EMRFD. Gary had a 9 MHz SSB filter, so he did his measurements down there. He has a tracking generator to go with his analyzer, so he was able to do a good measurement of the crystal filter characteristics. It was a good looking filter except for some severe passband ripple, which was not an issue here. By sliding the DDS synthesizer up above the filter passband, he attenuated the carrier by 70 dB and was able to see phase noise that was about 120 dB below the un-attenuated carrier. But here see a major goof, at least in the preparation of the paper. Gary didn’t tell us what the resolution bandwidth of the spectrum analyzer was, so we can’t transfer the observed 120 dB to a phase noise spectral

density. Looking at the carrier in the display, it looks like the measurement was done with a 100 Hz RBW. Assuming the noise bandwidth is close to this, this would put the spectral density at -140 dBc/Hz, which is quite good at a spacing of only 2 kHz. These kind of results are consistent with what we generally know about DDS. That is, the wideband phase noise performance is stellar, but we pay a price for this in the spurs that we find.

Adding the amplifier.

The direct output from the DDS chip is only +3 dBm or thereabouts. Many applications require from +7 to +17 dBm, or even more. So some gain is required. A pair of wideband amplifiers were included in the original design. These ran from 12 volts and used 2N3904 and 2N3906 parts. The first stage was a follower with 5 mA. The stage suffered from exactly the problem that I presented in EMRFD, Fig 2.31 and Fig 2.32. A follower won't follow if the output current must equal or exceed the standing emitter current. Gary recognized this immediately and shifted to a metal can 2n2222 with a LOT more current. This helped. But there were still many problems. Several modifications were suggested, but the bottom line was that the harmonic suppression of these amplifiers was so poor that they would probably compromise performance. Even order harmonics are best suppressed with balanced circuitry and this would be a fitting design approach for an amplifier to follow this synthesizer when wideband application is desired.

But this is just part of the difficulty. The amplified signal seems to have grown spurious output components in great profusion. While amplifier deficiencies may account for harmonic distortion, they should not produce spurs. It could be that the amplifier circuitry is picking up garbage from the two microprocessors which then intermodulates with the carrier and the harmonics. Also, the system includes a switching power supply that generates 5 volts from the higher 12 volt rail. Frankly, the very first thing I would do is to replace the switcher with a 7805 or other linear regulator. (It will take more than a 78L05.) While there is an inefficiency, this is a more conservative approach, at least for the first experiments. (Perhaps I missed some discussion on this with my quick read.)

Wide band op-amps.

Having encountered problems with the amplifiers included on the board, Gary proceeded to present some information on some of the many high speed op-amps that are now available for video and similar applications. There are a lot of them out there. Many are quite easy to use and do a wonderful job. Gary has done a good job, from what I can tell, of summarizing this problem and some solutions. This is good data to have on hand.

One part that might be worth including, even though it is intended for other applications, is the LMH6502. This is nominally an AGC part. I used one when I needed to do closed loop gain control. But the part has the feature that it will deliver an output of up

to +18 dBm from a single 15 volt supply, which is a lot for a 14 pin SOIC. (I don't think it is available in a leaded DIP format.) I don't recall what the harmonic distortion is with the part.

Summary

The report really is quite good. It certainly illustrates the good characteristics of the DDS synthesizer of low wideband phase noise and reasonable, if not stellar spurious responses. The difficulties encountered with the amplifiers led Gary to do a masterful job of suggesting some wideband op-amp solutions.

I may have missed it, but I didn't see any data on the accuracy of the quadrature phase relationships. This is critical in the intended application. Perhaps the best evaluation would be the construction of a phasing receiver that tuned at least an octave, if not a decade. The sideband suppression would then be a measure of the goodness of this approach to the problem. Perfect symmetry in synthesizer channels and perfect phase control on chip is still not the complete answer. Errors in the transformers or amplifiers can both inject phase errors that could compromise receiver sideband suppression.

I would also like to have seen the performance of the system when set up to tune only, for example, from 5 to 5.5 MHz, with a following bandpass filter. How bad would the spurs be? And what would they be if a one-on-one phase locked loop was added to the system? And how good would phase tracking be after two bandpass filters and/or tracking locked oscillators were added to the raw synthesizer? These go beyond the goal of the report, but are things that have tweaked my curiosity about such circuits. (I bet Rick is with me on these too!)