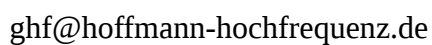


A Frequency Doubler and Distribution Amplifier for the Lucent KS-24361 GPS Disciplined Reference Generator



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Synopsis

Recently, a noteworthy number of new old stock Lucent KS-24361 frequency references have become available. These consist of a pair of similar boxes. Each box contains a MTI-260 crystal oven to implement redundancy, one of them has a GPS receiver to discipline both crystal oscillators.

The oscillators run on 5 MHz which is a sweet spot for crystals, the primary output is at 15 MHz which may fit into a Lucent telecom system but is of less interest to the general public. 10 MHz would be much more desirable, but there is only a test point output that seems quite noisy.

While the circuit of the KS24361 is unknown, some poking around shows that the output of the crystal oscillator itself is available on the unpopulated plug J8 on the mainboard. The level is abt. 1.75Vpp.

I used this signal, buffered it with slight gain in a LMH6702 stage and doubled it with a Push-pull doubler based on 2 JFETs BF862. The circuit is known as the NIST doubler, although I have seen similar circuits based on 12AX7. I preferred this circuit because it is inherently broadband and even can provide a small doubling gain. This is in contrast to the ring mixer approach that has 12 dB conversion loss and needs a phase shifter to produce a sine and cosine to multiply.

A phase shifter on the operation frequency is highly unwelcome when one wants maximum phase stability. It is bad enough that there is some filtering required to remove the input frequency and its unwanted harmonics. The low pass filter used has a corner frequency of around 20 MHz and features a broad notch at 25 MHz. This seems far enough from the 10 MHz output frequency that no large unwanted phase shifts are introduced at 10 MHz.

That leaves the unwanted frequencies of 5, 15 and 20 MHz. The drain impedance of the 2 BF862 is 200 Ohms or so, thus series resonances to GND can be used as a suppressor for each of these frequencies. It is possible to use either red Amidon T37 toroids or crystals. The first design iteration used molded 1812 chokes here, but their Q leaves to be desired. The resulting notches were more like craters and still were clearly visible on 10 MHz.

The Amidons are ok, but unavailable from the usual mass distributors. I finally used crystals; the required frequencies are easy to get everywhere but the quality varies considerably. We want a minimum series resistance here and the series resonance should be slightly below the 5 MHz multiple so we can pull the notch with a series capacitor only. (no tuning coil wanted)

Checking the crystals is easily done with a network analyzer between two 1:4 transformers. The crystals I used were cheap 30 cent devices from a local consumer electronics shop.

There is another 5 MHz trap after the LC low pass filter and before the distribution amplifiers since the subharmonic is the most annoying. I did not want to drive the impedance level too high since the backward isolation of the distribution amplifiers depends on a low source impedance, so I lost some attenuation.

The output stages use one LMH6702 current feedback amplifier each. They deliver 10 dBm with reasonable harmonic suppression. AD8009 should work just as well.

There can be upto 5 10 MHz outputs on the board. One of them can be sacrificed to get a buffered 1pps output. It consists of 2 SN74LVC1G04 inverters with a 50 Ohm source impedance. They can drive a 2.5V High-level to the end of a 50 Ohm terminated coax cable. That should be enough for 3.3V CMOS or 74HCT. If we want to push this, we can increase VCC for the driver to 6.0V. Abs. Max. rating is 6.5V. Rise/fall time is abt. 500 ps.

If you really want all 5 10 MHz outputs AND the 1pps you can take the buffered 1pps from P6 and place a bulkhead SMA somewhere else on the front plate.

The KS-24361 has a DC/DC converter that delivers +5V and + / - 15V. The +5V supply was assumed to be too noisy, so the Vcc/Vee supply was generated with LM317 / LM337 from the 15 Volt supplies. They run quite hot, so I used 2 strings of diodes / Zeners to dissipate most of the unneeded voltage off-board. In the long run, there should be a own DC/DC.

Circuits

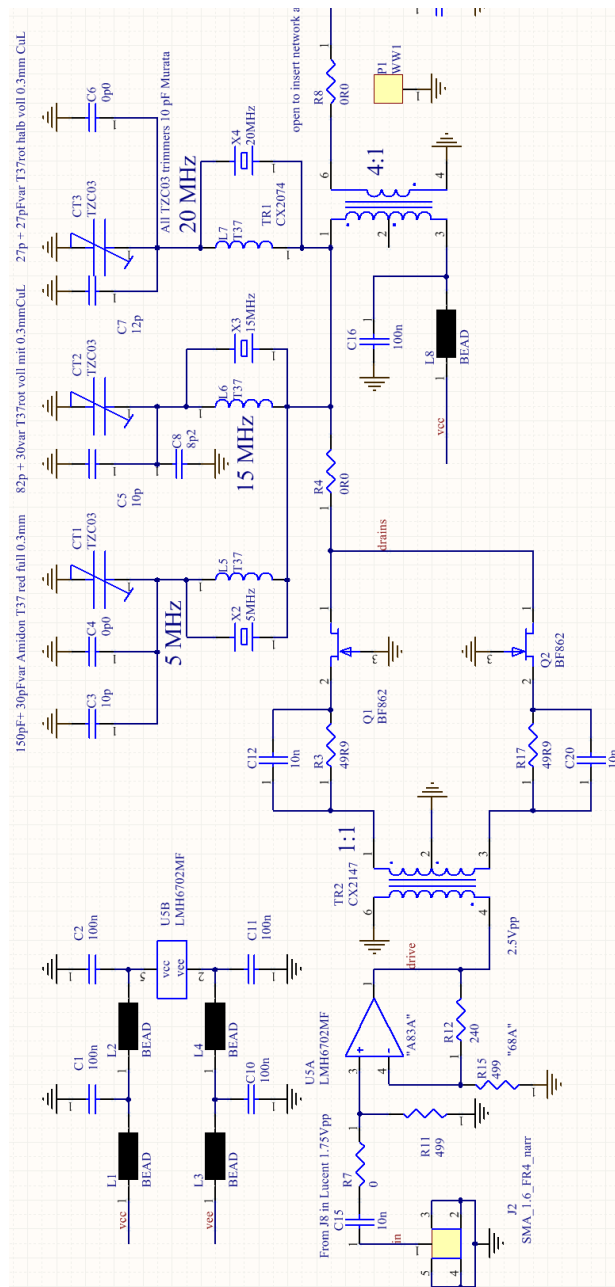


Abbildung 1: Input Buffer, Doubler And Notch Filter

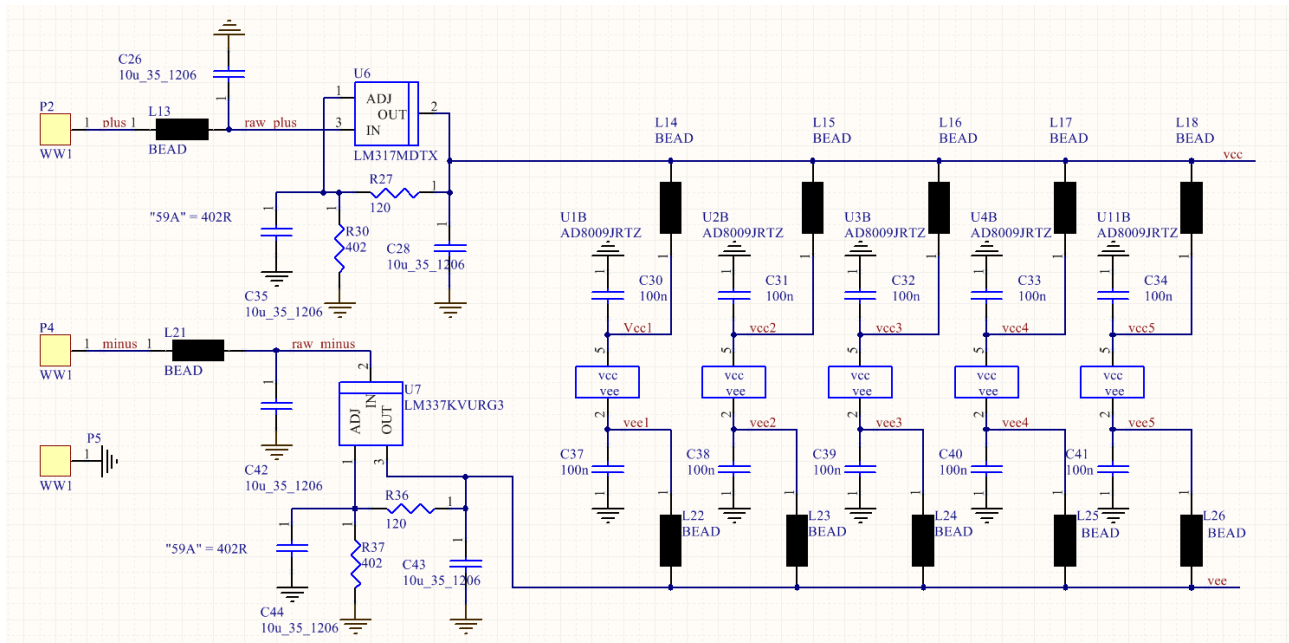


Abbildung 2: Power Supply

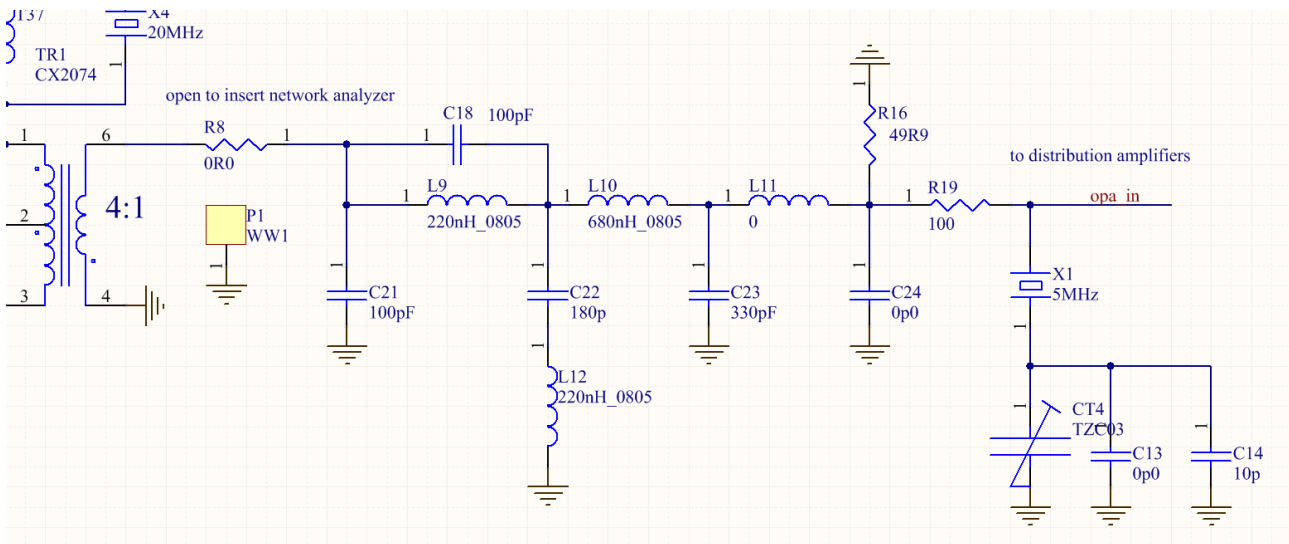


Abbildung 3: Lowpass Filter With 2nd 5 MHz Notch

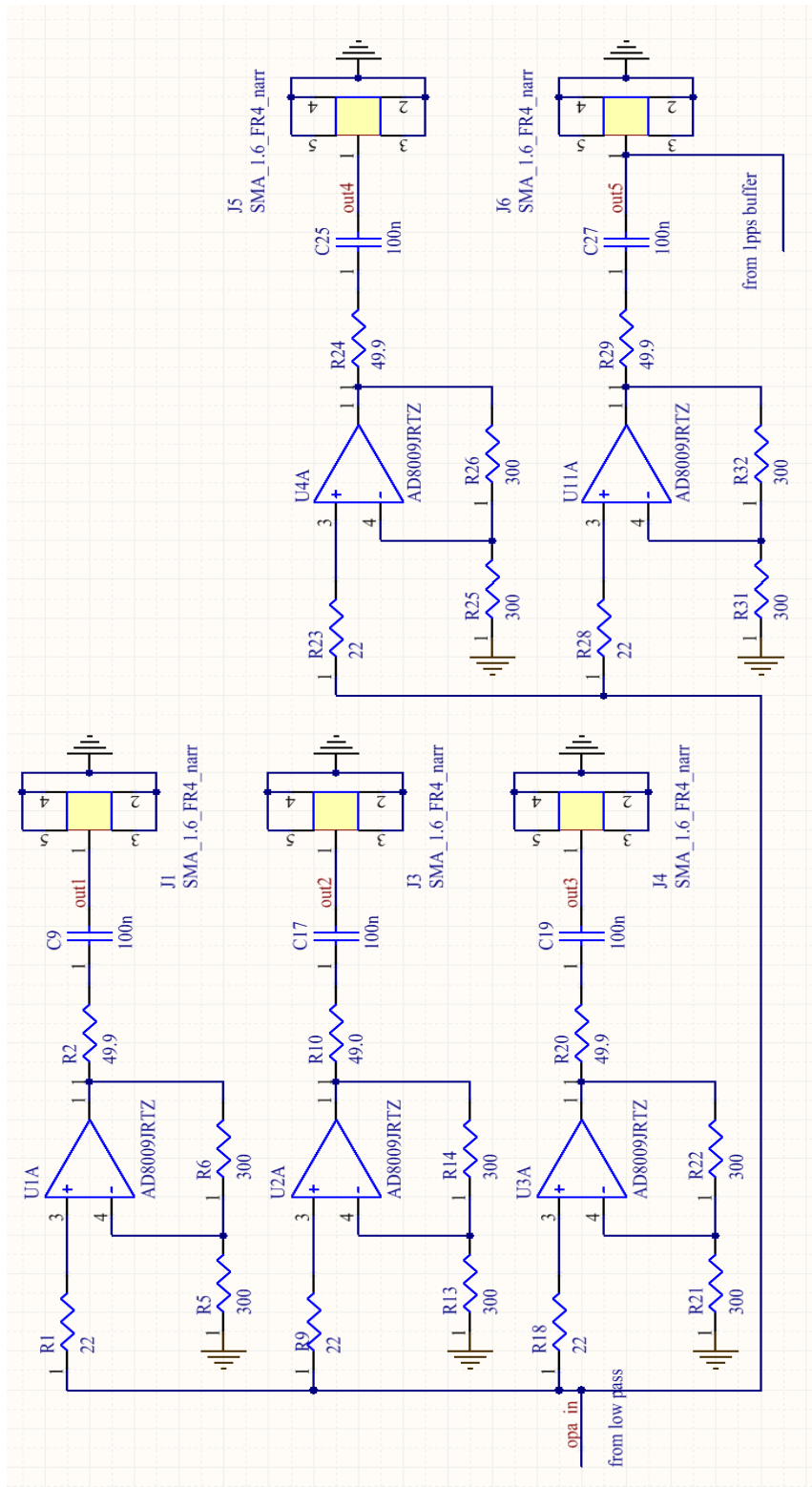


Abbildung 4: Distribution Amplifiers

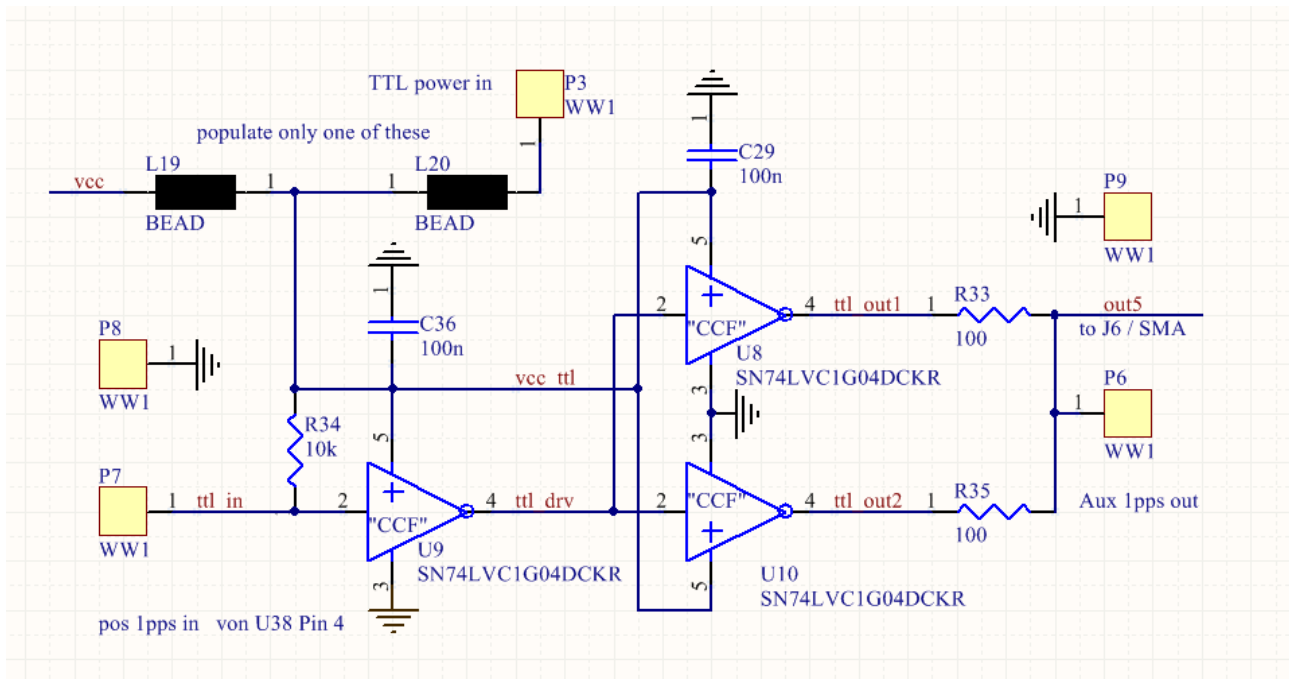


Abbildung 5: 1pps Buffer

Layout

The layout is 2 layers, the bottom side is only ground. The board is home-etched because the entire development took place during the Christmas season 2014.

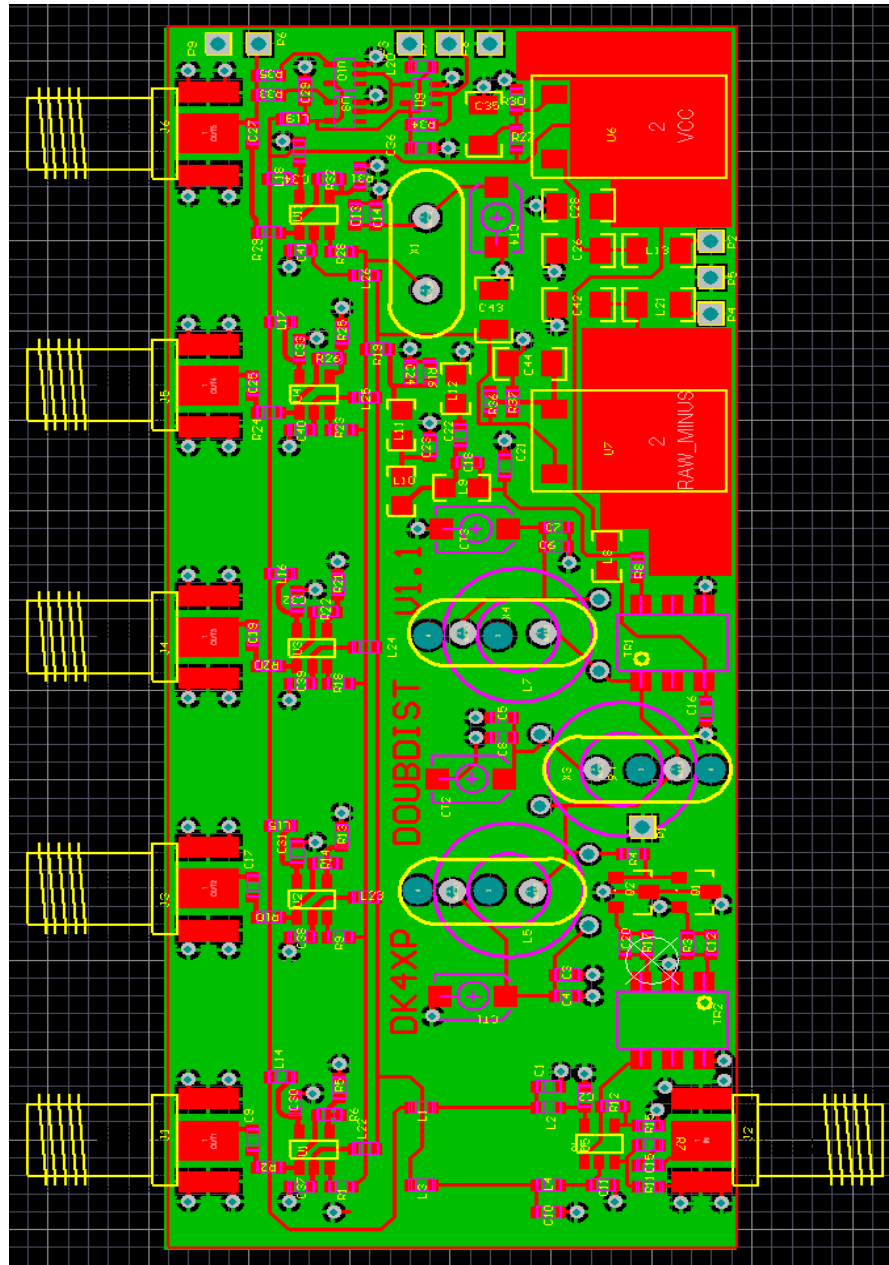


Abbildung 6: Layout

Properties of the 10 MHz Outputs

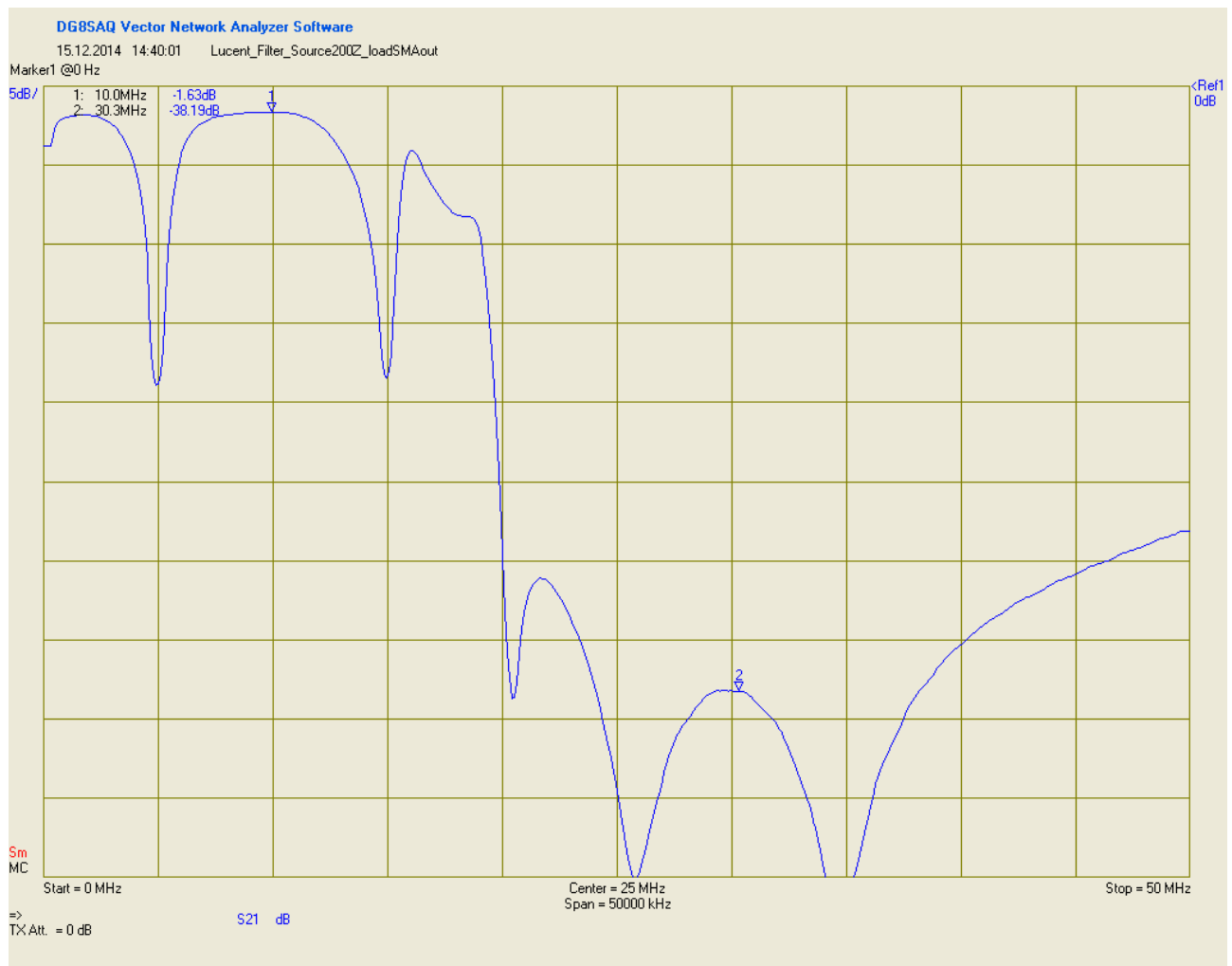


Abbildung 7: Harmonics filter, Version with Amidon toroids

The crystal notches would not be visible since they are too narrow.

Spectrum at the output of one of the 10 dBm 10 MHz outputs. Measured with Agilent 89441A. There is an external step attenuator to avoid overdriving the 89441A.

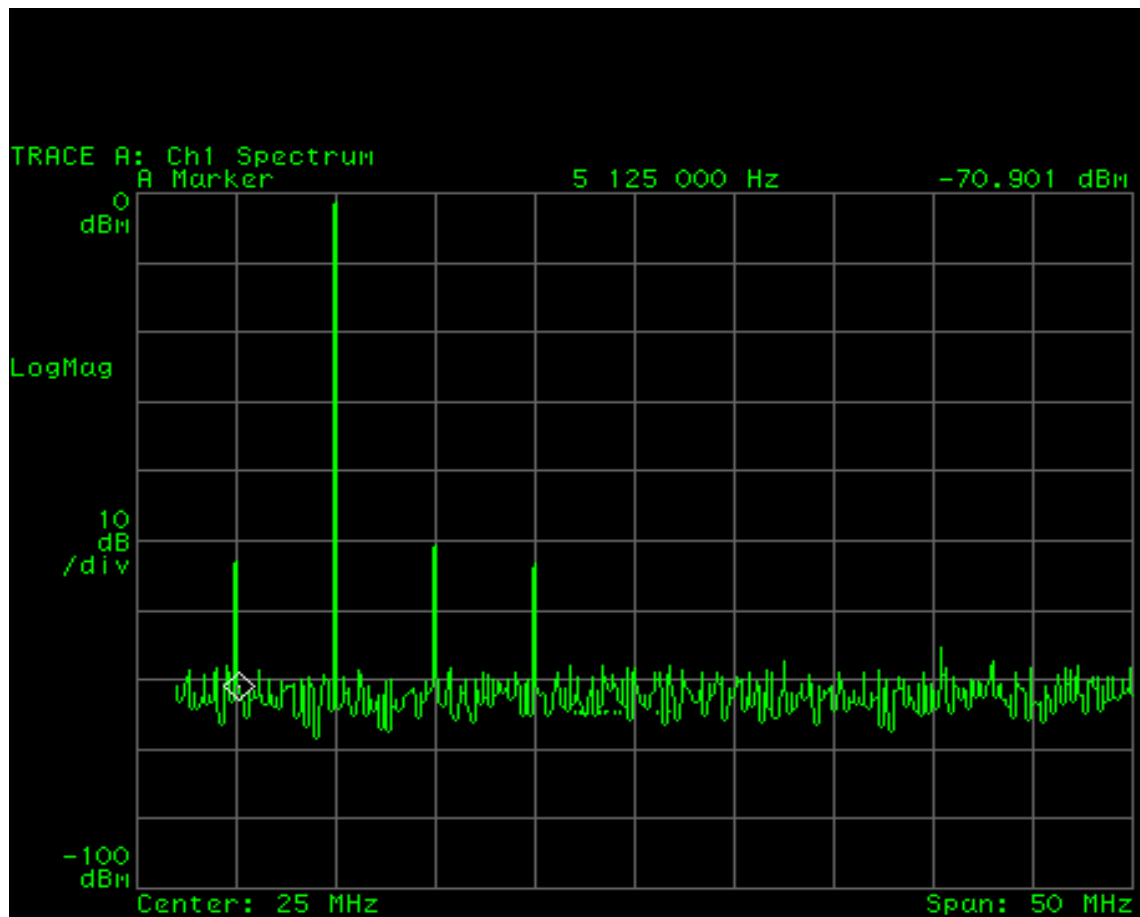


Abbildung 8: Wideband Spectrum Of 10 MHz Outputs

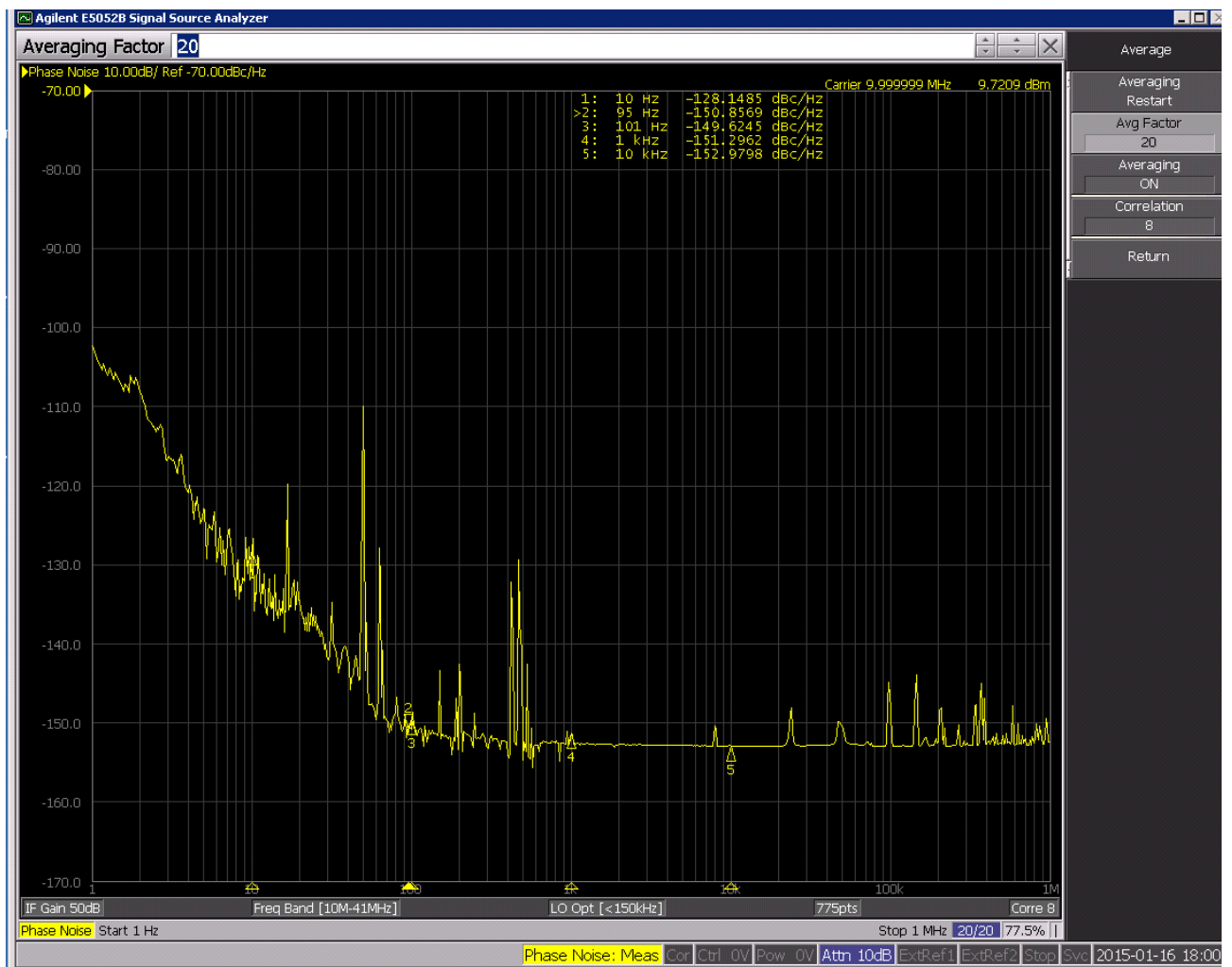


Abbildung 9: phase noise

The LMH6702 can reach at least -163 dBc far-off, here we have one in front of the doubler and that costs 6dB extra. I cannot easily measure the phase noise of the 5 MHz oscillator since the Agilent E5052B starts at 10 MHz; I'm not yet sure about the oscillators contribution. It could be that the crystal runs on really low RF power to help make it long-time stable. Also, the distribution stages could be run with somewhat less gain. Maybe the drain transformer of the doubler FETs should be changed back to 9:1, using the secondary winding in auto-transformer style. That would increase the doubler gain and would deepen the notches of the 5/15/20 MHz traps.

Properties of the 1PPS Output

Risetime, falltime and pulsewidth were measured with an Agilent 54846B scope with input set to 50 Ohm.

Results:

riset ime:	500 ps
fall time:	330 ps
pulse width:	406 us
high/low:	2.5V / 0V into 50 Ohm
	5V / 0V into high impedance

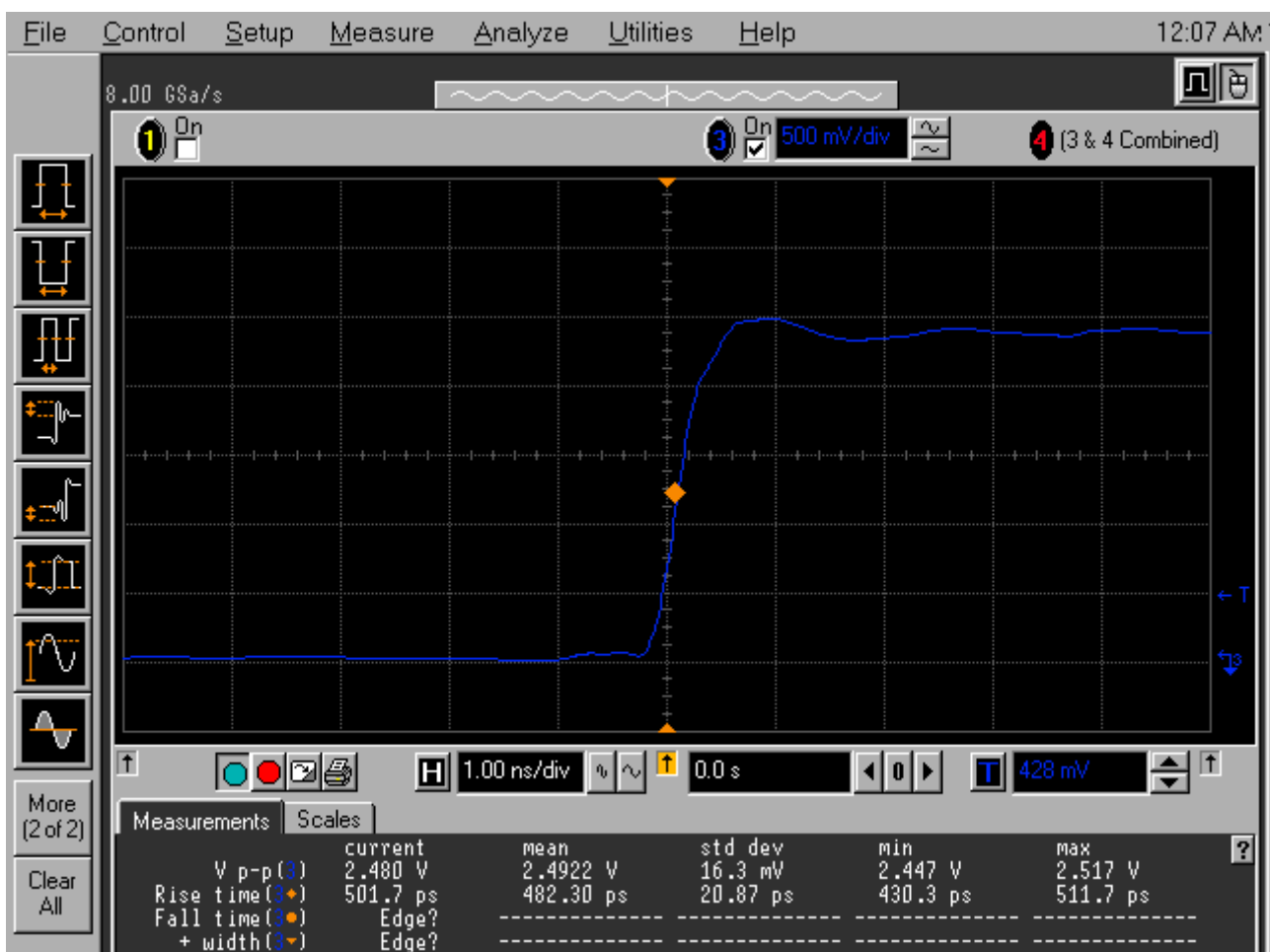


Abbildung 10: Rising edge of 1pps output



Abbildung 11: Falling edge of 1pps output

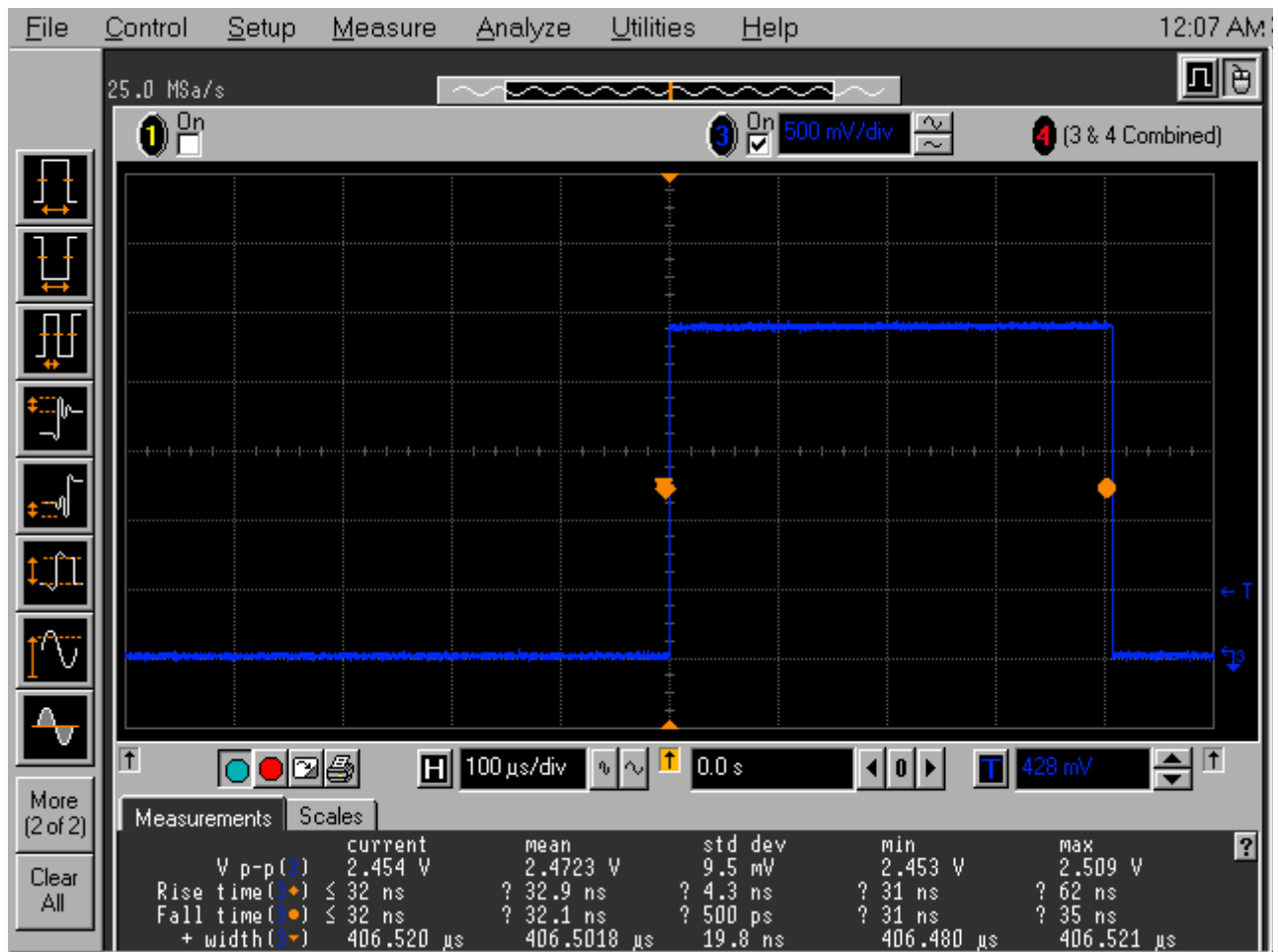


Abbildung 12: 1pps pulsewidth

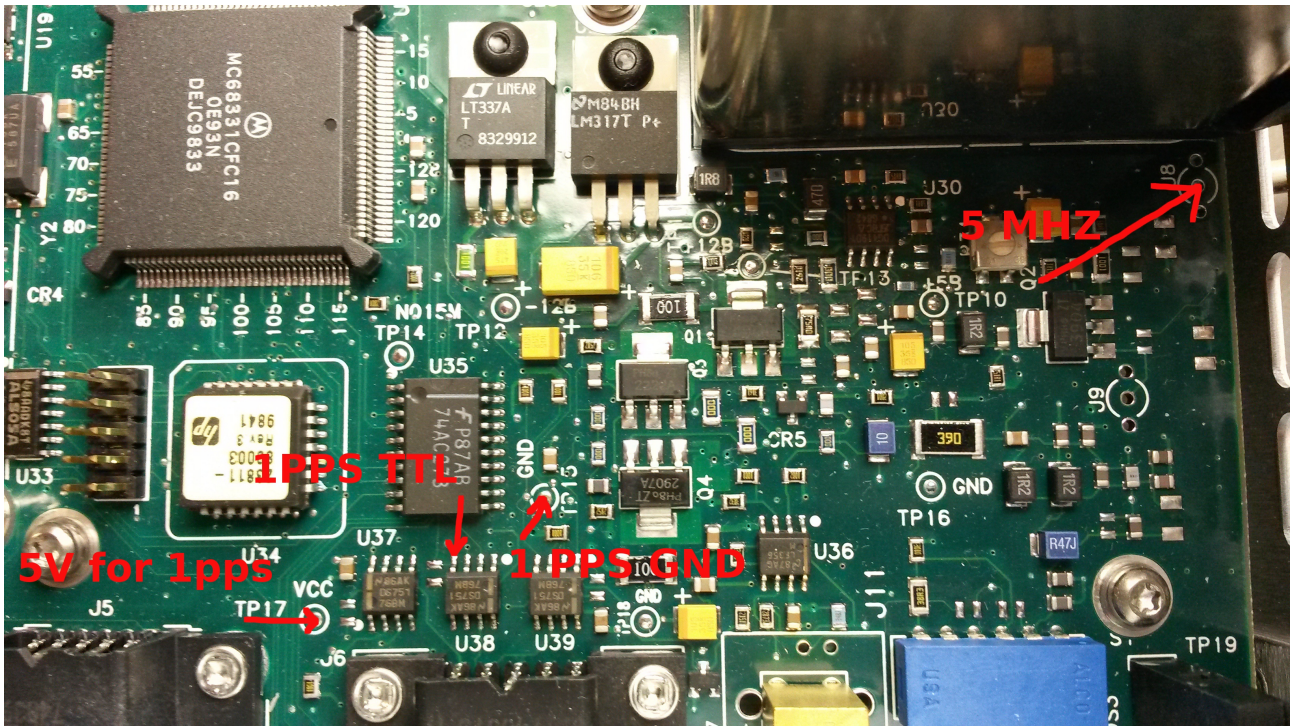


Abbildung 13: Where To Find The Required Signals

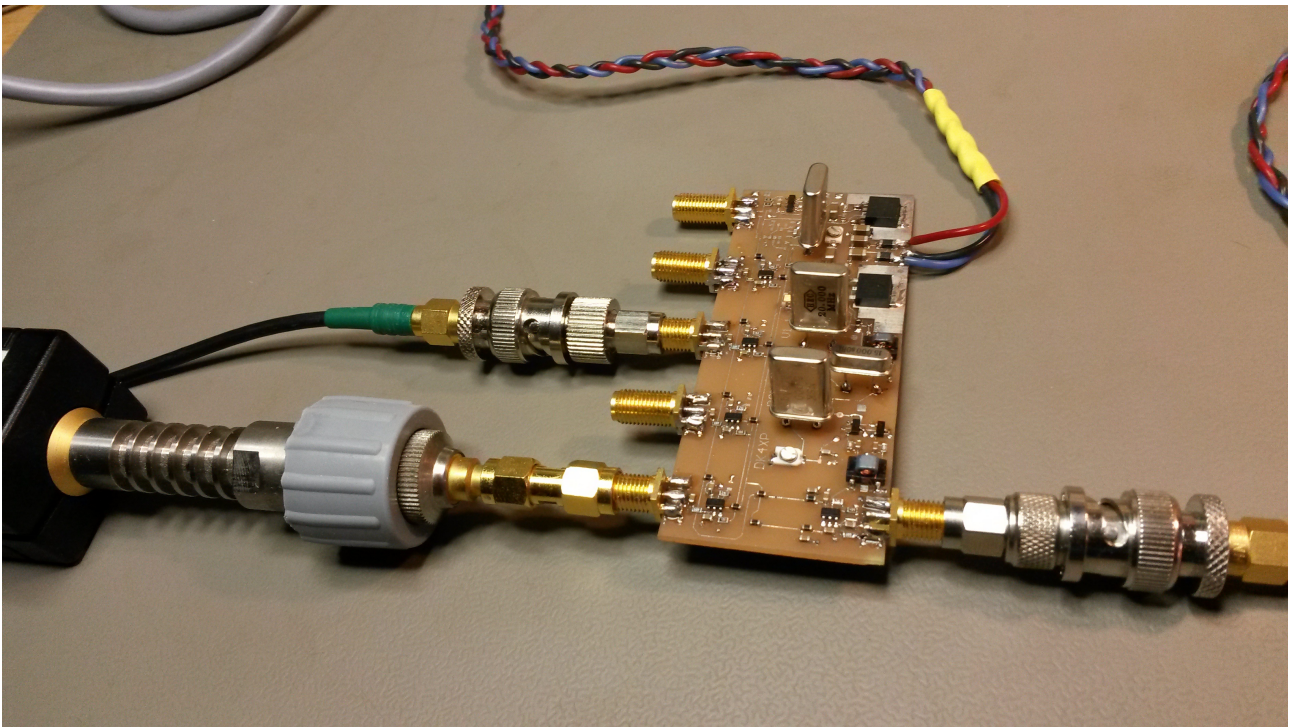


Abbildung 14: The Populated Board On The Test Table

The SMA in the background is the 1PPS output. Input from right, power meter and spectrum analyzer cable to the left.

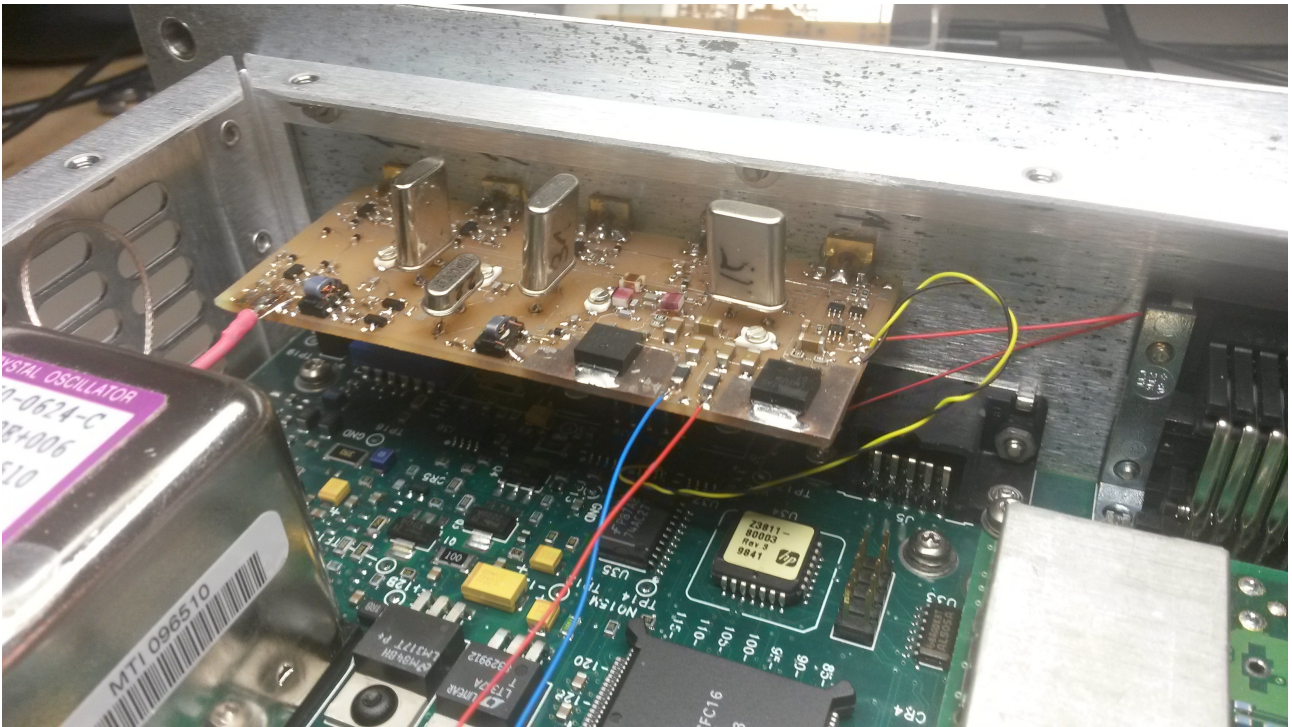


Abbildung 15: Doubler/Distributor Mounted Behind The Front Plate

The thin cable at the left wall is SM50 Coax, abt. 1 mm thick. It carries the 5 MHz. To the right is the 1PPS output. The black/yellow twisted pair is the TTL 1PPS from the main board. Red/blue is $\pm 8V$. The tinning of the front plate has suffered somewhat during storage but the electronics is OK.

Mysteries & ToDo

1. When the oven is cold, it delivers 3 dB more RF than when its warm. Even switching it off for 2 minutes to solder something increases the output by one or 2 dB. If you do not know that, it will drive you nuts when you want to adjust the gain for 10.00 dBm out. The higher level will also deteriorate the harmonic suppression, giving you your first disappointment of the day right early in the morning.

2. R5, 13, 21, 25, 31 should be 120R because of (1).

Also, all op amps are currently LMH6702 in sot-23-5 and the feedback resistors are 240 Ohms and not 300. The AD8009 is optimized for a 300 Ohm feedback resistor, one would have to scale the gain setting resistor accordingly. The exact value makes only the difference of 170 vs. 185 MHz bandwidth or so and some gain peaking. But do not double the feedback resistor if you want more gain. The gain is determined with the resistor from inverting input to GND. The feedback R should not change much with current feedback op amps.

All resistors are 0603 THIN film made by Susumu, available from Digi-key. Normal thick film should be avoided, they can be worse than carbon composition resistors.

The 10 MHz outputs got 2K resistors to GND as proposed by Bob Camp.

Selecting the BF862 so that they have at least nearly the same DC voltage drop over their source resistors helps a lot with 5 MHz suppression. When I was looking for BF862 with high I_{dss} for a low noise preamplifier they were ALL at 12.x mA in about 100 tested. Not so this time.

Document history

V1.0 2015-01-02	first published version
V1.1 2015-01-17	added phase noise plot and some clarifications.