Adding Synthetic Spurs to an Oscillator—An Experiment

Wes Hayward, w7zoi, October 30, 2023 ….

Spurious signals, or spurs, are a common problem with oscillators that are part of the communications equipment that we build. Some spurs are signals at a specific frequency such as reference sideband in a phase locked loop, PLL. Direct digital synthesis, DDS, is a popular scheme supported by special integrated circuits. DDS generates a plethora of spurs of limited strength. Phase noise is another kind of spur. Rather than a discrete frequency, phase noise appears as a pair of continuous sidebands centered about the oscillator carrier.

The builder/experimenter encounters a number of spur related questions when building equipment. How good must a transmitter oscillator be to avoid transmitting spurs that interfere with other spectrum users? What will happen when a contaminated source is used as the local oscillator (LO) in a receiver? Will the spur move in frequency as the oscillator is tuned? Does the spur have to be strong enough to turn the mixer diodes on to become a problem?

We usually try to answer these questions by measuring the spurious signals. These signals are voltages that change with time and/or with frequency. Hence, we examine the signals respectively with an oscilloscope and a spectrum analyzer. The spurs are often much weaker than the carrier making the measurements very difficult.

An alternative to the ultimate experiment of measuring a carrier with spurious signals is to generate a carrier and then add a weaker, known signal. This direct study might illustrate the problem and allow us to expand our intuition about the greater subject.

In thinking about this problem, I realized that I had all the needed equipment in my *lab*. A high-quality signal generator was available that can also be used to calibrate other homebrew instruments. Several sine wave generators are available as well as modules that can be used to combine the generated signals and to mix them to other frequencies. I have several oscilloscopes and spectrum analyzers to let me examine the outputs.

The results of these experiments are presented below. An appendix shows the homebrew elements that we built and used in the measurements.

Adding a spur

Two sources were available for the first experiment. One was a crystal-controlled oscillator at 7 MHz that originally served to calibrate a spectrum analyzer. It has also proved useful as a signal source in numerous experiments. The output is -27 dBm at 7 MHz. The circuit is rich in harmonics, so a 7.5 MHz low pass filter is added to the output to produce a pure tone. The second source is a general-purpose tunable LC oscillator. The +18 dBm output is attenuated to +7 dBm, for that is the eventual level that will be used with a diode ring mixer. Fig 1 shows the setup to add the 7 MHz signal as a spur on the side of the signal from the tunable generator, now set to 6.6 MHz.

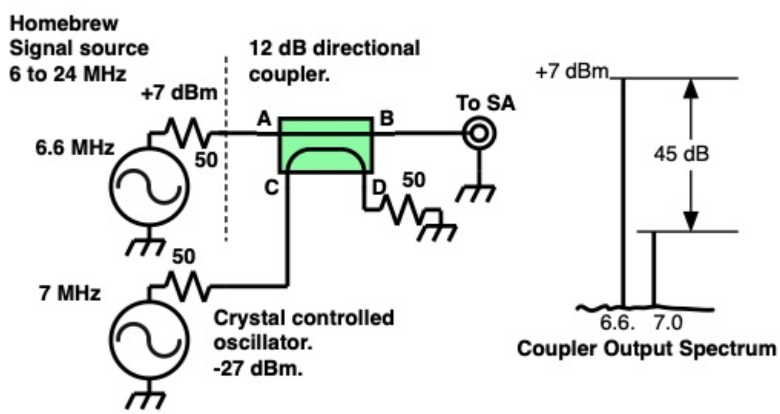

Fig 1. A directional coupler adds the two sine wave sources while providing some isolation. Coupler detail is found in the appendix.

The observed spectrum is shown in Fig 2. The *carrier* at 6.6 MHz is much stronger than the 7 MHz *spur*, so an oscilloscope measurement of this composite signal just looks like a sinusoid.

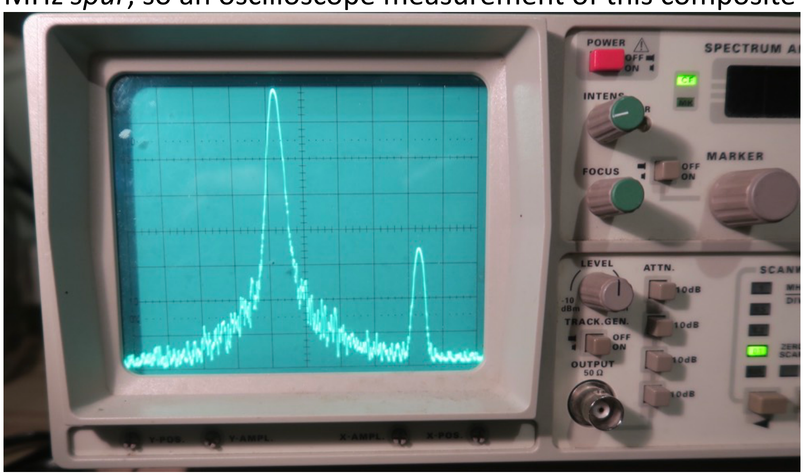

Fig 2. The spectrum of the LO signal, the sum of the 6.6 and 7 MHz signals. Spectrum analyzer phase noise is apparent; it's expected in this VHF analyzer without the phase lock or synthesis option found in a higher performance analyzer.

The two signals of Fig 2 are isolated from each other. Changing the amplitude or frequency of one does not alter the other. The 7 MHz signal is 45 dB below the main signal.

Adding a mixer

The composite signal of Fig 2 can now be used as an LO for a diode ring mixer. An SBL-1 mixer was available in a small box with BNC connectors. The setup is shown in Fig 3 with the IF spectrum in Fig 4.

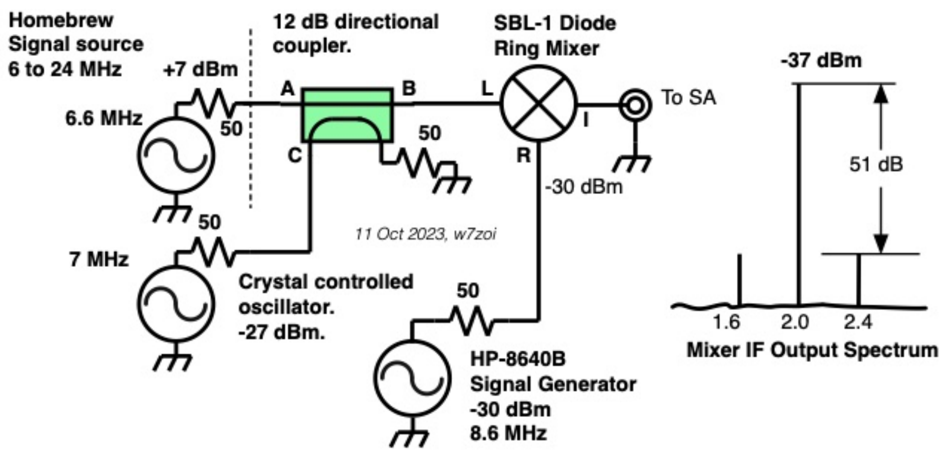

Fig 3. The output spectrum and the circuitry used to generate it. The RF port of the diode ring mixer is driven with a -30 dBm signal at 8.6 MHz, resulting in an IF at 2 MHz. The original LO spur at 7 MHz has split into to components, 0.4 MHz on either side of the LO. The 1.6 MHz signal will remain constant when the 6.6 generator is tuned, for it is the result of mixing of the 7 MHz and the 8.6 MHz from the HP generator.

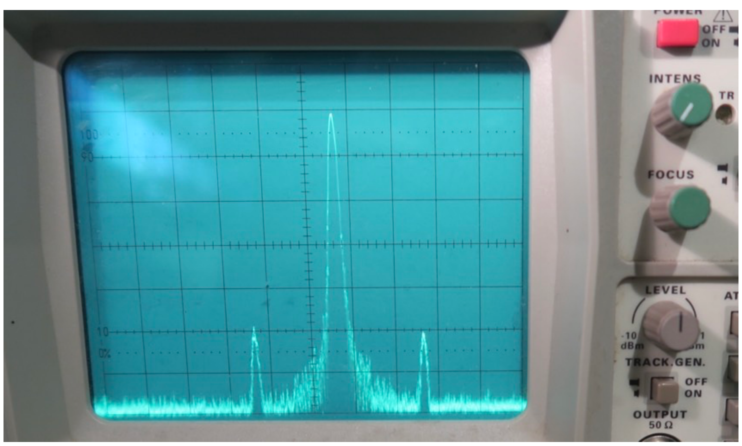

Fig 4. IF spectrum.

The levels are those expected. The 7 MHz spur of Fig 1 is consistent with the +7 dBm signal from the tunable generator, the -27 dBm level from the 7 MHz source and 12 dB loss in the directional coupler.

The IF level from the 6.6 MHz LO is -36 dBm at 2.0 MHz. The R level at the mixer is -30 dBm, but there is a 6 dB loss in the diode ring mixer. The carrier to spur level was 45 dB at the LO port. The IF carrier to spur level has grown to 51 dB and there is a second sideband at 2.4 MHz.

Drive levels were varied while observing the IF port. The 7 MHz level was changed by adding a pad in the 7 MHz line before it reaches the coupler. A 20 dB pad is enough to drop the sidebands into the noise.

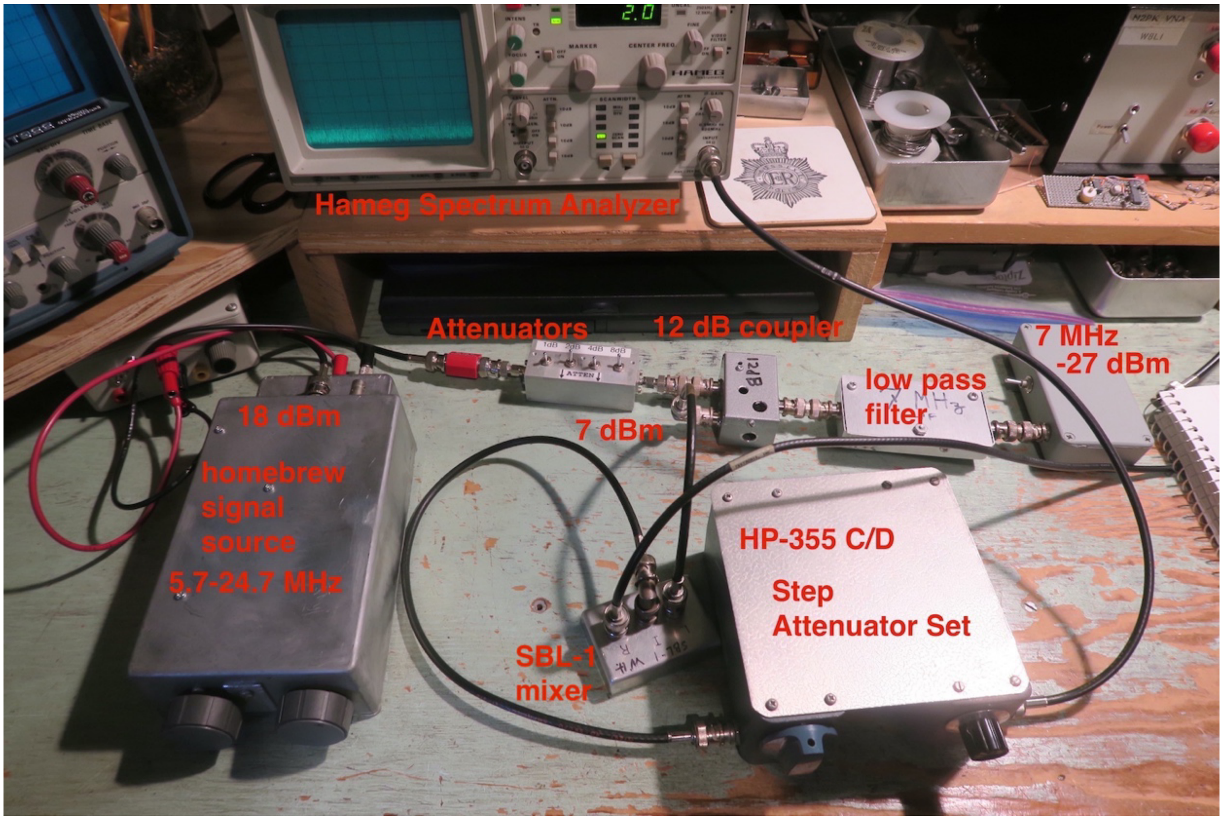

Fig 5. This shows the test bench when these measurements were done.

There is an elephant in the room, one that we almost missed because it's so familiar. The IF signal exiting the mixer is a carrier at a new frequency, but now with two sidebands. Where did we get that other sideband?

The Fig 1 experiment added a sinewave spur to a carrier, resulting in a pure upper sideband, Fig2. If we were to plow through the mathematics, we would find that a single sideband can be generated by simultaneously amplitude and frequency modulating a carrier. AM and FM modulation produce almost identical results if the carrier is much stronger than either of the modulating signals. Both schemes produce two sidebands. The AM sidebands are in phase with each other while the FM sidebands are out of phase with each other. When the AM and

FM sidebands are added, and the amplitudes are equal, one sideband is doubled and the other is cancelled.

Our experiment started with the single sideband of Fig 1. Translating the signal to a new frequency through mixing alters the phases to extract the sidebands. But the upper sideband of Fig 1 is, or could be the result of adding two identical signals from AM and FM. Hence, the amplitude voltage of each of the new sidebands is half that of the original synthetic spur.

The methods of Fig 3 can be extended to evaluate the phase noise density of a noisy local oscillator in a receiver. A spectrally clean and strong signal is applied to the receiver. The amplitude is increased until phase noise can be heard at a desired spacing. The equivalent single sideband noise power and the power of the applied signal are used to calculate a carrier to noise spectral density. The value is then reduced by 6 dB to characterize the local oscillator.

A remaining question

Diode ring mixers require a local oscillator that is strong enough to turn the diodes on and off at the LO rate to produce the familiar commutating action. The diodes are then acting like ideal switches. But, do the spurs have to be strong enough to turn on the diodes?

In Fig 1 we attached our synthetic spur of -27 dBm to the +7 dBm LO. The attenuating action of the coupler reduces the -27 dBm level by 12 dB to -39 dBm. The resulting carrier to spur ratio is then 46 dB. (Our measured ratio was 45 dB.) The composite of the +7 dBm signal and the spur are then applied as the LO for mixing, Fig 3. The RF input for that example was -30 dBm, resulting in an IF carrier at 2 MHz of -37 dBm, indicating a 7 dB conversion loss in the mixer.

If the mixer behaved as an ideal multiplier, the measured 45 dB carrier to spur level should be preserved. The converted spurs of Fig 3 should be 45 dB below the converted carrier at -37 dBm, or -82 dBm. We measured a new carrier to spur level of 51 dB, placing the converted sidebands at -88 dBm. The 6 dB difference is exactly the 6 dB related to the single sideband to double sideband conversion described above.

This experiment shows that it is not necessary for a spur to have enough amplitude to turn on the diodes. Rather, it is only necessary that the main LO have a high level. The LO signal is termed a ***carrier*** for good reason. It is useful to think of a real spur as being an FM signal that modulates the carrier. Assume a jitter of 10 Hz. If at one moment the carrier has moved upward by 10 Hz, the spur that is riding with it will have moved upward. The ultimate mixing action is the same as would be observed if the spur was alone, devoid of a carrier, but with enough strength to turn the diodes off and on.

Appendix

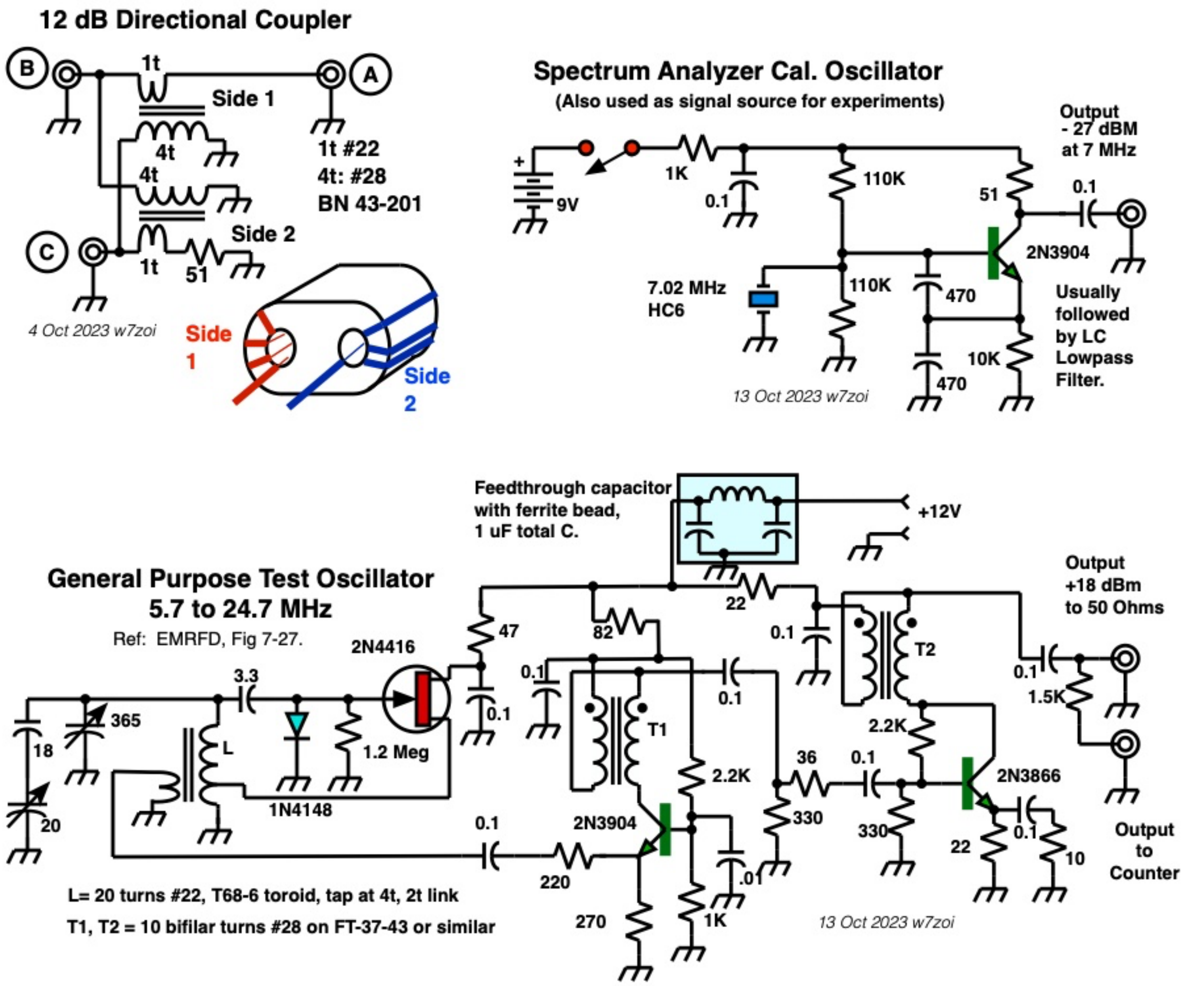

Fig 6. Schematic for the homebrew signal source, the directional coupler, and the low level crystal controlled oscillator.

Fig 7. General Purpose Tunable RF Source.

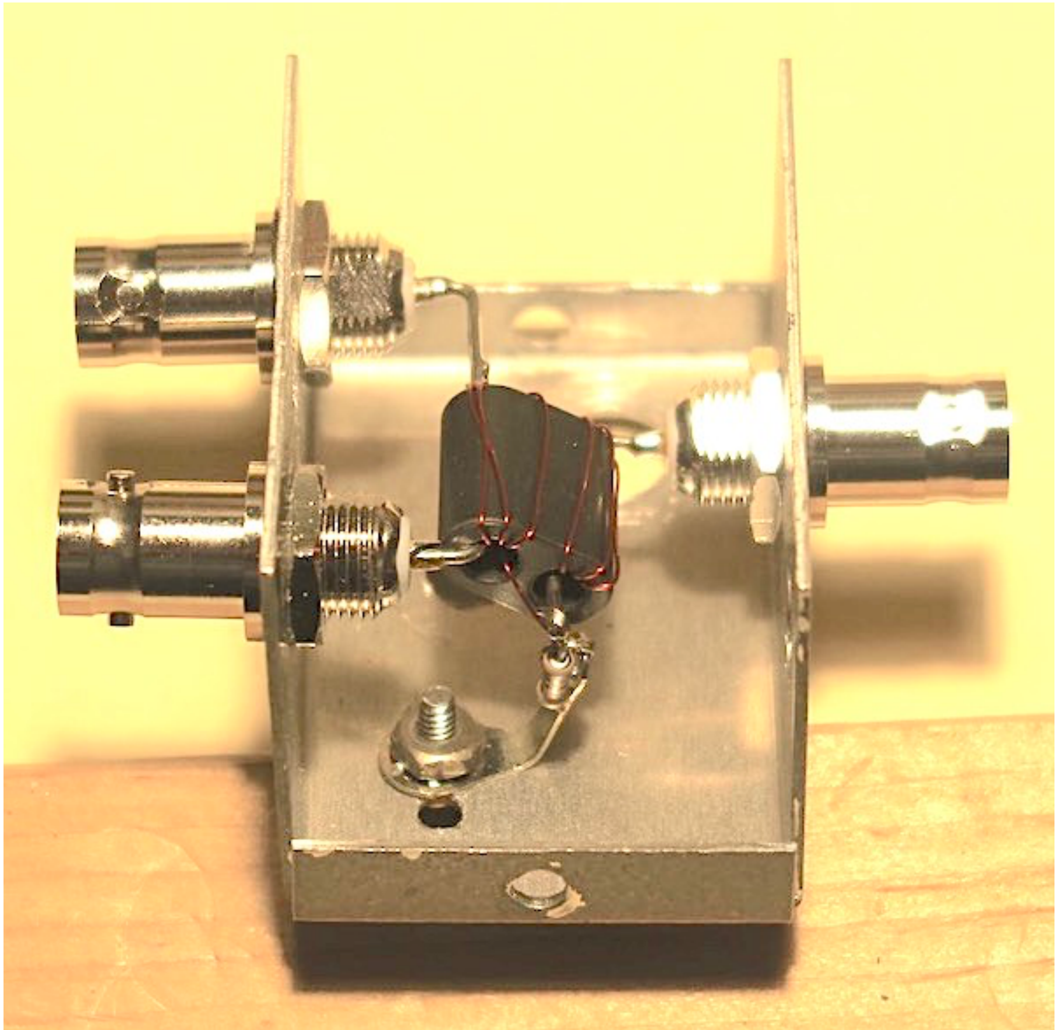

Fig 8. Inside view of the directional coupler.

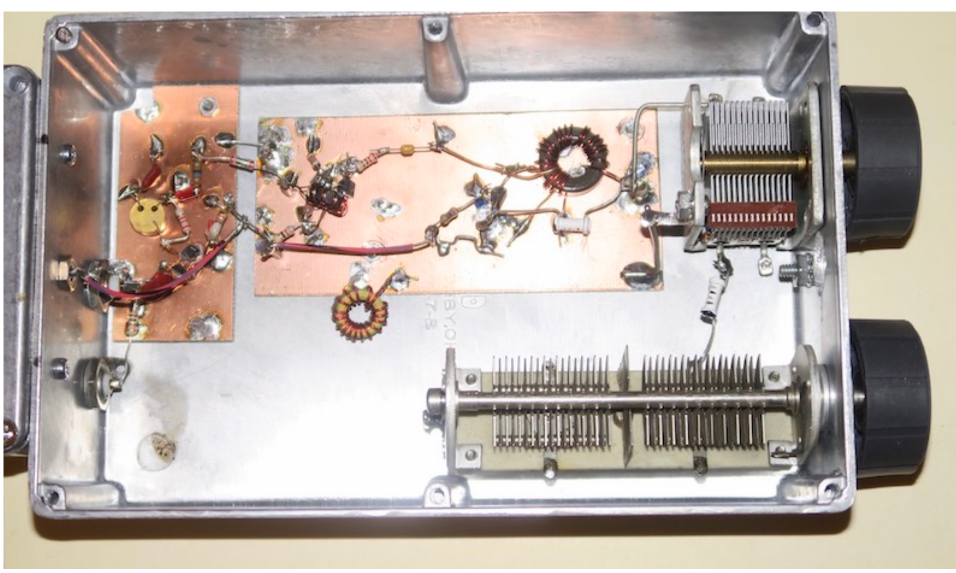

Fig 9. Inside the source.