Preamplifiers for Callisto Solar Radio Spectrometer

Whitham Reeve and Christian Monstein

1. Introduction

We investigated the performance of three amplifiers (figure 1) for Callisto applications by measuring their noise figure, gain, overload compression and S-parameters. Two amplifiers of special importance to us because of their low noise characteristics are the Mini-Circuits ZX60-33LN-S+ and an unbranded unit obtained from China through eBay from seller "kitmanlaw2008" (the unit is believed to be FM User or chzfmtransmitter.com model E201). We call the Chinese amplifier CxLNA. Both amplifiers are advertised as low noise amplifiers with approximately 1.0 dB noise figure and 20 dB gain.

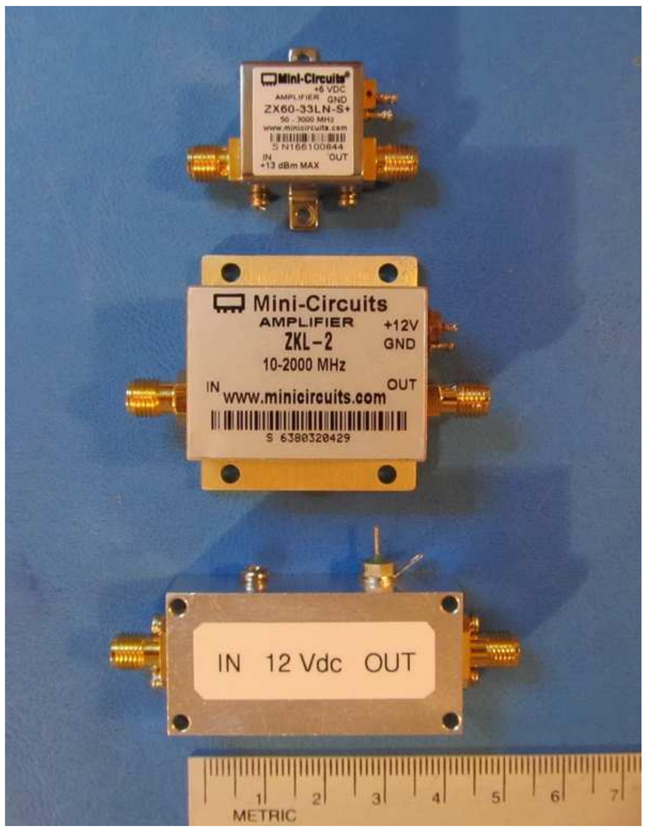


Figure 1 ~ Amplifiers, from top: ZX60-33LN-S+, ZKL-2, and CxLNA

Our measurements show very similar performance of these two amplifiers in our labs. The CxLNA has advantages of cost and an internal voltage regulator that allows it to be used with the same 12 Vdc power supply as the Callisto (the ZX60 has a maximum input voltage of 5.5 Vdc and requires a step-down power supply). Also, the CxLNA amplifier has slightly higher gain than the ZX60 at frequencies below 200 MHz.

We also performed comparative measurements on the Mini-Circuits ZKL-2. This amplifier has much higher gain of 31 dB but also a higher noise figure of 4 dB. This amplifier was evaluated for use as an intermediate amplifier where long coaxial cable runs are used between a remote low noise preamplifier, such as the ZX60 or CxLNA, and the Callisto. It also has applications as an intermediate frequency (IF) amplifier in up- and down-converters used with Callisto or other systems.

The basic data for the three amplifiers are summarized (table 1). Each set of measurements is described in separate sections below followed by a brief description of amplifier construction and measurement methods. All measurements involving a Callisto were made at Anchorage, Alaska using Callisto s/n NA008.

Table 1 ~ Amplifier basic specifications

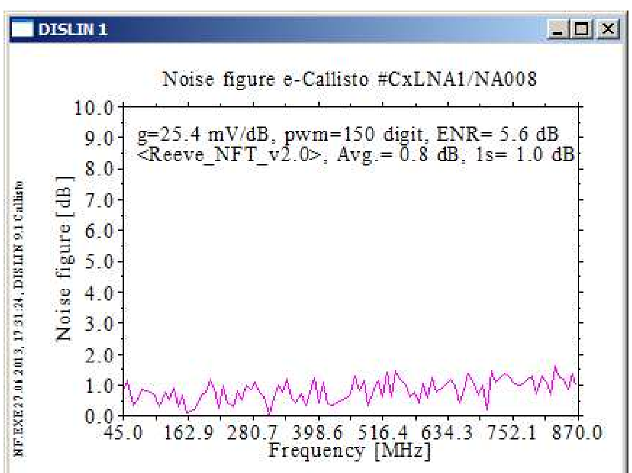
Model	Manufacturer	Frequency (MHz)	Gain (dB)	Noise figure (dB)	Voltage (V)	Current (mA)	Price (US$)	Notes
ZX60-33LN-S+	Mini-Circuits	50 to 3000	19	1.1	3.3 to 5.0	80	80	Note 1
CxLNA	Unknown	20 to 1000	20	0.6	8 to 14	40	61	Note 2
ZKL-2	Mini-Circuits	10 to 2000	33	4	9 to 12	120	150	Note 1

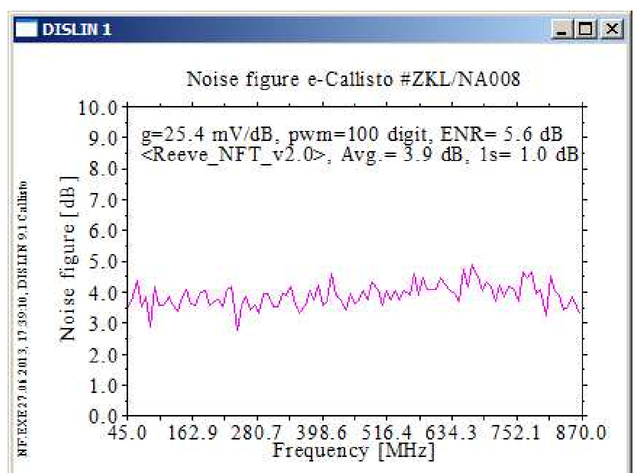
Table notes:

1. The specifications shown are from the manufacturer's datasheet. Prices do not include shipping.
2. The manufacturer and model number of this amplifier are unknown, so it was given the designation CxLNA; CxLNA1 in the test results indicates one of several amplifiers. The input current for the CxLNA was measured at 12.0 Vdc input. The price includes free shipping to US destinations.

2. Noise Figure

The noise figures were measured at 200 individual frequencies spaced evenly in the Callisto frequency band (figure 2). These measurements agreed quite well with the datasheet values.





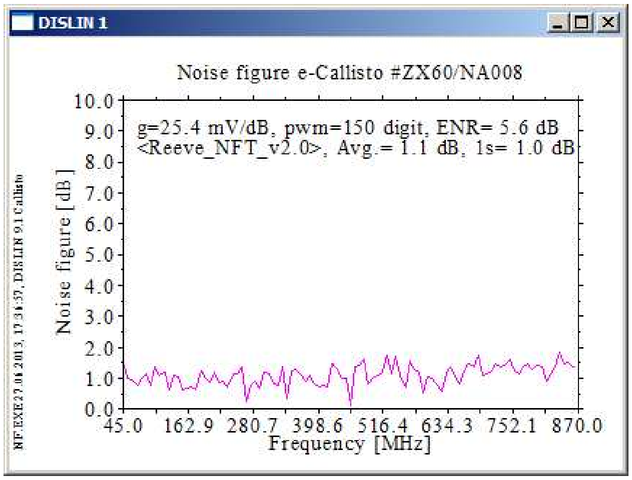
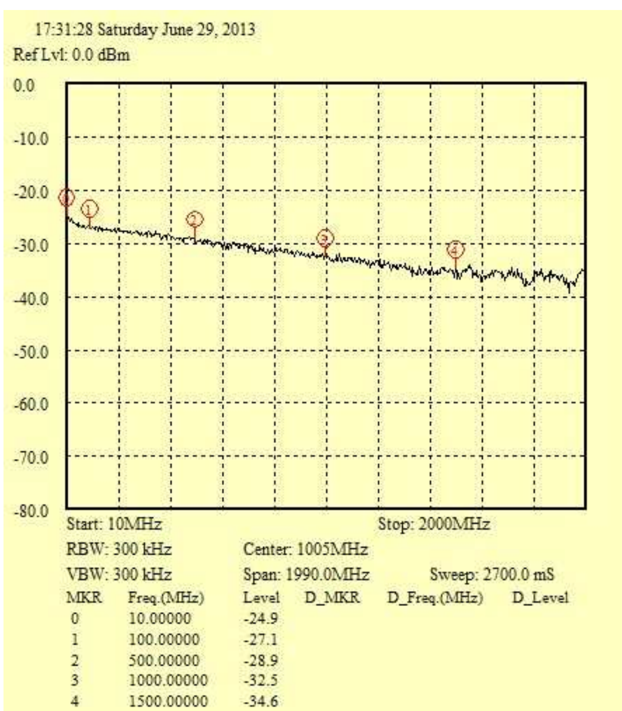
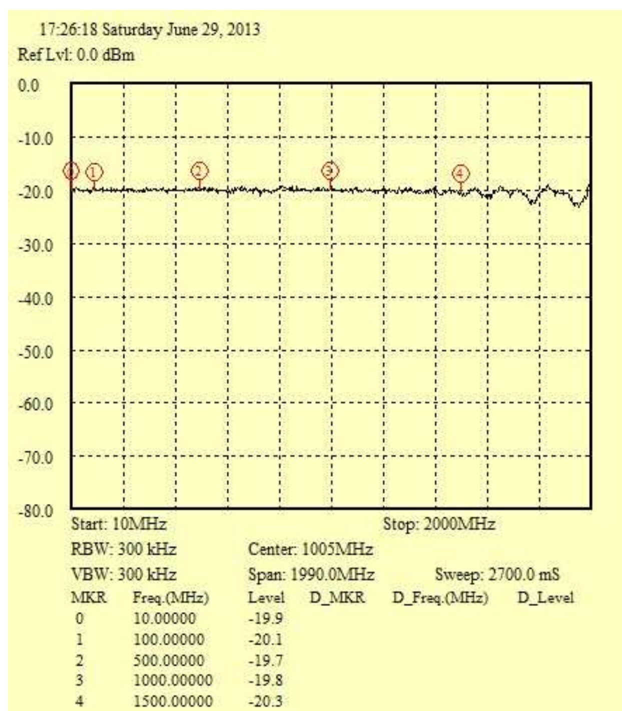


Figure 2 ~ Amplifier noise figure measurements. The amplifier type is indicated on the top text line of the noise figure plots (CxLNA1 is the Chinese amplifier, ZKL is a Mini-Circuits ZKL-2+ and ZX60 is a Mini-Circuits ZX60-33LN-S+). The text data at the top of the plots indicates details of the measurement and the average (Avg.) and standard deviation (1s) of the noise figure. All measurements were made in conjunction with Callisto s/n NA008 using the NF software tool v2.0. Note that the Callisto gain was reduced for measurement of the higher gain ZKL amplifier.

3. Gain

The power gain of the three amplifiers varies a little with frequency; for the ZX60 and CxLNA, gain decreases with increasing frequency (figure 3).





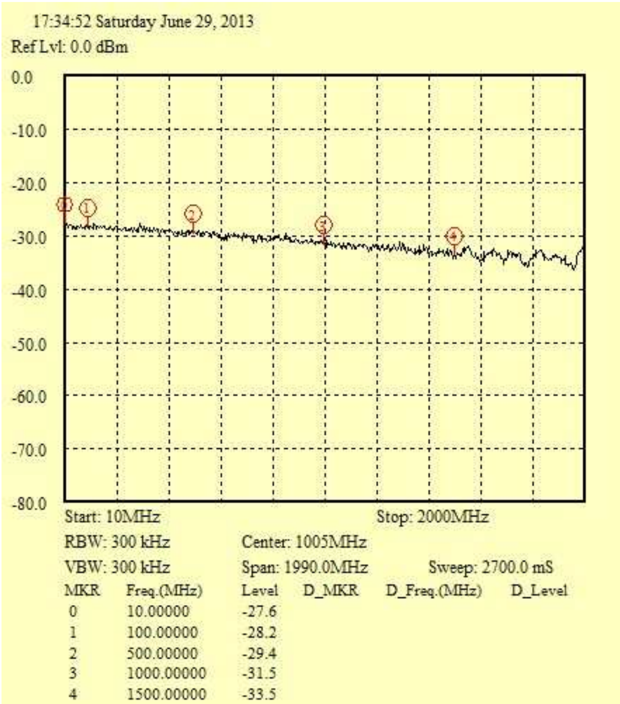


Figure 3 ~ Amplifier gain over the frequency range 10 to 2000 MHz. CxLNA1: Upper-left; ZKL: Upper-right; ZX60: Lower-left.

The tracking generator output level for all measurements was -30 dBm, and 10 dB attenuators were placed on the amplifier input and output for isolation. Therefore, gain = Indicated level + 50 dB. Some of the loss indicated on the plots for higher frequencies is due to the connecting cables and connectors. Connecting cables were 50 cm long RG-142 coaxial cables and SMA-M/N-F adapters were required to adapt the cables to the amplifier connectors.

4. Overload compression

The response of the amplifiers was measured at high input powers to determine the point at which the output becomes compressed 1 dB due to overload (figure 4). For the ZX60 and CxLNA, the 1 dB compression point is about –3 dBm and for the ZKL is about –12 dbm. Both values are much higher than the expected operating levels for the Callisto applications as a solar radio spectrometer except where the antenna is directly pointing toward a nearby transmitter.

5. General spectral performance

Several measurements were made to evaluate general performance with live signals received on a collapsible whip antenna. The main purpose of these tests was to find evidence of amplifier overload in a high RFI environment, but we found none.

The spectrum plots (figure 5) show relative power (Y) as a function of frequency (F). All spectrum plots were taken at Anchorage, Alaska. Very strong signals are apparent in the FM broadcast band (88 to 108 MHz), VHF air navigation and communications band (108 to 137 MHz), TV broadcast bands (54 to 88, 174 to 216 and 470 to 692 MHz) and mobile radio services above (864 MHz and above).

The live measurements with the whip antenna also were recorded to a flexible image transport system (FITS) file and then plotted. The FITS file contains one data element for each measurement of the received power (color, Y) as a function of frequency (F) and time (T) (figure 6). The power level measured at the output of the Callisto's internal logarithmic detector (AD8307) is encoded with 10-bit resolution but divided by 4 to reduce resolution to

8-bits for the FITS file. The application used to view the file (Java-based RAPP Viewer) allows the pixel associated with these three parameters to be read at the PC mouse position.

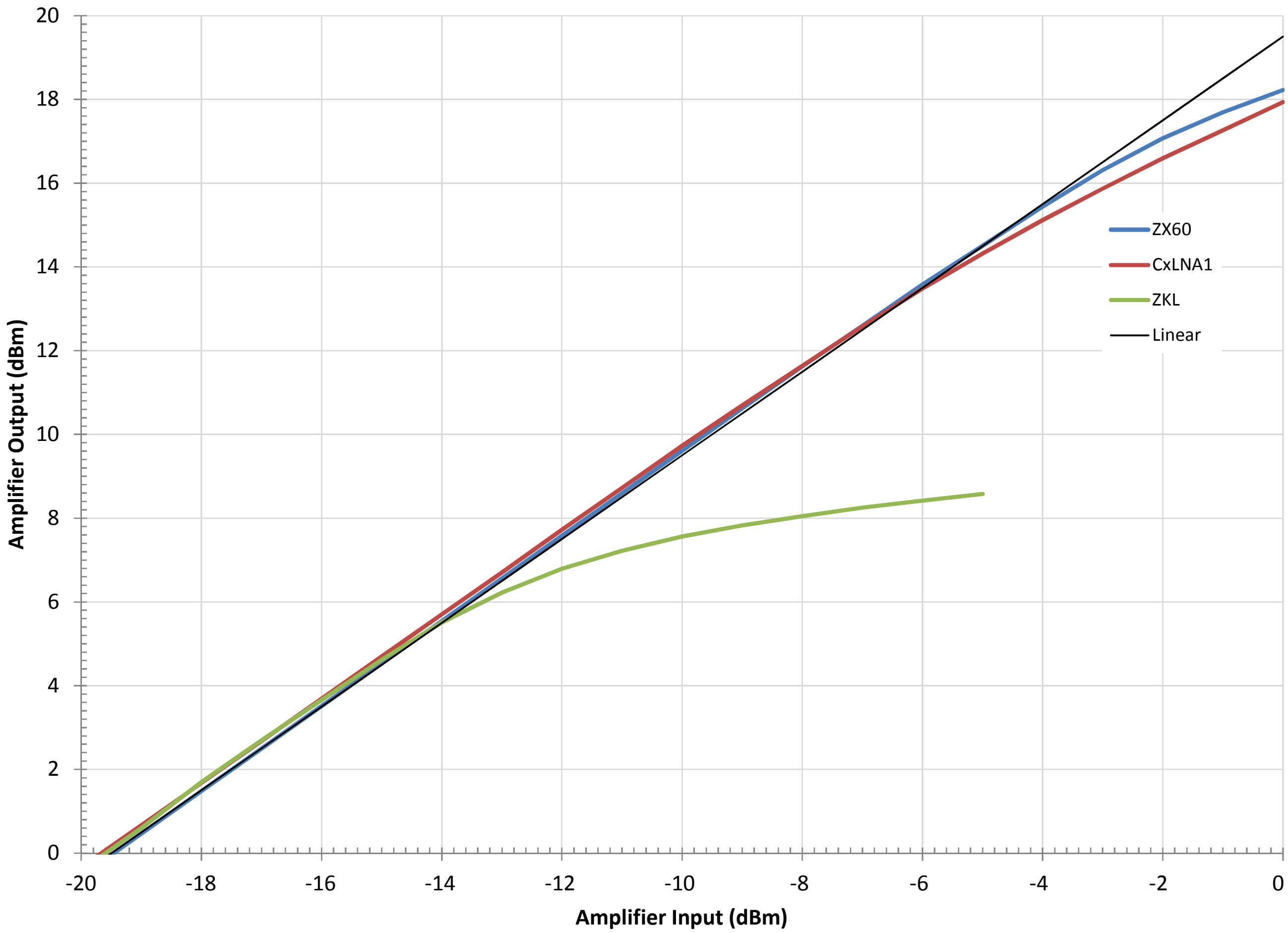
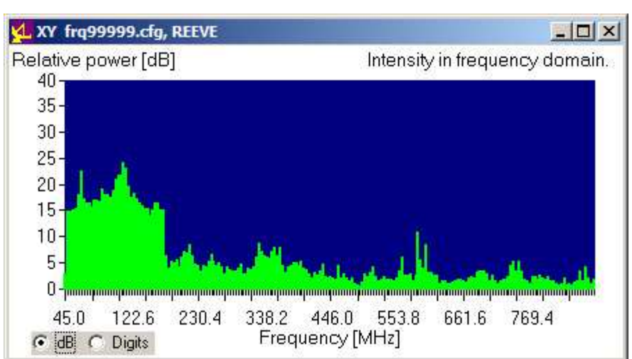
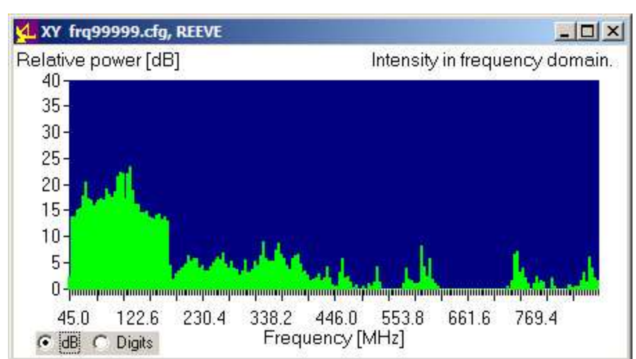


Figure 4 ~ Overload compression for the three amplifiers at 457.5 MHz. This was a 1 dB compression point measurement, where the linearity of the amplifier changes by 1 dB. The ZX60 and CxLNA have nearly identical performance at high input powers, with the compression point approximately –3 dBm. The higher gain ZKL amplifier has a much lower compression point at approximately –12 dBm. A linear trend line also is shown.





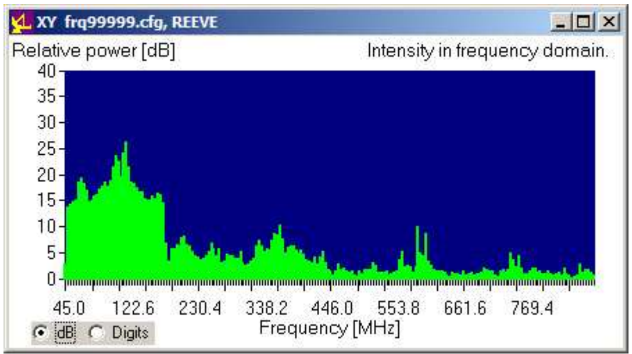


Figure 5 ~ Live spectrum y(f) plots produced by Callisto software with 200 channels distributed evenly throughout the Callisto frequency range. All measurements are with respect to the background noise (amplifier + Callisto). The amplifier outputs were connected directly to the Callisto RF Input port through a coaxial adapter. To obtain the relative measurements, the amplifier input was first connected directly to a 50 ohm termination resistor to obtain background noise level. No gain reduction was used with the ZKL amplifier. The plots were produced about 1 minute apart.

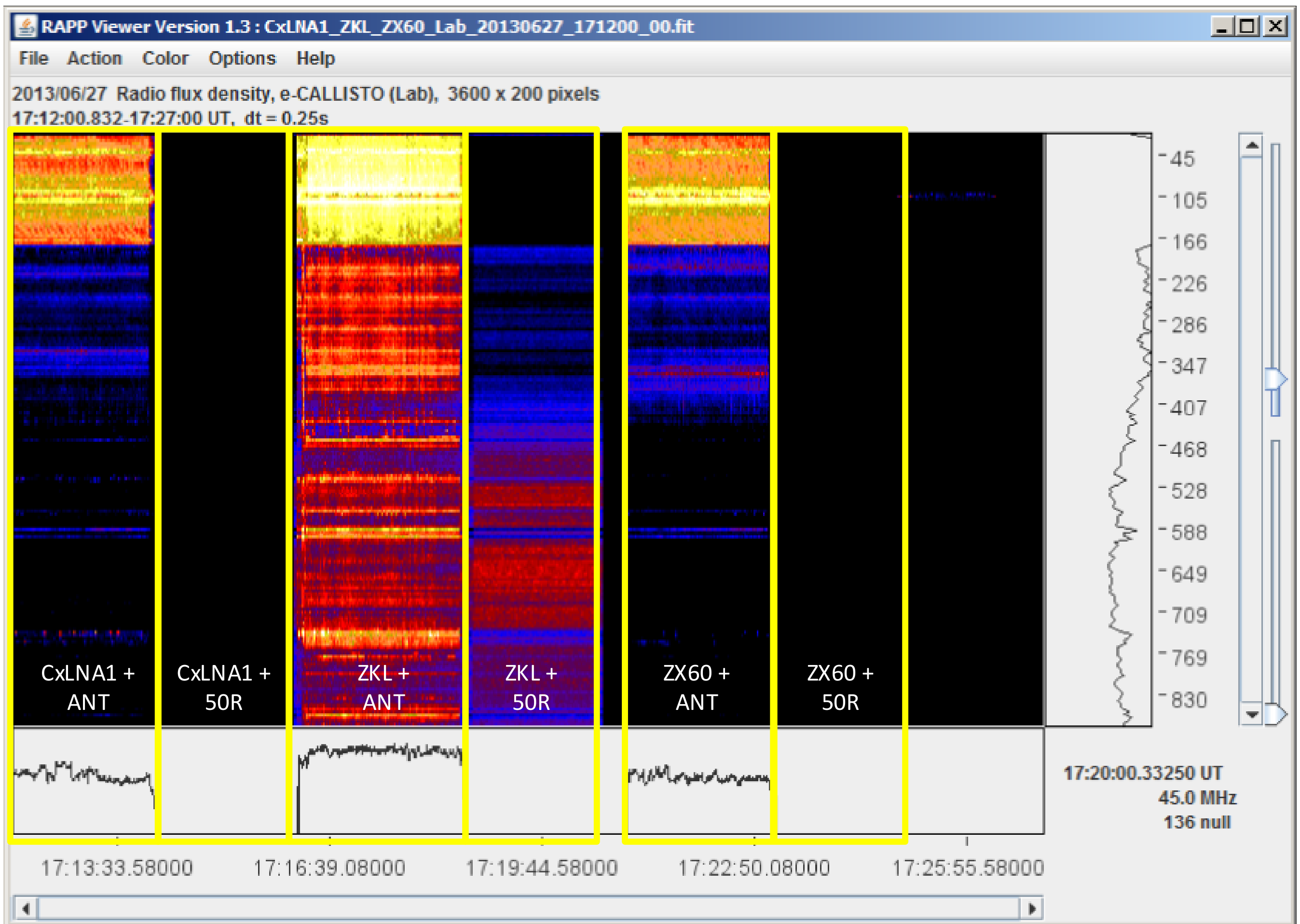


Figure 6 ~ Presentation of the FITS test file using the freely available Java-based RAPP Viewer application. The RFI received with the whip antenna in the various frequency bands previously mentioned is readily apparent. Of particular interest are the CxLNA1 at the beginning of the record and the ZX60 at the end. The ZKL is included in between for comparison. The Callisto gain was set to one value (PWM = 150) and not reduced for the ZKL amplifier. For these measurements each amplifier was first connected to the whip antenna for 2 minutes and then to a 50 ohm termination for 1.5 minutes, the latter to provide a comparatively quiet input. Pixel comparisons at several random points for the CxLNA1 and ZX60 revealed that for a given frequency, the received power level agreed within ±1 digit out of 256 (8 bits).

6. Additional detailed Spectrum Measurements

The 0.5 m whip antenna was again used to measure the power of 200 channels evenly distributed within the Callisto frequency range. The results are plotted for the CxLNA1 and ZX60 amplifiers (figure 7) and ZKL amplifier (figure 8). These plots also show the spectrum response of the Callisto (NA008) alone for comparison.

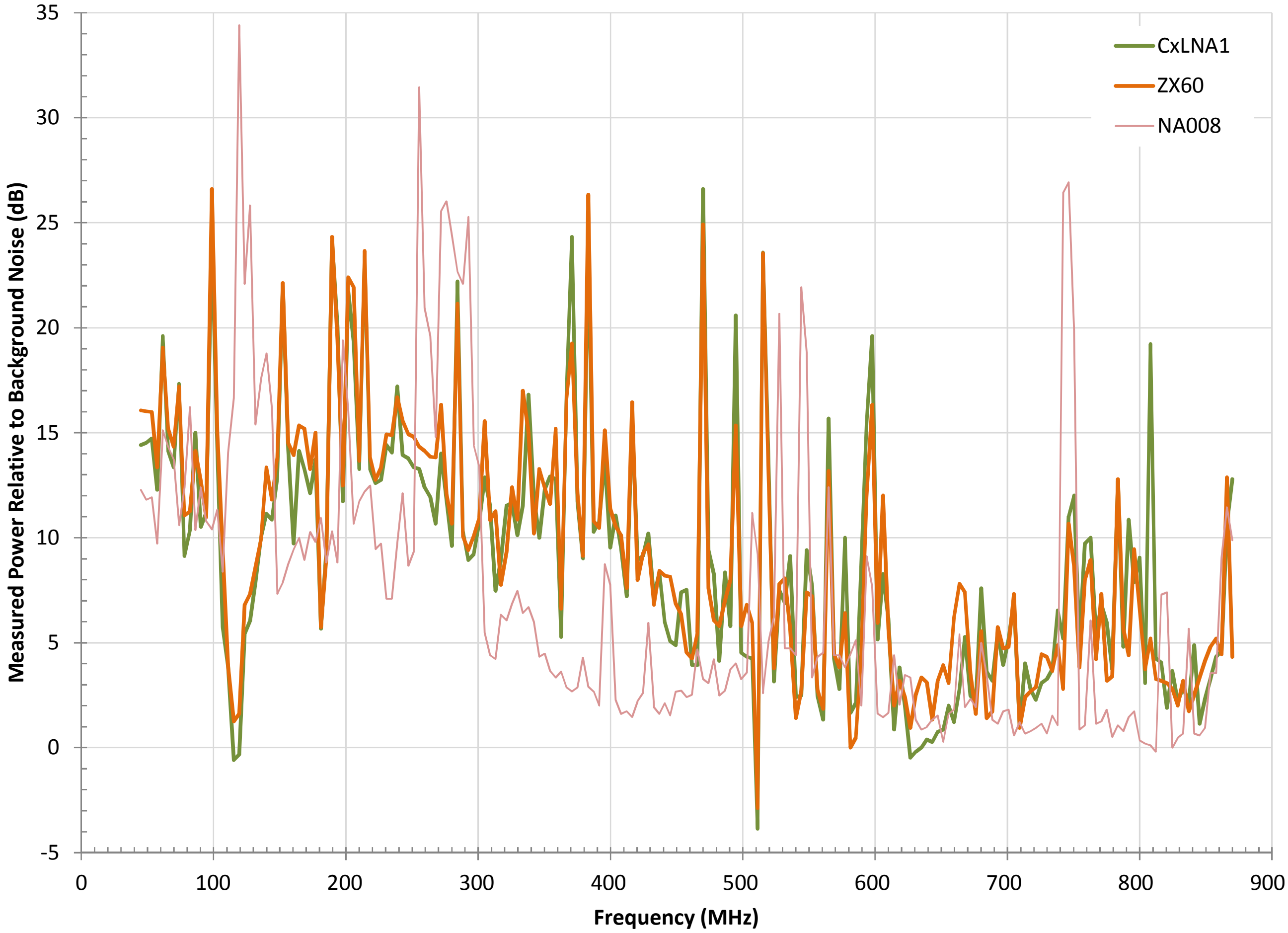


Figure 7 ~ Live spectrum for the CxLNA1 and ZX60 amplifiers and receiver compared to the receiver alone. The Callisto was setup to record the power for 200 channels evenly distributed in the 45 to 870 MHz frequency band. Callisto overload is indicated around 120 and 510 MHz where the relative response drops below 0 dB.

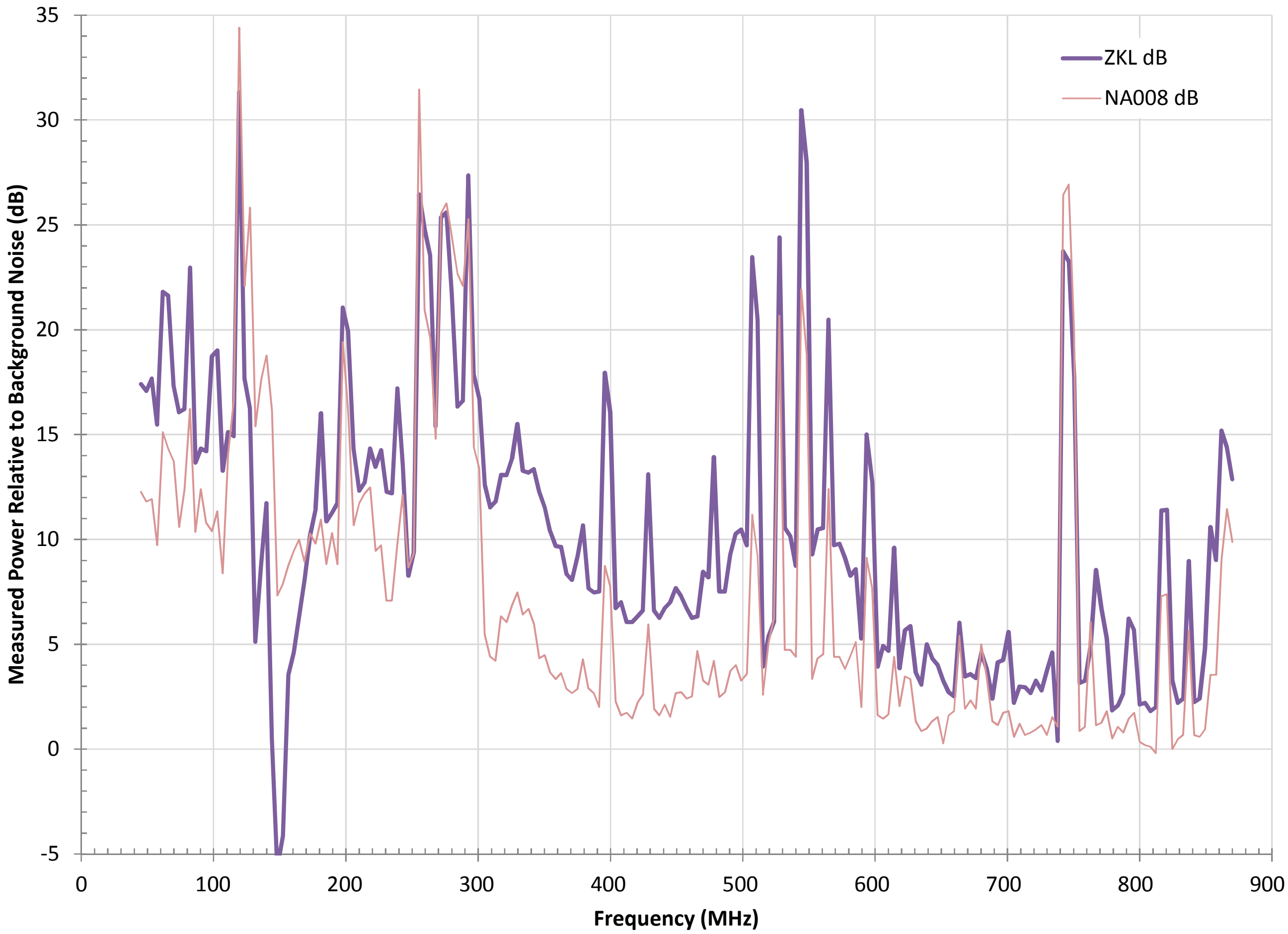


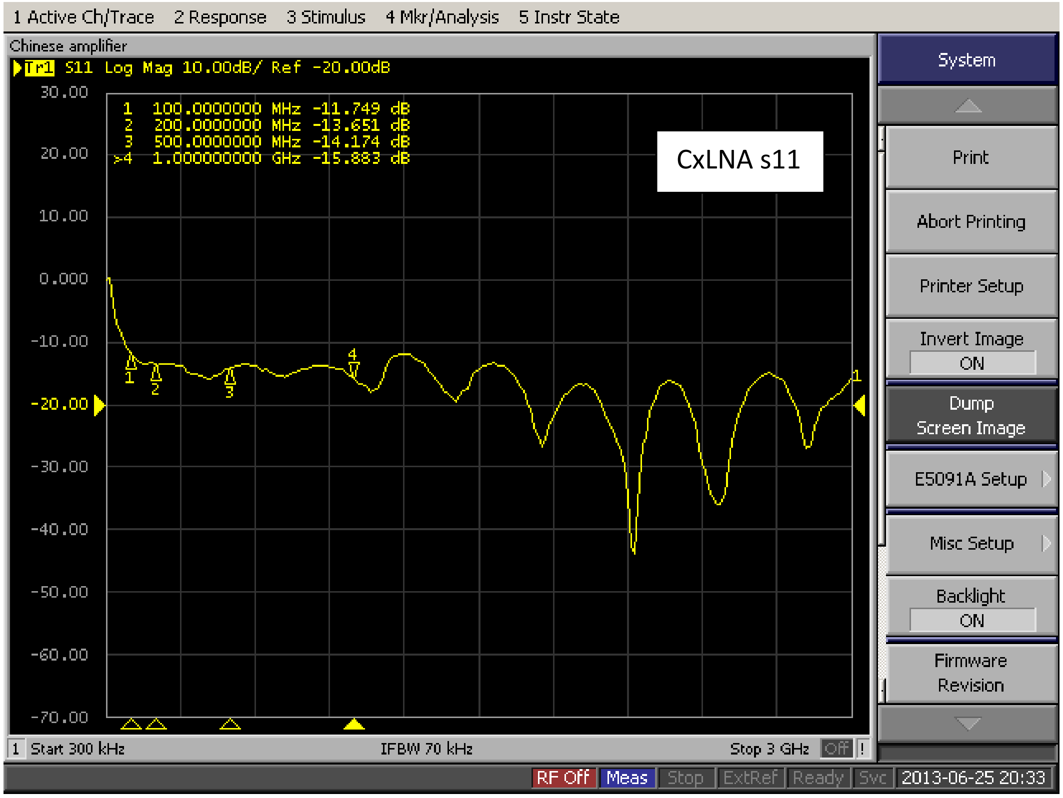
Figure 8 ~ Spectrum for the ZKL amplifier and receiver compared to the receiver alone. The Callisto was setup to record the power for 200 channels evenly distributed in the 45 to 870 MHz frequency band. Callisto overload is indicated around 150 MHz.

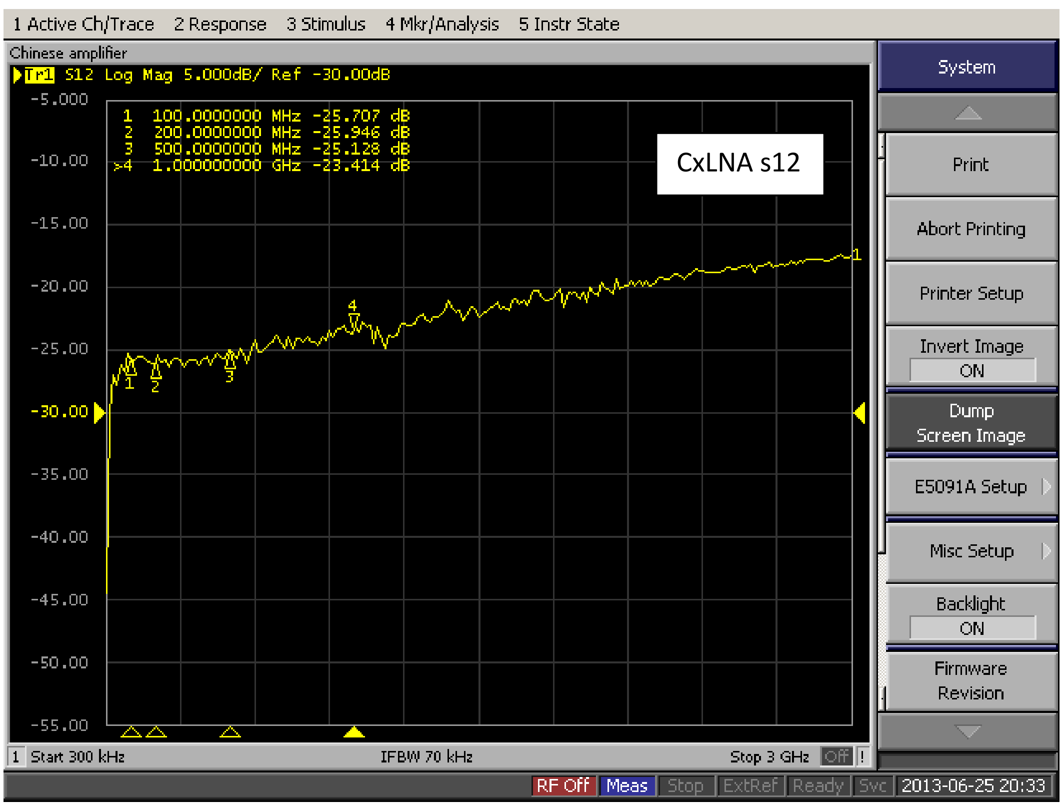
7. S-parameter measurements

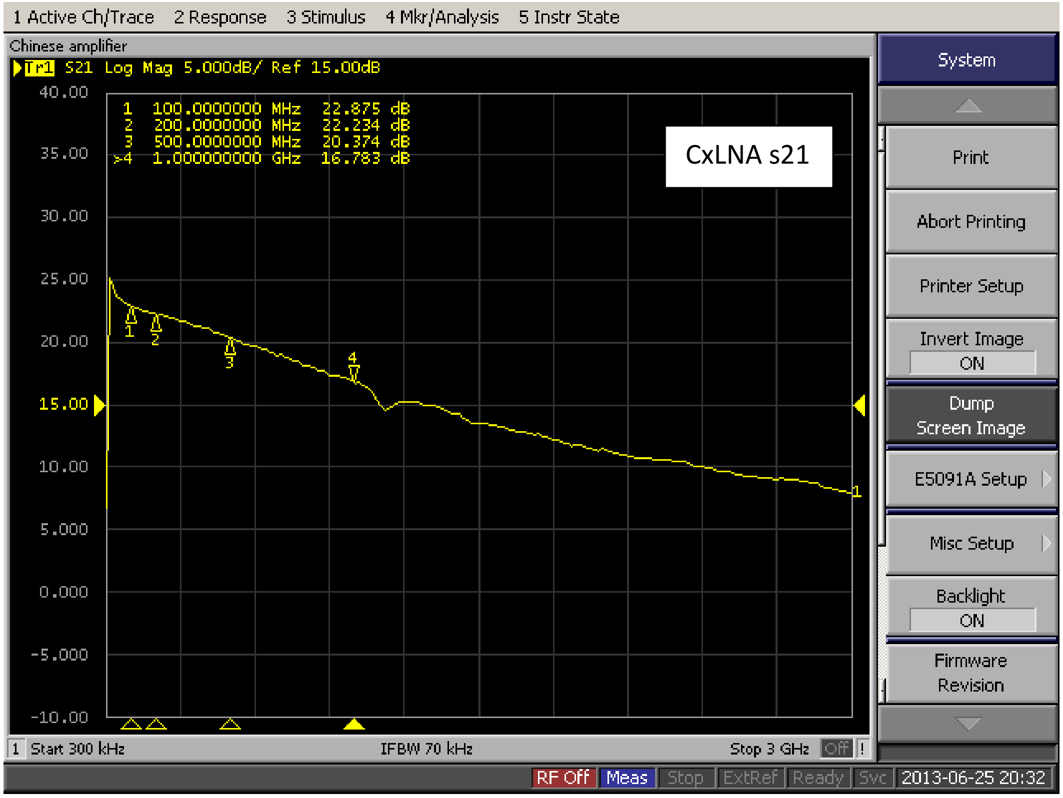
The scattering parameters (s-parameters) were measured at ETH Zurich, Switzerland over a frequency range of 300 kHz to 3 GHz on the CxLNA (figure 9), ZX60 (figure 10) and ZKL (figure 11). The s21 measurements are equivalent to the forward gain measurements previously discussed. The s11 and s22 measurements indicate how well the inputs and outputs are matched to 50 ohm impedance, and the s12 measurements indicate the backward gain, or the amount of signal applied to the amplifier output that is coupled back through to the input. In the case of reflections or spurious signals coupled into the amplifier from the output transmission line, a low s12 may be lead to self-excitation of the receiving system.

We were mainly concerned with the CxLNA and ZX60 amplifiers so we limit our comments on their comparative s-parameters to these:

s11: CxLNA has better input matching compared to 50 ohms above 200 MHz;
s12: ZX60 has slightly better backward gain (higher loss) above 500 MHz;
s21: CxLNA forward gain is slightly better below 200 MHz but slightly worse above 500 MHz;
s22: CxLNA has slightly better output matching compared to 50 ohms at most frequencies.


1 Active Ch/Trace 2 Response 3 Stimulus 4 Mkr/Analysis 5 Instr State
Chinese amplifier
Tr1 S11 Log Mag 10.00dB/ Ref -20.00dB
1 100.0000000 MHz -11.749 dB
2 200.0000000 MHz -13.651 dB
3 500.0000000 MHz -14.174 dB
>4 1.000000000 GHz -15.883 dB
CxLNA s11
30.00
20.00
10.00
0.000
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
1 Start 300 kHz
IFBW 70 kHz
Stop 3 GHz
System
Print
Abort Printing
Printer Setup
Invert Image ON
Dump Screen Image
E5091A Setup
Misc Setup
Backlight ON
Firmware Revision
RF Off Meas Stop ExtRef Ready Svc 2013-06-25 20:33


1 Active Ch/Trace 2 Response 3 Stimulus 4 Mkr/Analysis 5 Instr State
Chinese amplifier
Tr1 S12 Log Mag 5.000dB/ Ref -30.00dB
1 100.0000000 MHz -25.707 dB
2 200.0000000 MHz -25.946 dB
3 500.0000000 MHz -25.128 dB
>4 1.000000000 GHz -23.414 dB
CxLNA s12
-5.000
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
-50.00
-55.00
1 Start 300 kHz
IFBW 70 kHz
Stop 3 GHz
System
Print
Abort Printing
Printer Setup
Invert Image ON
Dump Screen Image
E5091A Setup
Misc Setup
Backlight ON
Firmware Revision
RF Off Meas Stop ExtRef Ready Svc 2013-06-25 20:33



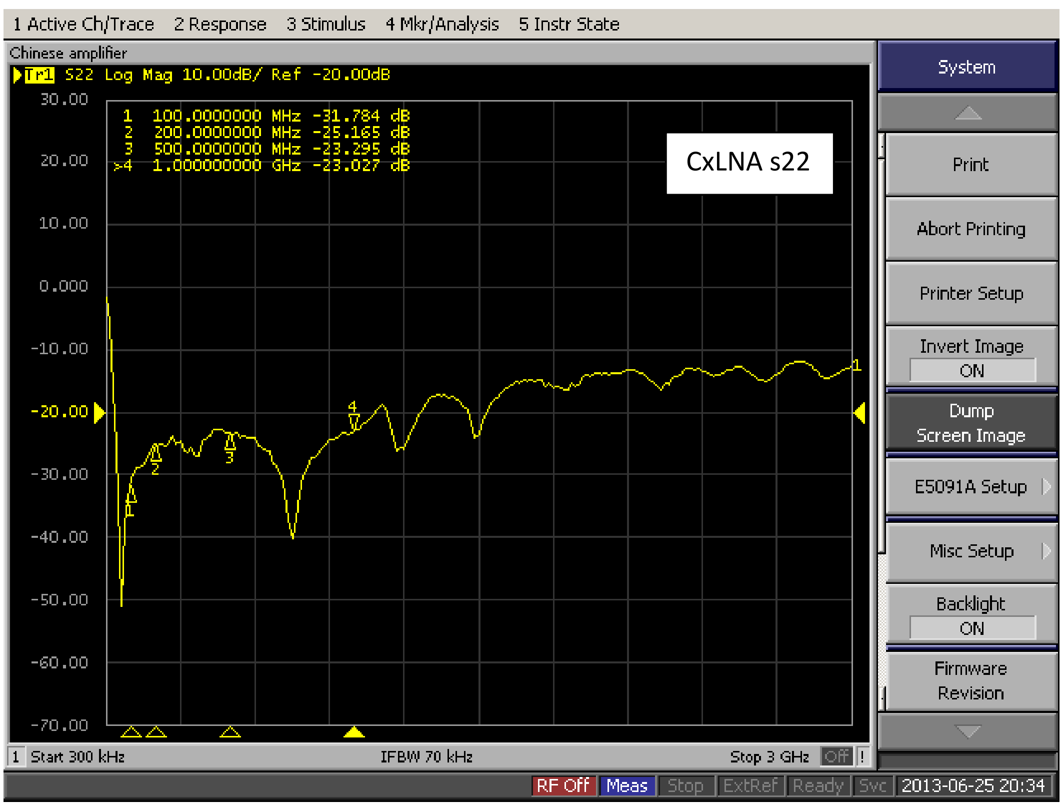
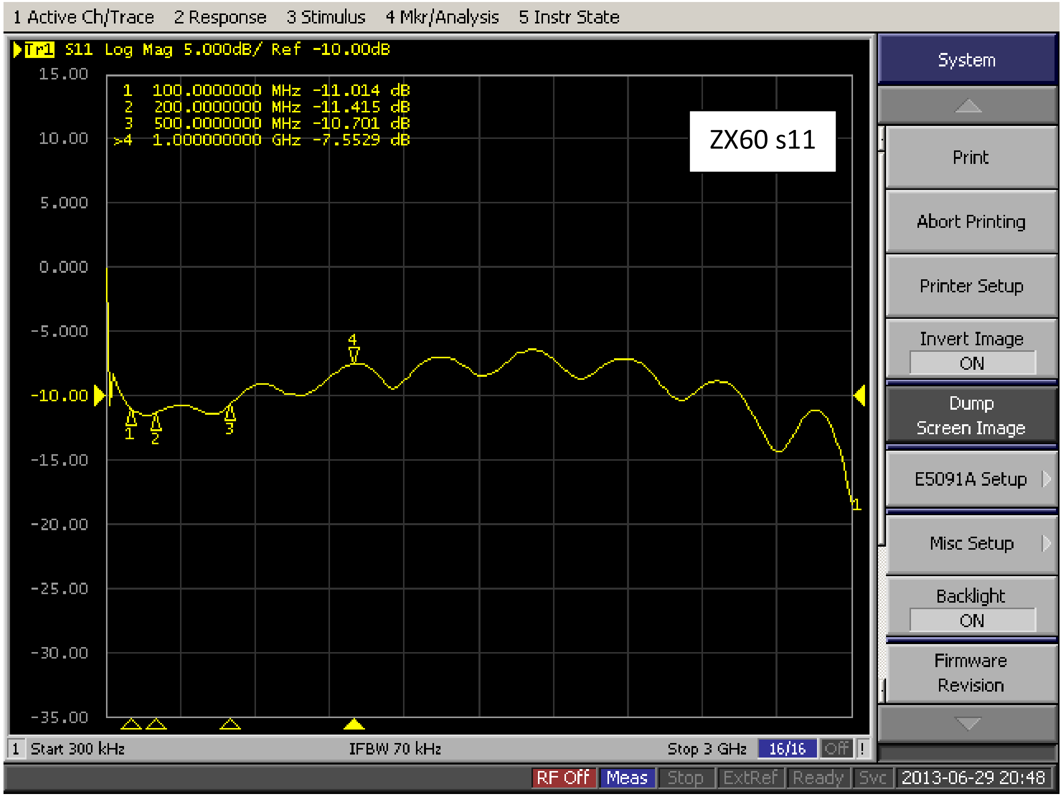
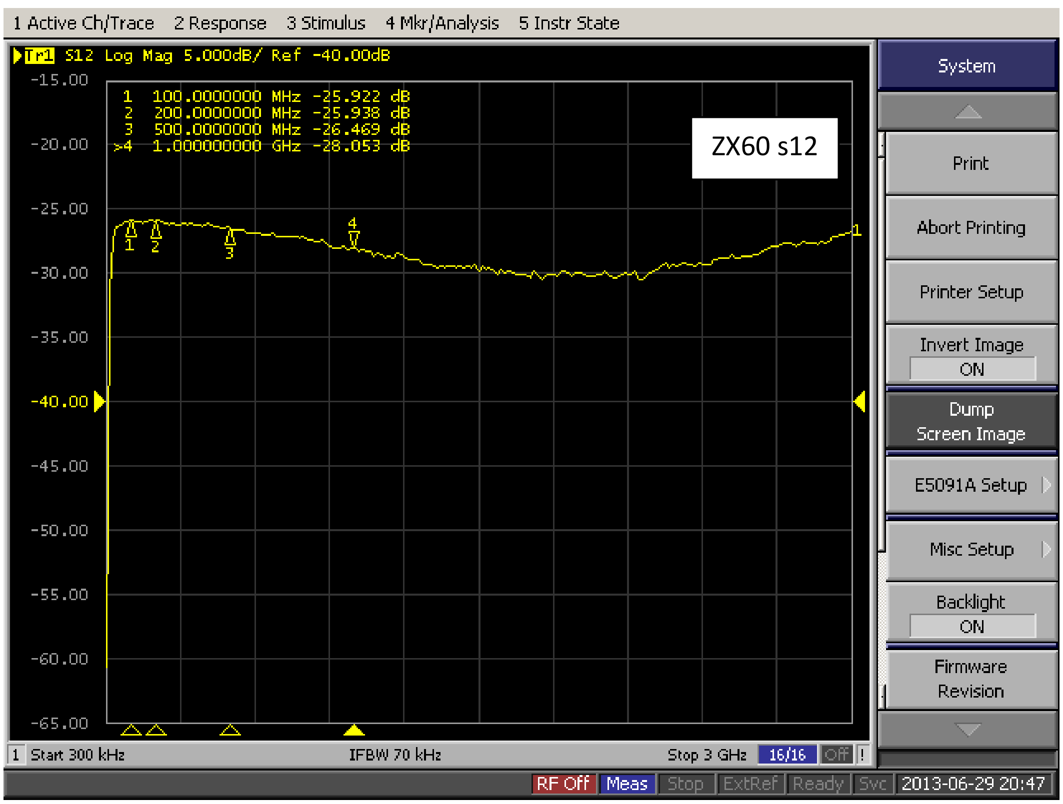
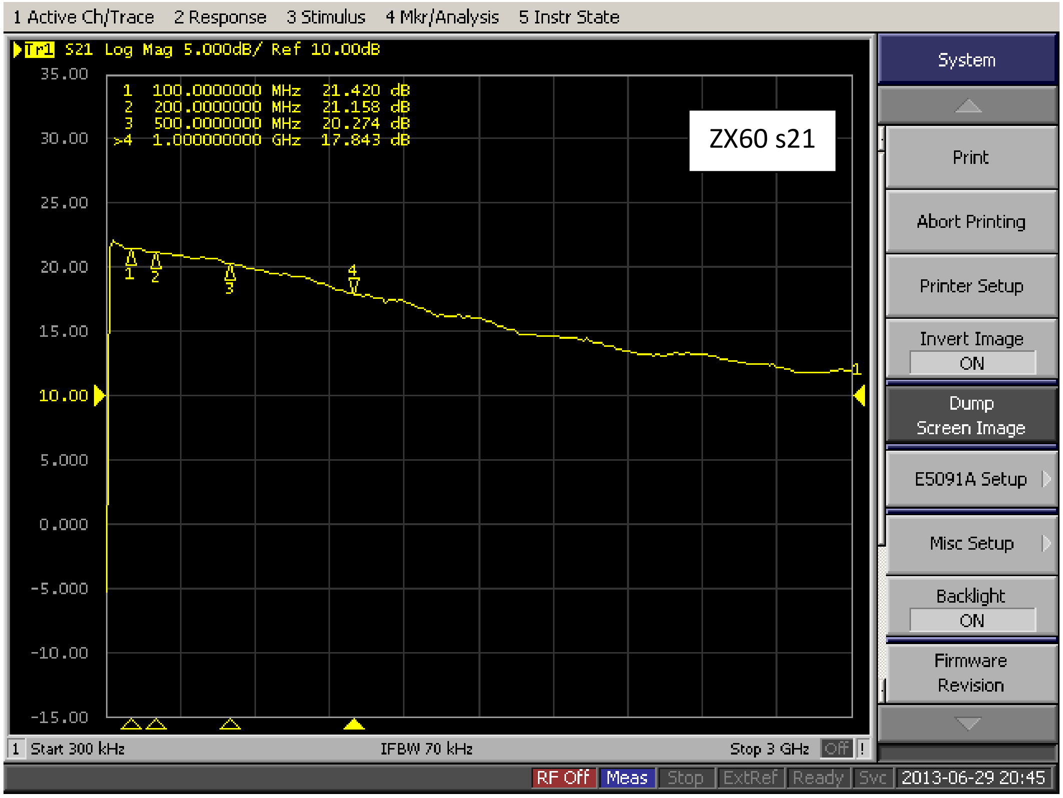


Figure 9 ~ CxLNA S-parameters


1 Active Ch/Trace 2 Response 3 Stimulus 4 Mkr/Analysis 5 Instr State
Tr1 S11 Log Mag 5.000dB/ Ref -10.00dB
1 100.0000000 MHz -11.014 dB
2 200.0000000 MHz -11.415 dB
3 500.0000000 MHz -10.701 dB
>4 1.000000000 GHz -7.5529 dB
ZX60 s11
15.00
10.00
5.000
0.000
-5.000
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
System
Print
Abort Printing
Printer Setup
Invert Image ON
Dump Screen Image
E5091A Setup
Misc Setup
Backlight ON
Firmware Revision
1 Start 300 kHz
IFBW 70 kHz
Stop 3 GHz
16/16
RF Off Meas Stop ExtRef Ready Svc 2013-06-29 20:48


1 Active Ch/Trace 2 Response 3 Stimulus 4 Mkr/Analysis 5 Instr State
Tr1 S12 Log Mag 5.000dB/ Ref -40.00dB
1 100.0000000 MHz -25.922 dB
2 200.0000000 MHz -25.938 dB
3 500.0000000 MHz -26.469 dB
>4 1.000000000 GHz -28.053 dB
ZX60 s12
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
-50.00
-55.00
-60.00
-65.00
System
Print
Abort Printing
Printer Setup
Invert Image ON
Dump Screen Image
E5091A Setup
Misc Setup
Backlight ON
Firmware Revision
1 Start 300 kHz
IFBW 70 kHz
Stop 3 GHz
16/16
RF Off Meas Stop ExtRef Ready Svc 2013-06-29 20:47



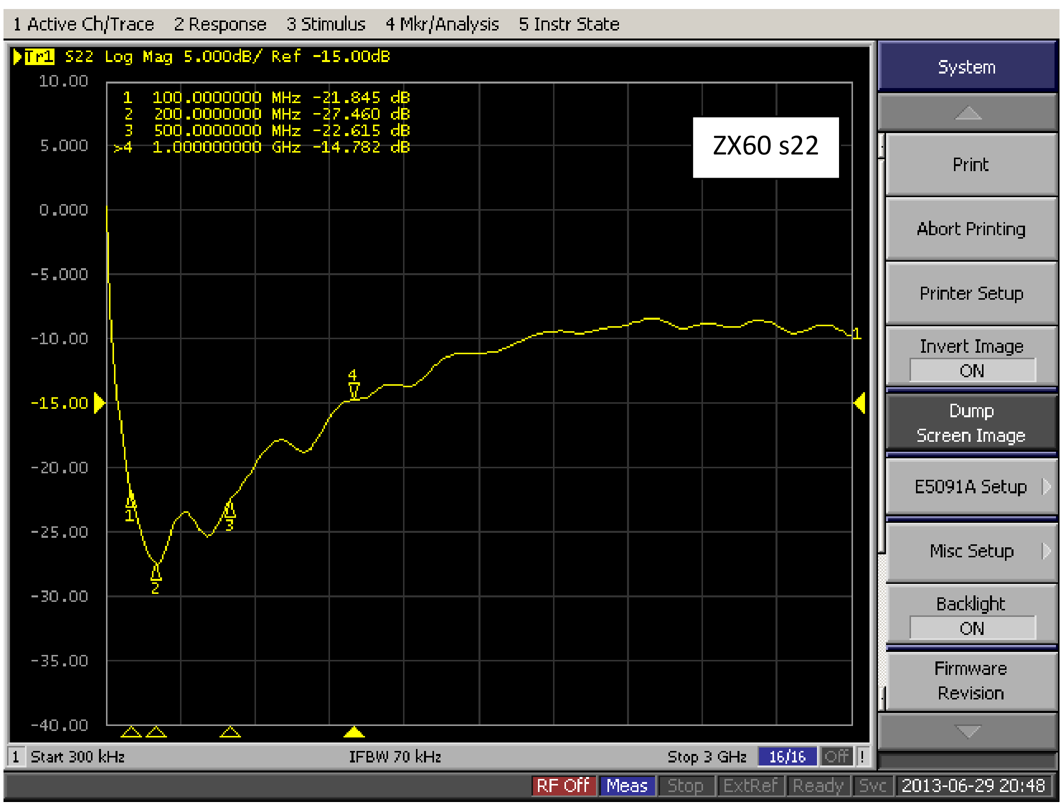
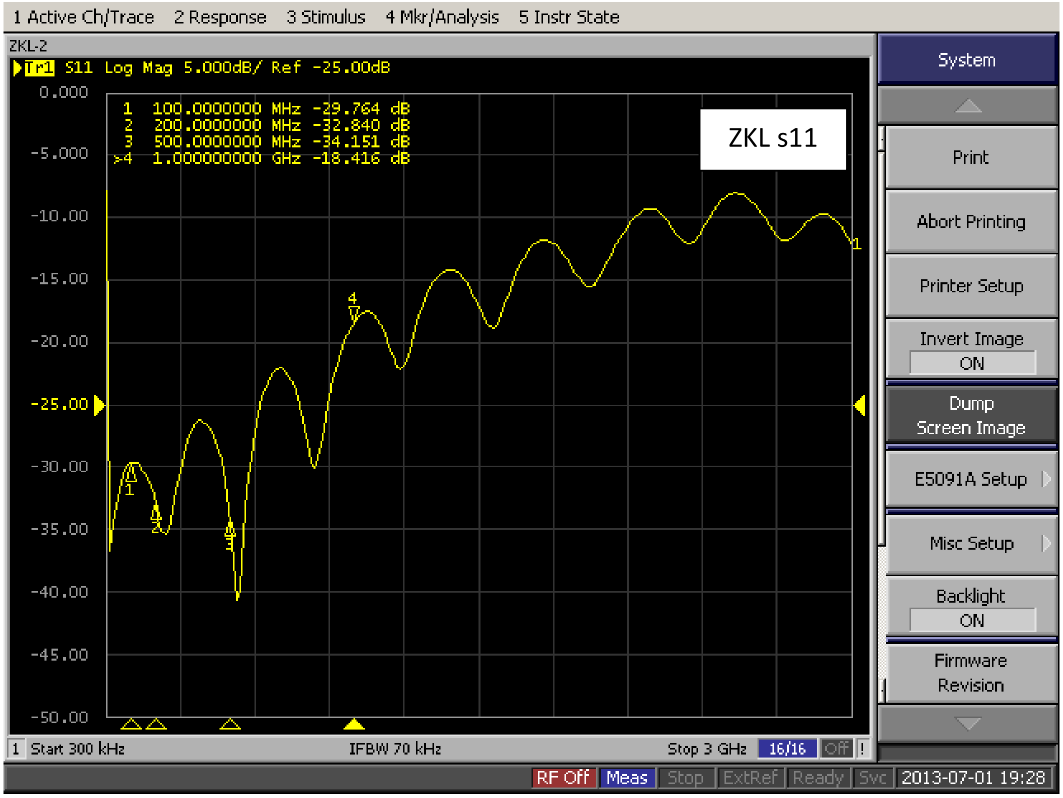
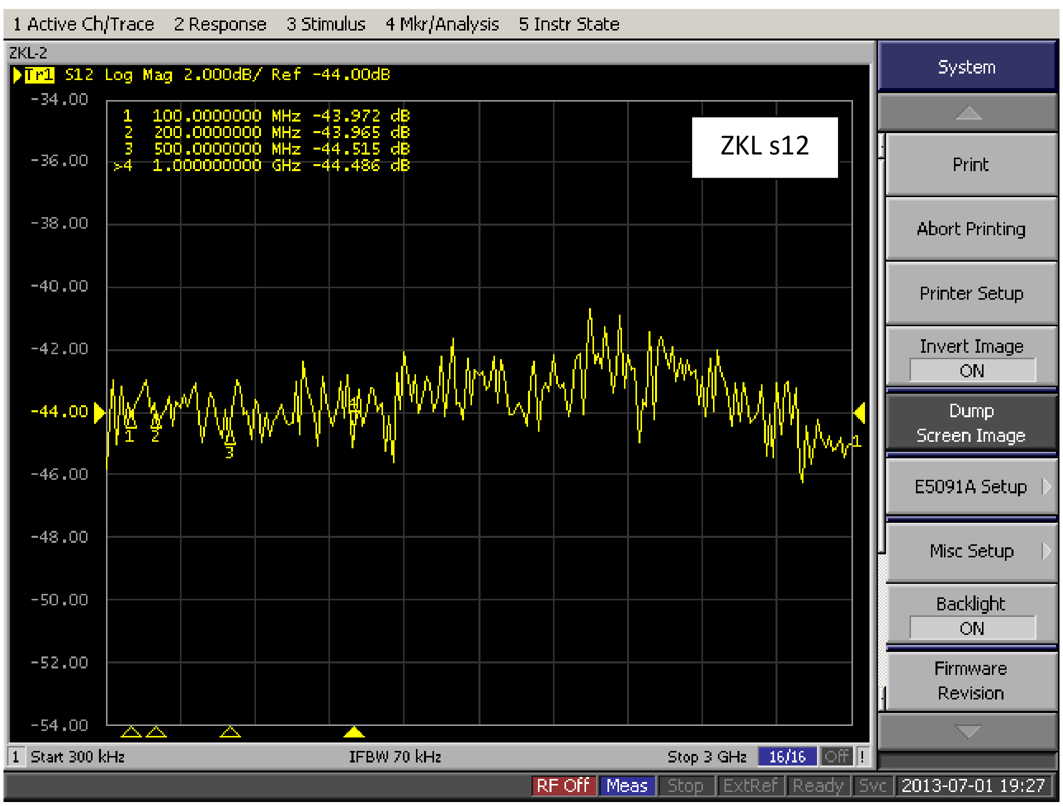


Figure 10 ~ ZX60 S-parameters


1 Active Ch/Trace 2 Response 3 Stimulus 4 Mkr/Analysis 5 Instr State
ZKL-2
Tr1 S11 Log Mag 5.000dB/ Ref -25.00dB
1 100.0000000 MHz -29.764 dB
2 200.0000000 MHz -32.840 dB
3 500.0000000 MHz -34.151 dB
>4 1.000000000 GHz -18.416 dB
ZKL s11
0.000
-5.000
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
-50.00
System
Print
Abort Printing
Printer Setup
Invert Image ON
Dump Screen Image
E5091A Setup
Misc Setup
Backlight ON
Firmware Revision
1 Start 300 kHz
IFBW 70 kHz
Stop 3 GHz
16/16
RF Off Meas Stop ExtRef Ready Svc 2013-07-01 19:28


1 Active Ch/Trace 2 Response 3 Stimulus 4 Mkr/Analysis 5 Instr State
ZKL-2
Tr1 S12 Log Mag 2.000dB/ Ref -44.00dB
1 100.0000000 MHz -43.972 dB
2 200.0000000 MHz -43.965 dB
3 500.0000000 MHz -44.515 dB
>4 1.000000000 GHz -44.486 dB
ZKL s12
-34.00
-36.00
-38.00
-40.00
-42.00
-44.00
-46.00
-48.00
-50.00
-52.00
-54.00
System
Print
Abort Printing
Printer Setup
Invert Image ON
Dump Screen Image
E5091A Setup
Misc Setup
Backlight ON
Firmware Revision
1 Start 300 kHz
IFBW 70 kHz
Stop 3 GHz
16/16
RF Off Meas Stop ExtRef Ready Svc 2013-07-01 19:27

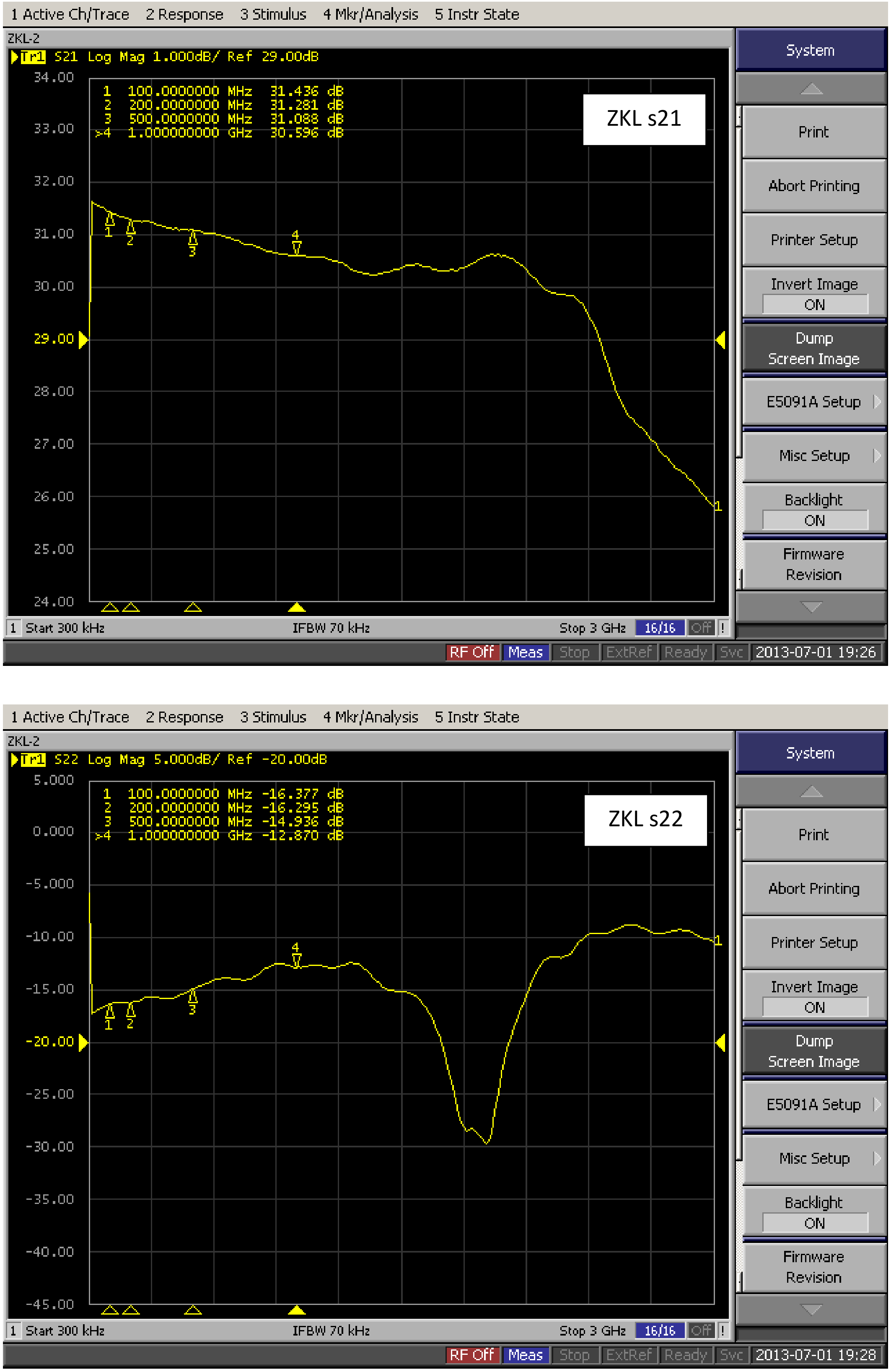
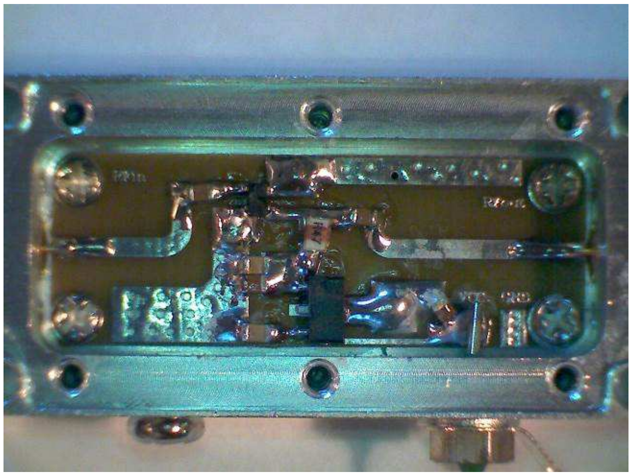
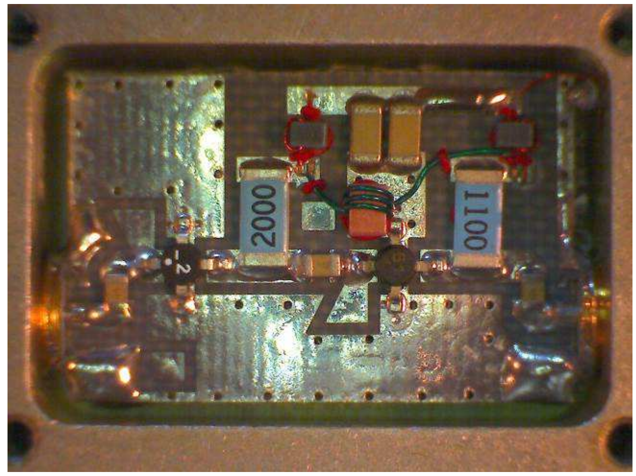


Figure 11 ~ ZKL S-parameters

8. Amplifier construction

The three amplifiers share the same basic construction – a machined aluminum enclosure with covers held by screws. Also, the three amplifiers all use SMA-F connectors for input and output, and power is connected by leads soldered to a feed-through capacitor and ground lug located near the output connector. The two Mini-Circuits amplifiers appear to be machine-built while the Chinese CxLNA appears to be hand-built (figure 12).





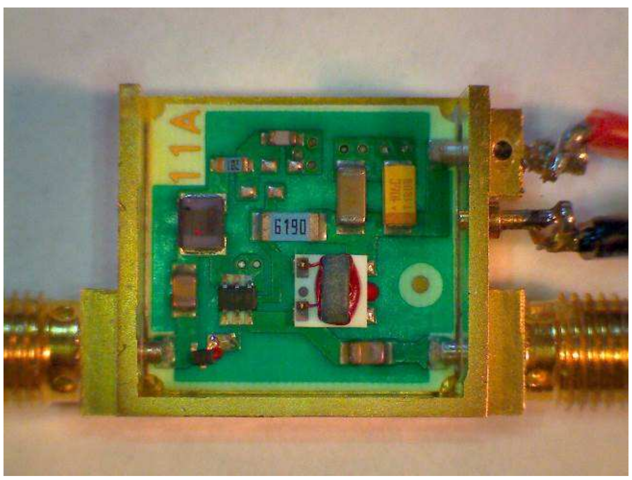


Figure 12 ~ Interior photographs. CxLNA1: Upper-left; ZKL: Upper-right; ZX60: Lower-left. For all amplifiers, input is on the left side. The magnification is the same for the ZKL and ZX60 and about 25% higher than the CxLNA.

The amplifier integrated circuit in the CxLNA is visible just to left of upper-center, and the voltage regulator IC is at the bottom-center. The ZKL appears to have two amplifier stages – just below middle-left and middle-right. Not visible in the ZKL picture are two conductive mesh cylinders below the PCB that bond the PCB to the bottom cover. The amplifier IC in the ZX60 is at bottom-left, very close to the input connector. All other components in the ZX60 appear to be related to power filtering and voltage regulation.

9. Methods

Noise figure measurements:
The amplifiers were connected directly to the Callisto RF Input port through an SMA-M/N-M coaxial adapter (figure 13). The Callisto software tool NF, which uses the Y-factor method, and the RF Design RFD2305 noise source were used for the measurements. The RFD2305 has an excess noise ratio (ENR) of 5.8 dB in the frequency range of interest. For calculation purposes, this was reduced by 0.2 dB to 5.6 dB to account for connection losses.

The amplifier noise figure measurements include amplifier noise as well as the effects of the Callisto. The gains of the CxLNA1 and ZX60 are approximately 20 dB and the noise figure of the Callisto is 7.5 dB, resulting in an amplifier noise measurement that is a few tenths dB higher than actual. Measurement uncertainty also amounts to at least a few tenths dB. The higher gain of the ZKL reduces the effect of the Callisto noise figure in the measurement.

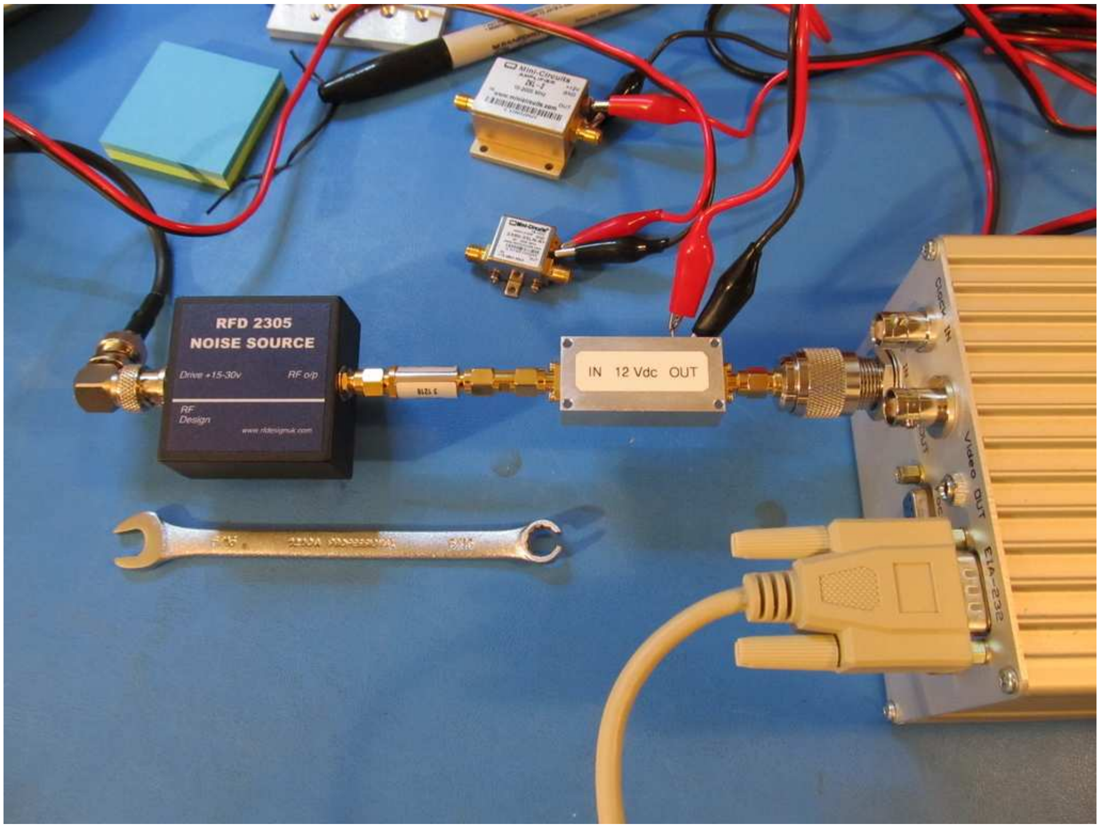


Figure 13 ~ Noise figure measurement setup for the CxLNA. The ZX60 and ZKL amplifiers used the same setup. The RFD2305 noise source (blue box on left) was connected directly to the RF Input of the amplifier through its 10 dB attenuator. The RFD2305 was factory calibrated with the attenuator, which can be seen between the blue box and amplifier. The amplifiers were connected to a power supply using temporary leads (red and black wires and alligator clips). The Callisto (right) was setup in the normal way with EIA-232 connection to the PC and power connection to a 12 Vdc lab power supply. The PC used the NF test tool.

Spectrum Y(F) measurements:
The spectrum measurements were produced with the Callisto software. The frequency file ran from 45 to 870 MHz with 200 channels evenly distributed within that band. A 0.5 m whip antenna was connected directly to the amplifier inputs. The amplifier outputs were connected directly to the Callisto RF input (figure 14). Callisto gain (PWM value) was set to 150 for all measurements.

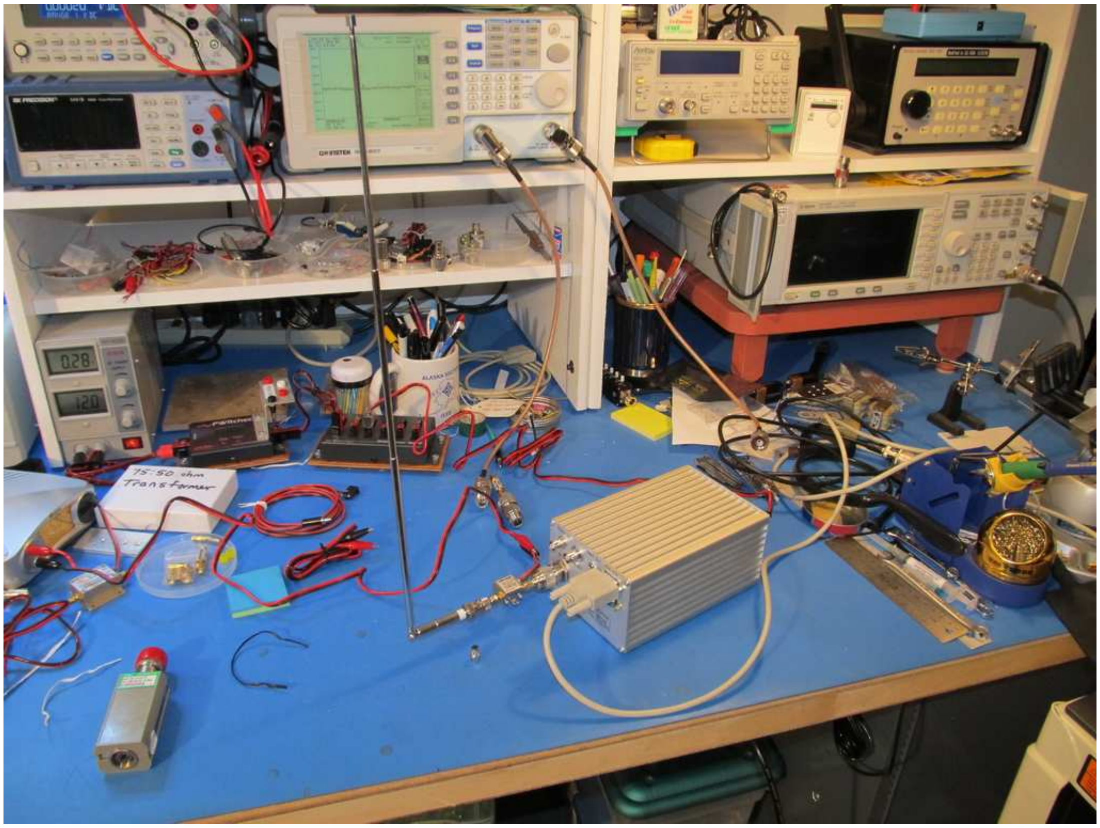


Figure 14 ~ Spectrum measurements setup. The amplifier output was connected directly to the Callisto RF input and a 0.5 m whip antenna connected to the amplifier input. The measurements were of the lab RFI environment as a substitute for live observations.

Gain measurements:

A spectrum analyzer with tracking generator (Instek GSP-827TG) was used for gain measurements. All amplifiers were isolated from the tracking generator/spectrum analyzer with 10 dB attenuators, resulting in an input level of –40 dBm for the CxLNA1 and ZX60 and –50 dBm for the ZKL. All amplifiers use SMA-F connectors for input and output, so adapters were used for connect the amplifiers to RG-142 coaxial test cables with N-M connectors.

Overload compression measurements:

For all overload measurements, the amplifier inputs were connected to an Agilent E4422B RF signal generator set to 457.5 MHz (mid-way between 45 and 870 MHz). Amplifier output power level was measured by an HP 437B RF power meter with HP 8481A sensor.

FITS:

The FITS file was produced with Callisto software v118 setup for 900 second (15 minute) measurement interval. The frequency file ran from 45 to 870 MHz with 200 channels evenly distributed within that band. The amplifier RF input was connected directly to a 0.5 m whip antenna, so the measurements were of the RFI environment in the Anchorage lab. Callisto s/n NA008 was used with the amplifiers for all measurements.

Detailed spectrum measurements:
The NF software tool v2.0 was used to produce measurement data for 200 channels within the frequency range of 45 to 870 MHz. As with the spectrum and FITS measurements, a 0.5 m whip antenna was connected to the amplifier RF input. Callisto s/n NA008 was used with the amplifiers for all measurements.

S-parameter measurements:
S-parameters were measured with an Agilent E5071B ENA RF Network Analyzer over a frequency range of 300 KHz to 3 GHz.

10. Weblinks

Chinese (CxLNA) amplifier:
http://www.ebay.ch/itm/320989235933?ssPageName=STRK:MEWNX:IT&_trksid=p3984.m1439.l2648
http://www.ebay.com/itm/320989235933?ssPageName=STRK:MEWNX:IT&_trksid=p3984.m1497.l2649

Mini Circuits ZX60-33LN: http://www.minicircuits.com/pdfs/ZX60-33LN+.pdf

Mini Circuits ZKL-2: http://www.minicircuits.com/pdfs/ZKL-2.pdf

Document information

Authors: Whitham Reeve, Christian Monstein

Revision: 0.0 (Draft started, 27 Jun 2013)
0.1 (Added tests and s-parameters, 29 Jun 2013)
0.2 (Edited and added interior photographs, 1 Jul 2013)
1.0 (Final edits and issued for distribution, 4 Jul 2013)
1.1 (Additional clean-up, 6 Jul 2013)
1.2 (Final cleanup, 25 Jul 2013)
1.3 (Formatted for distribution, 27 Aug 2013)