The Orion-I ADF4351 PLL Synthesizer

By Joseph Haas, KEØFF
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joeh-*at*-rollanet-*dot*-org

Sometimes, it is interesting to look back and ponder the path you have followed to get to where you are. Sometimes it is informative, and sometimes it is just for the sake of nostalgia. I leave it as an exercise for the reader to judge which is the case here.

The Orion-I Synthesizer was conceived rather accidentally, as conceptions can sometimes happen. The Orion is a PLL synthesizer that covers 35 to 4400 MHz, with a nominal +15 dBm output and fairly good phase noise. It features an on-board microcontroller that is used to send the PLL data to the ADF4351 IC that forms the heart of the synthesizer. Some ancillary functions are also handled by the microcontroller (mostly housekeeping functions to set channel data and monitor system functions). It was decided to implement a 2-digit BCD channel input to allow several (up to 100) channels to be pre-programmed and recalled at will.

Before Orion, there was e-bay…

I originally started down this path when I purchased an ADG4351 PLL board from an e-bay seller for $45 to use in a tracking generator project. When I first examined the board, I was astonished at the apparently poor layout choices. Power traces routed under RF output traces and a single (non-low-noise) voltage regulator were the primary offenses.

Before making any changes, the PLL board was connected to my HP8566B spectrum analyzer via a 10 dB attenuator and a plot at a narrow span (500 KHz, Photo 1) was recorded.

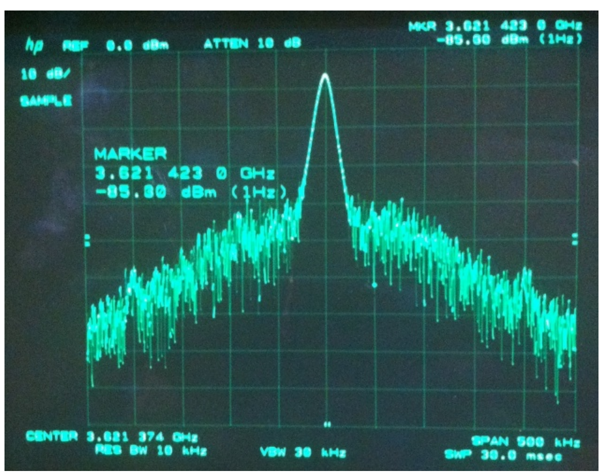


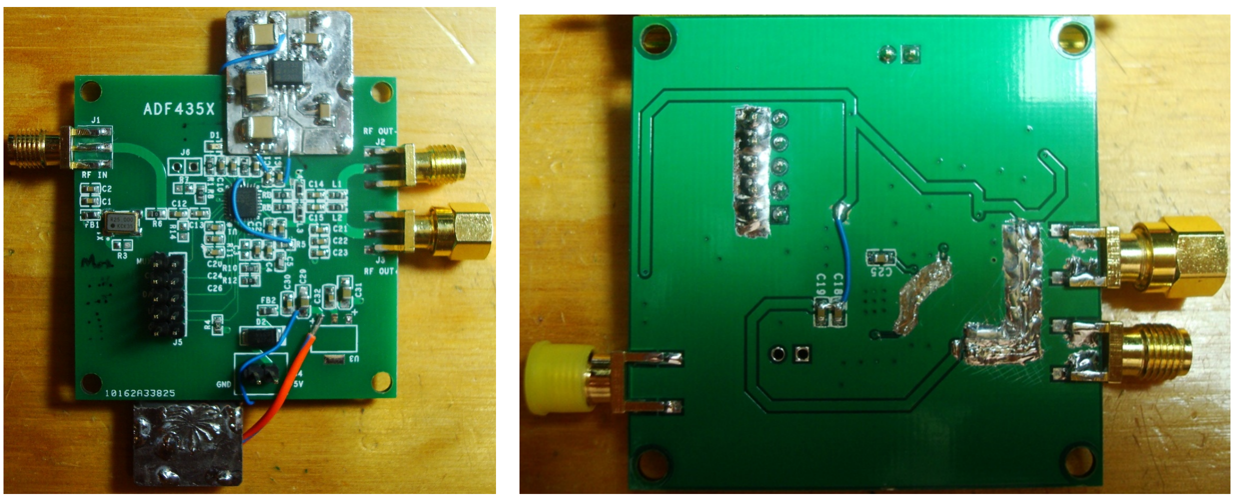
Photo 1. S/A plot (500KHz span) of un-modified e-bay PLL board

It is difficult to see, but the marker is about 50KHz right of center. Fc is at about -7.5 dBm, so the PN reading is about -85.5 + 7.5 = 78 dB/Hz. For some of the plots, I forgot to set the ref level = the Fc level, so the PN measurements have to take this into account.

To improve the isolation between the output traces and the power supply trace (not shown in the picture below), the power trace was cut, and the GND plane gap was bridged with Cu foil. The power trace was then re-routed with a jumper wire. SPI ground returns were added by drilling an extra row of pins next to the existing header. The solder-mask was scraped away and the copper tinned, and a strip of header material was then soldered to make a 2x5 header, with 5 signal return pins.

These efforts didn't seem to make as much improvement as was expected. At best, the signal level was just a bit higher, but no other changes were noted. It was observed that the output was sensitive to one touching the power trace even though it was no longer routed under the RF output traces. Analog Devices recommends that one use low-noise regulators (at least two and preferably three) to power many of its PLL devices.

I got hold of a couple of ADM7154ARDZ-3.3-R7 ULN-LDOs and fabricated add-on PCBs to add two of these devices to the ebay board. Photo 2a and 2b illustrate the modifications that were performed.



(a) (b)

Photo 2. Low-cost PLL board with ULN-LDOs (a) and power trace modifications (b).

Again, the module was attached to the spectrum analyzer to see the result (Photo 3). This time, I set the REF level to the amplitude of the Fc. This allows the PN to be read directly from the S/A, but makes it a little more difficult to compare to the previous plots.

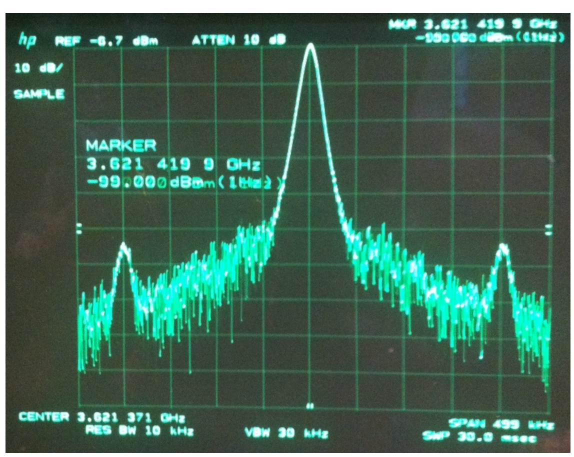


Photo 3. Spectrum with two ULN-LDOs powering the ADF4351

At first, I was concerned that the spurs at 200KHz either side of Fc had suddenly appeared. But then, I realized that it was the noise that was reduced, and these same spurs were actually just barely visible in the original scan. This plot shows that the PN is about -100 dB/Hz at 50KHz from Fc, a reduction of about 22dB from the un-modified board!

At this point, it was clear that I would need more synthesizers for my future projects, but the prospect of modifying off-the-shelf boards was not very enticing. I also wasn't anxious to pursue a PCB project as this would entail a great deal of overhead in terms of PCB cost. However, a friend of mine, Ben, NO5K, offered to purchase some of the boards, so I decided to take the plunge. Thus, Orion was conceived.

Behold, Orion …

I had a few requirements for the board design:

- There needed to be a microcontroller to send data to the PLL allowing stand-alone operation
- The design needed to be two layers to reduce cost
- The bottom layer was to be a continuous copper layer around RF or sensitive circuits
- Better than +10 dBm output over the entire output range
- Capability of using an external reference without using a soldering iron to switch between the on-board reference and the external connection

I chose an SiLabs microcontroller as I had development tools for their 8051 family. The C8051F53x series was small, had a reasonable compliment of peripherals, and was available from Mouser. I had to break the ground plane in a few locations, but these were well removed from the RF paths and were limited in scope to reduce their effects. The addition of a GVA-62+ from MiniCircuits would give enough gain to stay well over +10 dBm at the RF output. Another MiniCircuits part was employed for the reference switch, and a pad for an external switch was provided to switch the on-board reference off when the RF switch was set to route the external REF connection to the PLL.

Once I had the layout to a point that both Ben and I were happy with it, I stitched together three Orion boards (along with a host of other small designs to maximize the return on investment) and placed the order. The boards arrived after a couple of weeks, upon which time I quickly assembled the first Orion and gave it a spin on the test bench (Photo 4 illustrates one of the first Orion boards):

- PLL max output:
  - 500MHz: +15 dBm
  - 1152 MHz: +15 dBm
  - 3000 MHz: +15 dBm
  - 4400 MHz: +16 dBm
- PN (Fc+1KHz)
  - 500 Mhz: -104 dBc/Hz
  - 1152 Mhz: -91 dBc/Hz
  - 3000 MHz: -82 dBc/Hz
  - 4400 MHz: -87 dBc/Hz

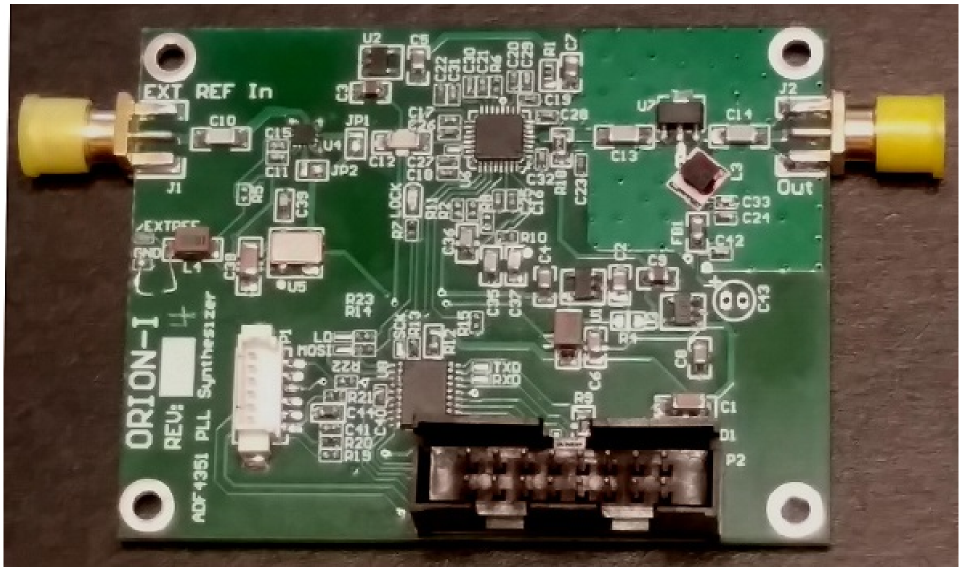


Photo 4. One of the first Orion boards

A number of these were built, and many were given to other interested parties. Before long, the synthesizer pantry was nigh bare, and thoughts returned to making more PCBs. By this time, several possible improvements had presented themselves, but having insufficient impetus to make more boards, these were jotted down for reference, but nothing was done to pursue the changes.

We approached the local microwave group and pitched a proposal to execute a group buy of PCBs and components that members could pre-purchase as a kit. After a favorable initial response, I set out to re-design the Orion to incorporate the changes that were desired. Most were tweaks that didn't modify the overall layout. Things like, increase component sizes to 0805 or larger, add a 5V regulator to allow operation from 12Vdc, etc…

Photo 5. Revision C Orion board

The board size grew somewhat, and I explored the option of having the boards assembled (at least partially). This added some cost, but greatly reduced the sweat equity required of the kit builder. Basically, the kit builder would place the through-hole parts, SMA connectors, and bottom side SMD parts. The overall cost of assembly by an over-seas vendor was surprisingly affordable, and the group members approved the option unanimously. The result was the revision C Orion, shown in Photo 5. Revision B was an intermediate prototype commissioned by NO5K prior to the group buy – this revision proved to be very beneficial to the ultimate outcome of the revision C activity in that it revealed some issues with noise generated by the RS-232 transceiver IC.

A snap-off prototype area was also added to revision C. This allowed for some custom add-ons that might be useful to some. The snap-off feature meant that this prototype area could be removed if it wasn't needed. The performance of the revision C was generally better than that of revision A:

- PLL max output:
  - 500MHz: +14.7 dBm
  - 1152 MHz: +17.6 dBm
  - 3000 MHz: +17 dBm
  - 4400 MHz: +16 dBm
- PN (Fc+1KHz)
  - 500 Mhz: -108 dBc/Hz
  - 1152 Mhz: -101 dBc/Hz
  - 3000 MHz: -93 dBc/Hz
  - 4400 MHz: -72 dBc/Hz

"So, what might I possibly DO with one of these things???"

Before I had even broached the idea of designing a microwave synthesizer, I was reading a web-article by someone who had modified an HP sweep oscillator module to function as a tracking generator using a synthesizer that they had designed. They said something to the effect of, "I never needed a synthesizer until I designed one…now I use them all the time!" I have found nothing but truth in those words. So far, we have used the Orion for the following:

- A 902 MHz FM exciter for a NBFM transmitter for the IC-901 transceiver
- A sweep oscillator to sweep attenuators and filters using both the fundamental and 3rd harmonic of the Orion output
- A beacon exciter (special software is used to on-off key the beacon Morse code message) – ***Note: The beacon-enabled Orion would also make an compact, low-power fox transmitter!***
- An LO for a 1296 transverter
- With the addition of a tripler, an LO for a 10 GHz transverter

While the performance of the Orion is very good, there are some things that users have to keep in mind. Namely, the harmonic output of the ADF4351 is notoriously high. Any use of Orion in a communications application will generally require the addition of a low-pass filter on the output of the device. This can complicate wide-band applications where the frequency range approaches or exceeds an octave.

The choice of 5V regulator also leaves something to be desired. Several dB of PN improvement can be attained by using a low-noise LDO for the 5V regulator. Also, the thermal performance of the regulator limits it to low input voltages (8.5V, max) without the addition of a heat sink. Even with a heat sink, the maximum ambient temperature is limited. Any future re-spin will make adjustments for these limitations.

Orion is an excellent example of what one can accomplish when they don't consider the potential pitfalls of an endeavor at the outset. This is a difficult thing for an engineer to admit since we generally want to consider ALL of the pitfalls…up-front. Still, if I had worried over how I might possibly design a circuit that can operate at 4.4 GHz before actually trying my hand at it; I might never have given the wheel a spin.

Abbreviations

BCD	Binary-Coded Decimal
Cu	Copper
Fc	Center Frequency
FM	Frequency Modulation
GND	Ground
IC	Integrated Circuit
LDO	Low-Dropout
LO	Local Oscillator
NBFM	Narrow-Band Frequency Modulation
PCB	Printed Circuit Board
PLL	Phase-Locked Loop
PN	Phase Noise
REF	Reference
RF	Radio Frequency
S/A	Spectrum Analyzer
SMD	Surface Mount Device
SPI	Serial Peripheral Interface
ULN	Ultra-Low Noise