Kea 2

Spectrometer hardware retests – 6 April 2017

(Eduard Chekmenev - K0022/K0074)

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Software versions

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Prospa V3.54 (9-March-2017)
Kea-2 DLL V2.26
```

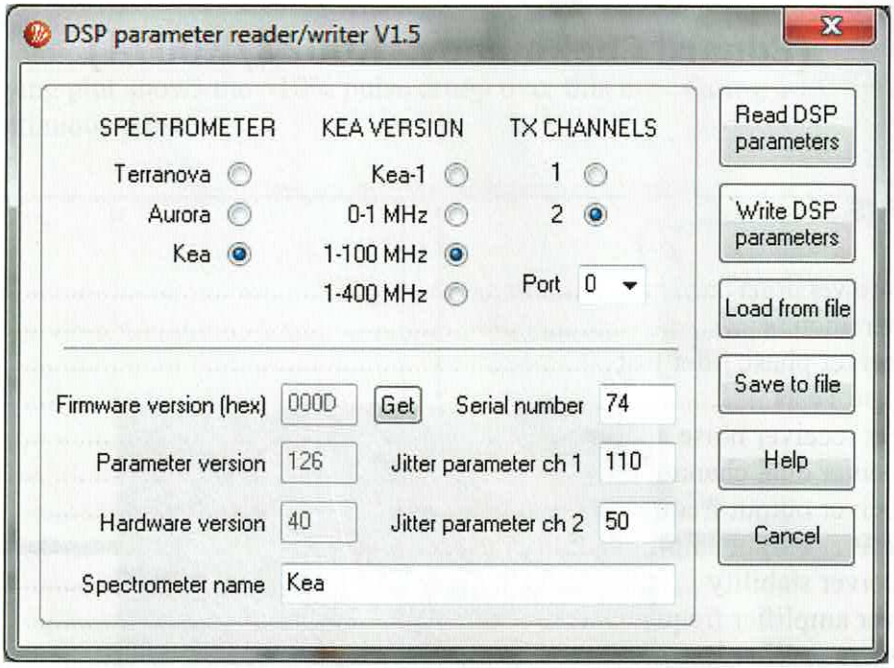
DSP hardware and firmware version

```
DSP firmware version 0x0D V3
WinUSB DLL 32 bit V1.70
```

Transceiver hardware and firmware version

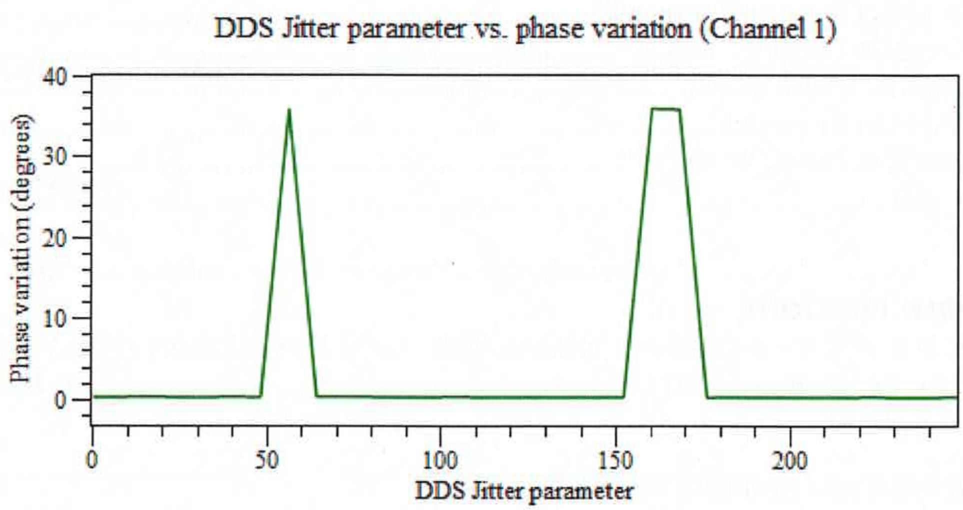
FPGA Firmware version 36

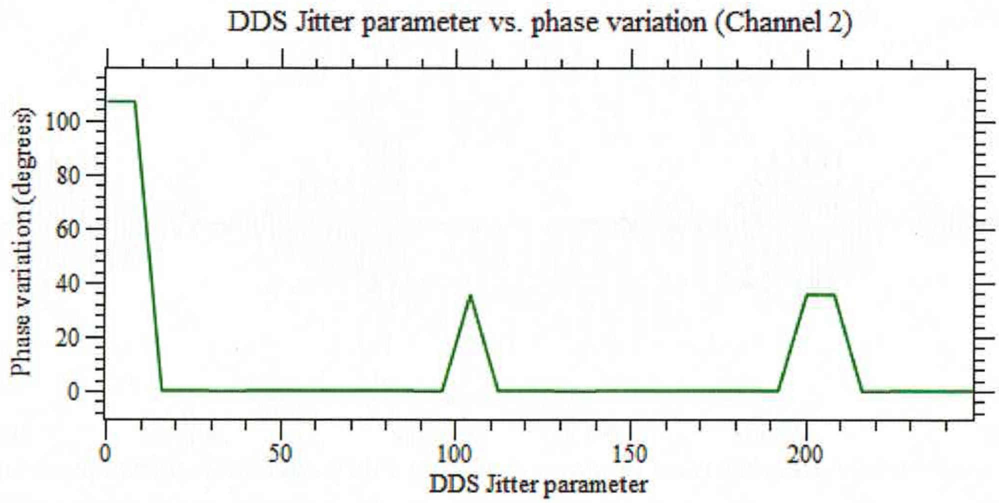
DSP parameters



Transceiver phase jitter test

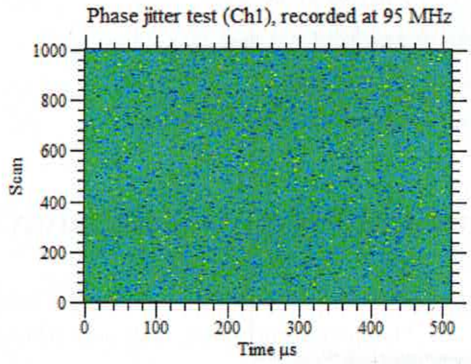
Here the output of the transceiver is connected to the input and many scans are made to ensure that the detected frequency matches the output frequency. Two small delays in the transceiver are varied to optimise any phase errors

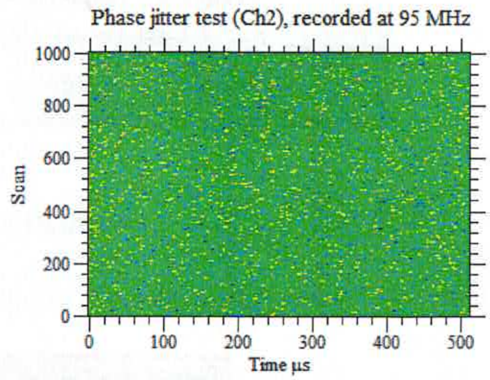




From these graphs we find that suitable jitter parameters are 110 for channel 1 and 50 for channel 2

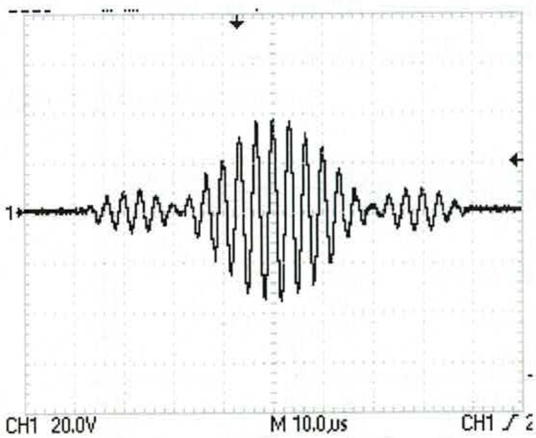
These values are then written into the DSP parameter block and then tests are made to ensure there is no jitter using these parameters. Any phase variations show up as streaks in the image. These tests show no phase jitter with the supplied software on either channel with these delays:



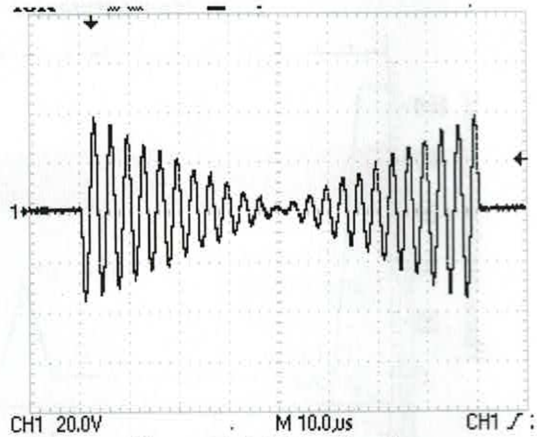


Softpulse Tests

This shows Ch1 and Ch2 of the transceiver producing different soft-pulses



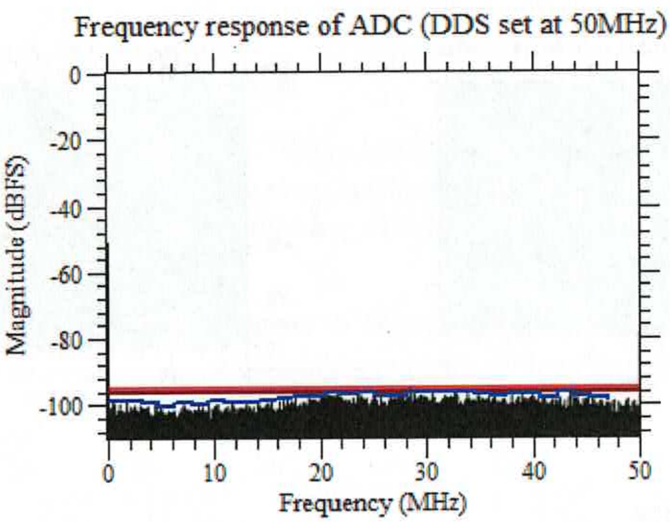
Channel 1 RF softpulse



Channel 2 RF softpulse

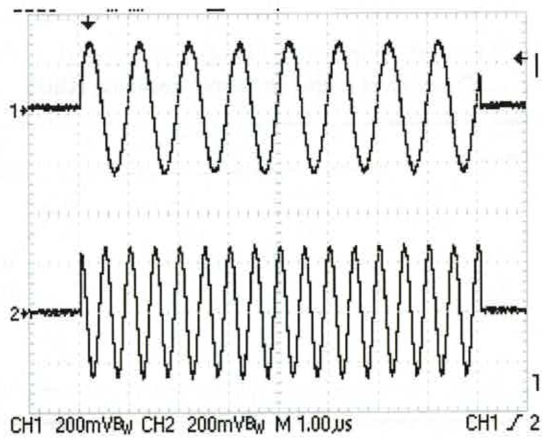
50 MHz receiver noise analysis

This test collects noise data over the complete 50 MHz receiver bandwidth from a 50 ohm resistor plugged into the transceiver Rx In port. Over most of the frequency range the noise floor is 95 dB below the maximum input signal. This is slightly higher than normal (-100 dB is typical)

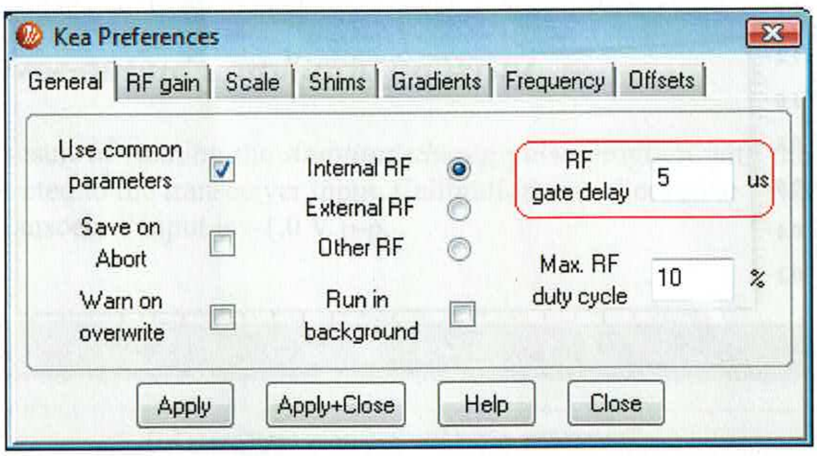


Transceiver dual channel test

Here both transceiver RF channels output a pulse. In this case maximum output at 1 and 2 MHz for 8 us.

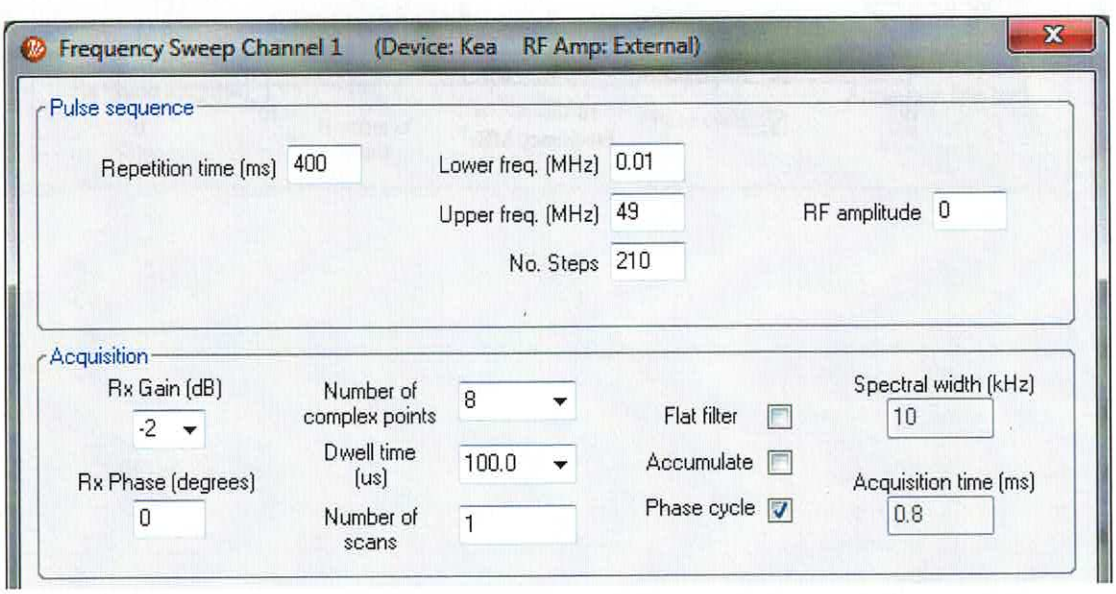


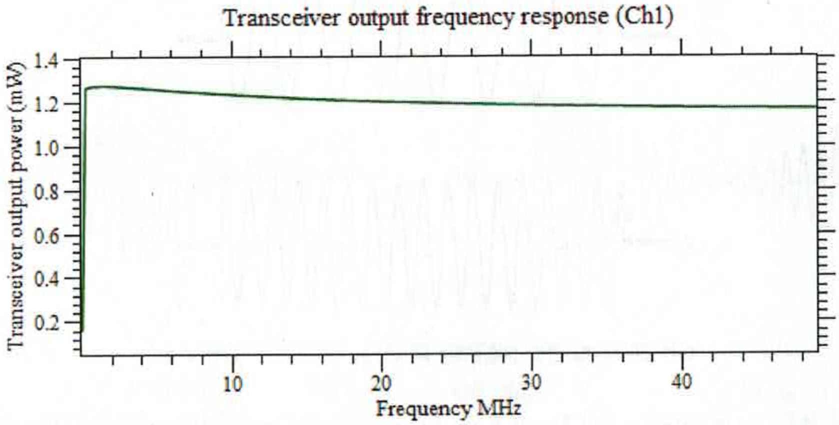
Note that an RF gate delay of at least 5 us is required for these pulses to be synchronised. Single channel control only requires 1.5 us

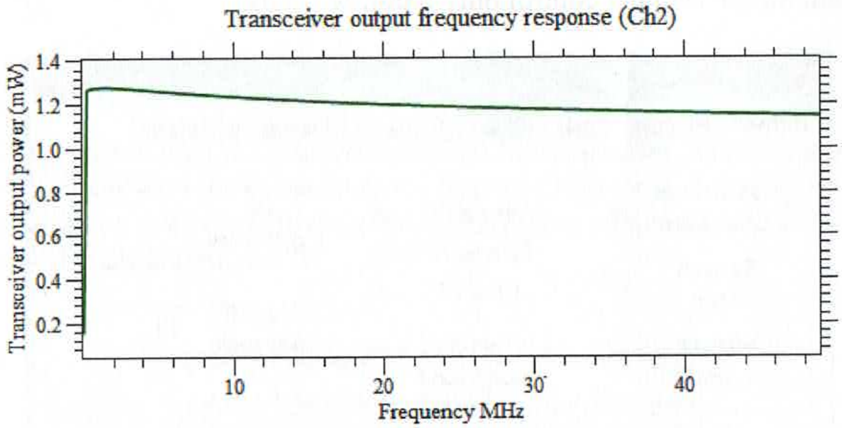


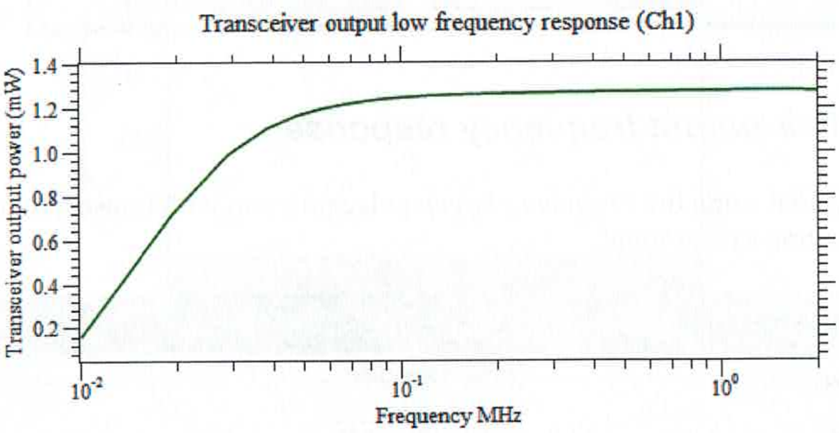
Transceiver output frequency response

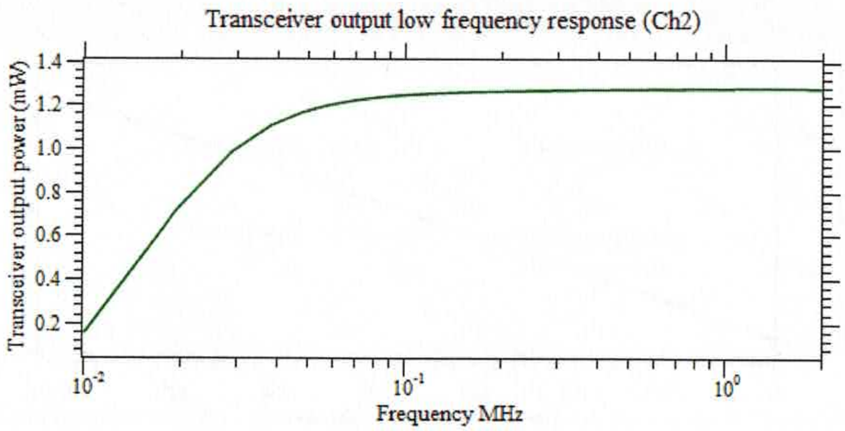
This is measured using the *FrequencySweep* pulse program with transceiver output connected to transceiver input.




Transceiver output frequency response (Ch1)
Transceiver output power (mW)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
10
20
30
40
Frequency MHz


Transceiver output frequency response (Ch2)
Transceiver output power (mW)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
10
20
30
40
Frequency MHz

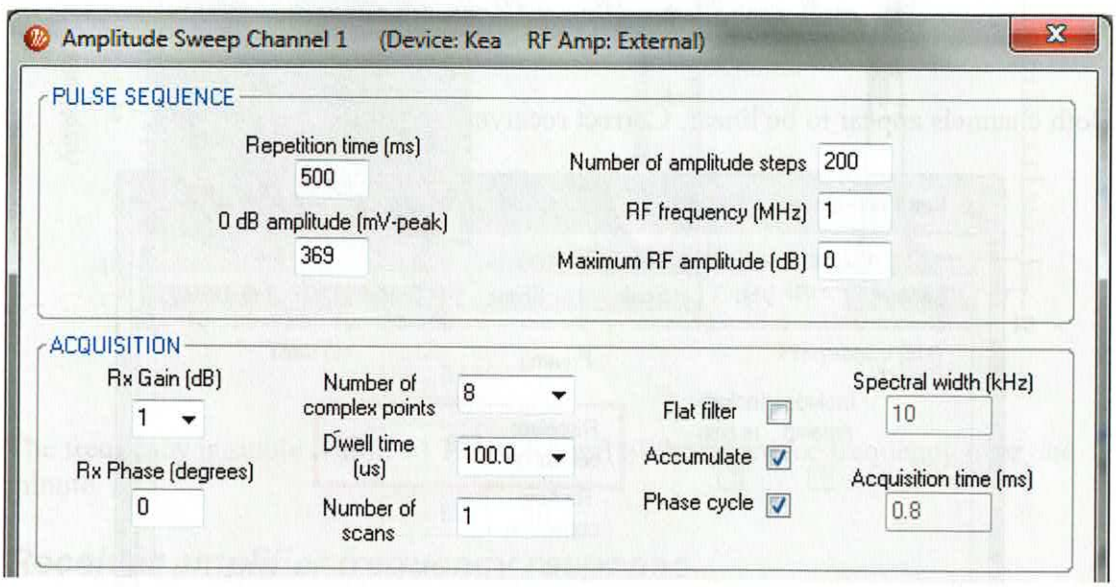

Transceiver output low frequency response (Ch1)
Transceiver output power (mW)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
10^{-2}
10^{-1}
10^{0}
Frequency MHz

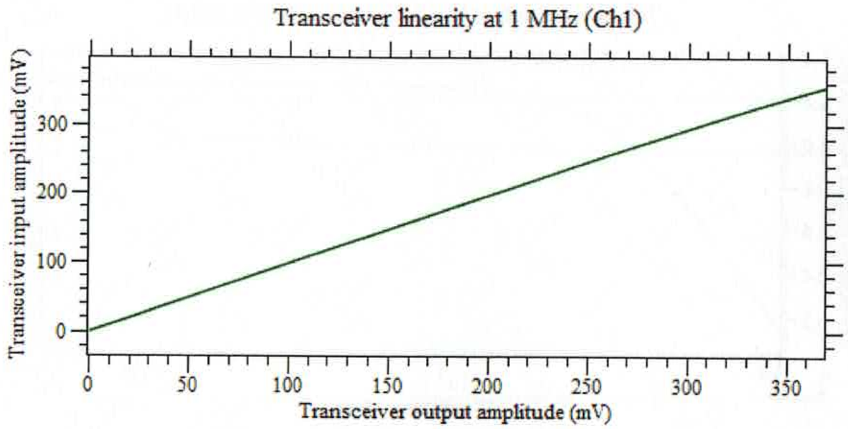


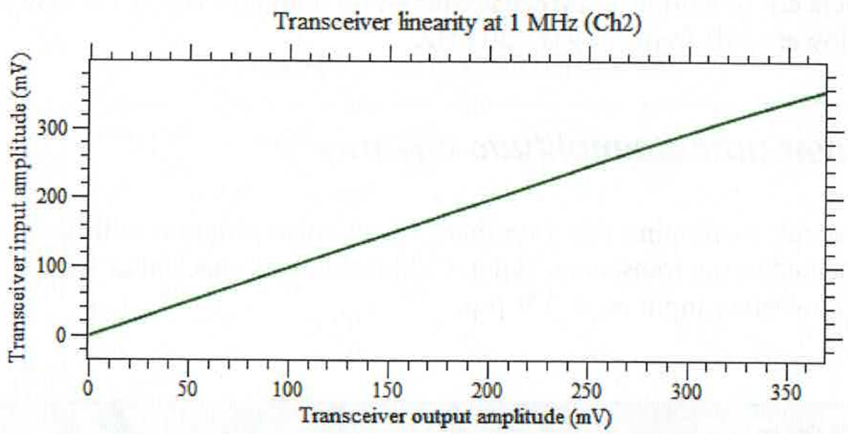
Both channels are functioning correctly. Maximum output power is 1.2 mW into 50 ohms. The lower -3dB frequency is ~20 kHz.

Transceiver output amplitude linearity

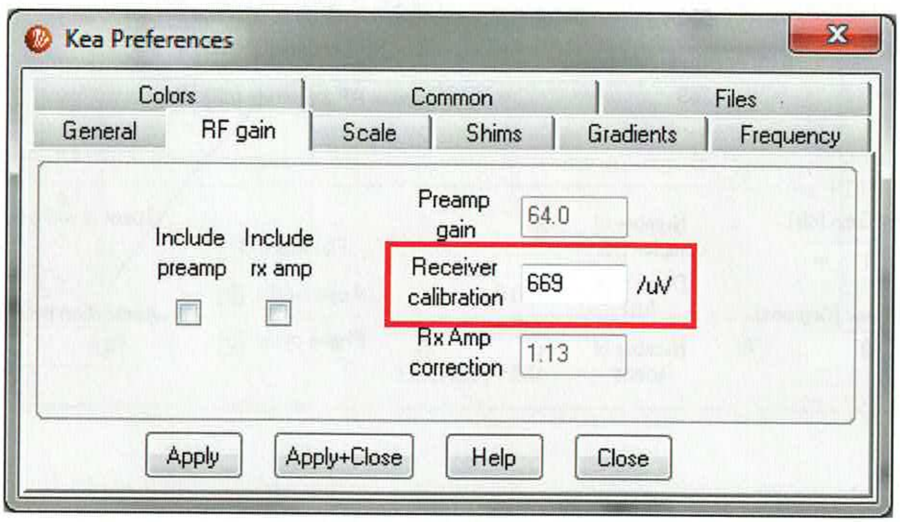
This is the result of running the *AmplitudeSweep* pulse program with the transceiver output connected to the transceiver input. Calibration was checked at 1 MHz. Note the maximum transceiver input is ~1.0 V p-p.





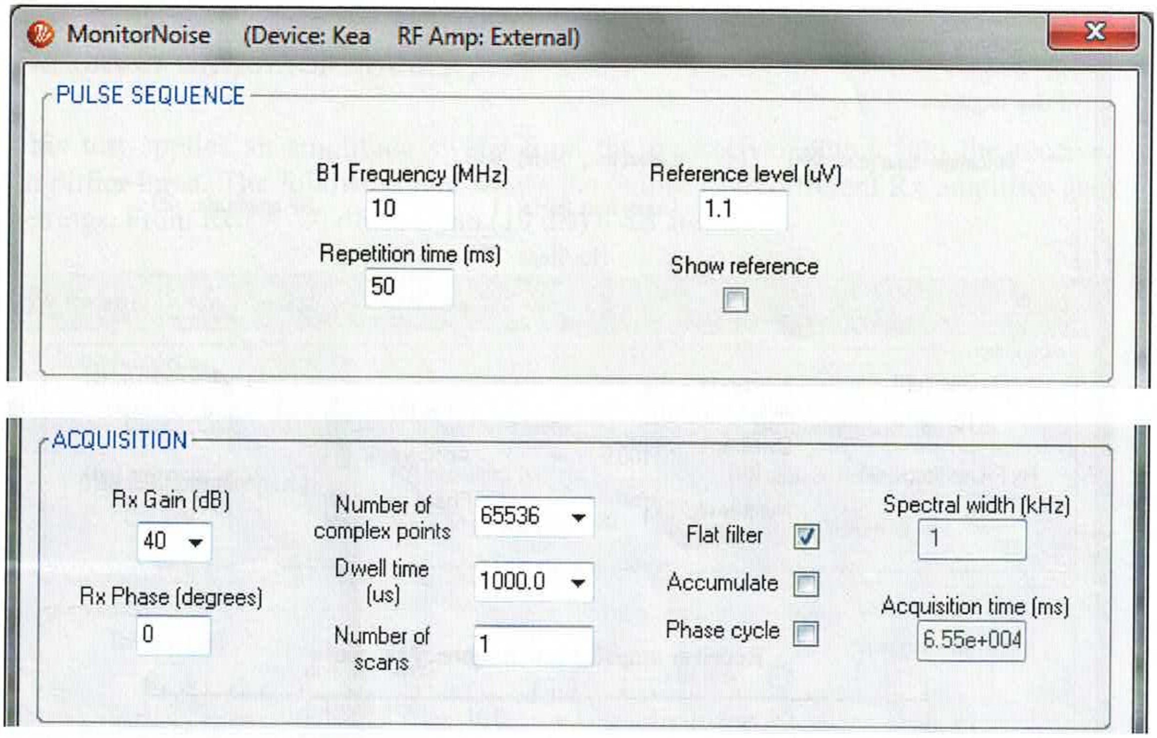


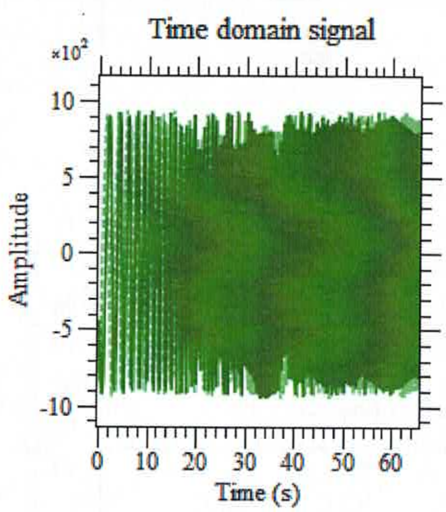
Both channels appear to be linear. Correct receiver calibration factor is 669.

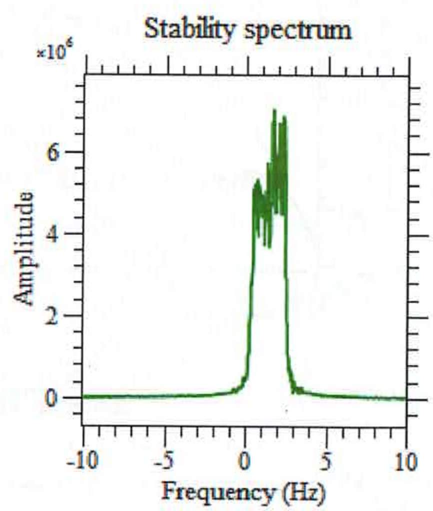


Transceiver stability

Here a 10 MHz signal from a thermally stable PTS 250 frequency synthesizer is connected to the digital transceiver input and the monitor noise program is run with a long acquisition time (the Kea had been switched on for about 30 min first)



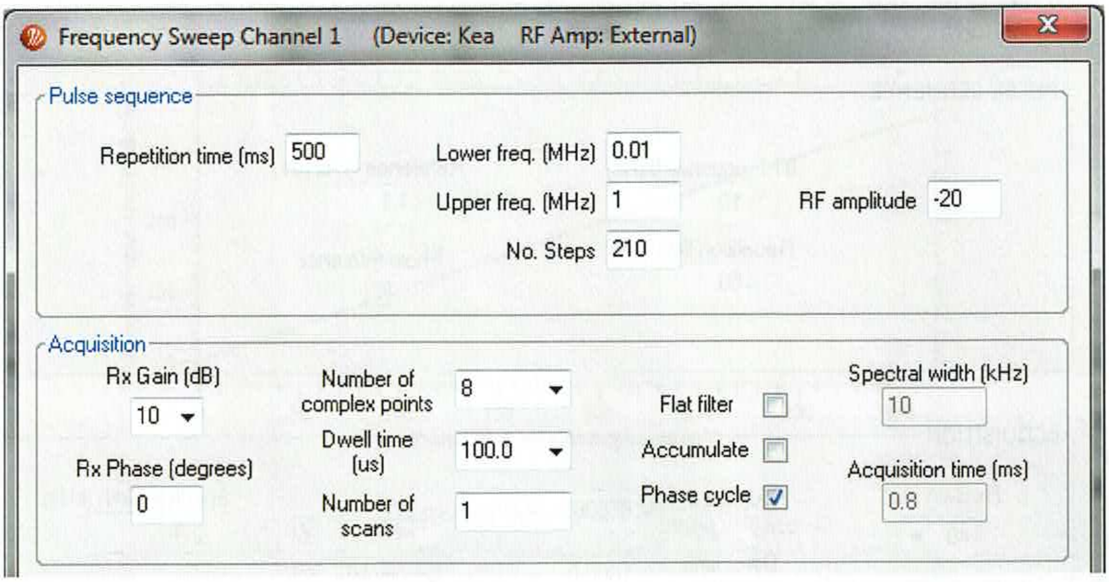




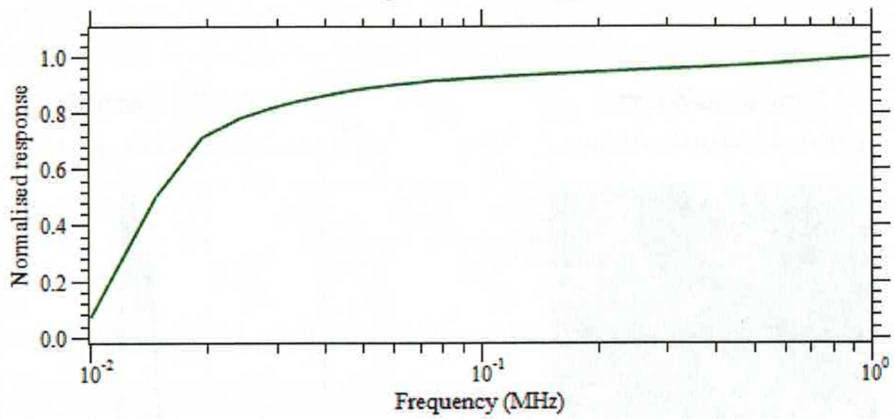
The frequency is stable within ±1 Hz (0.1 ppm) of the reference frequency over one minute.

Receiver amplifier frequency response

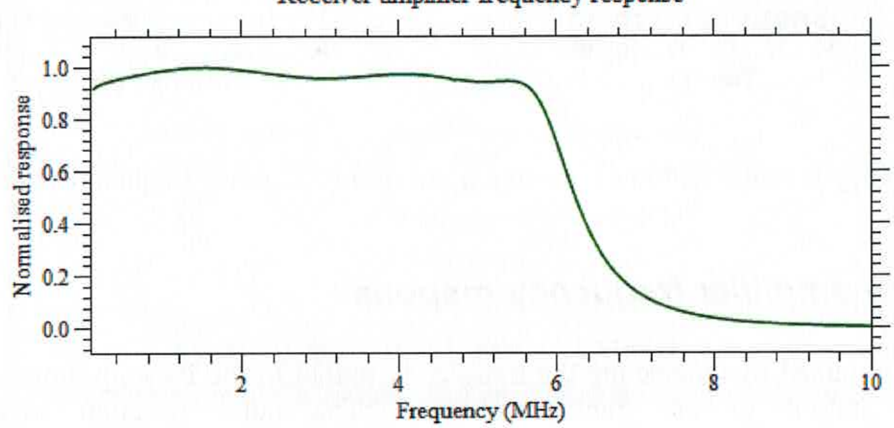
This was obtained by connecting the transceiver output to the Rx amp input and the Rx amp output to the transceiver input. The pulse program used was *FrequencySweep.mac*. It shows the frequency drop off in the Rx amplifier above 6 MHz and below 100 kHz due to the low filter on the output and the coupling capacitors used. Correction has been made for the transceiver frequency response.



Receiver amplifier low frequency response



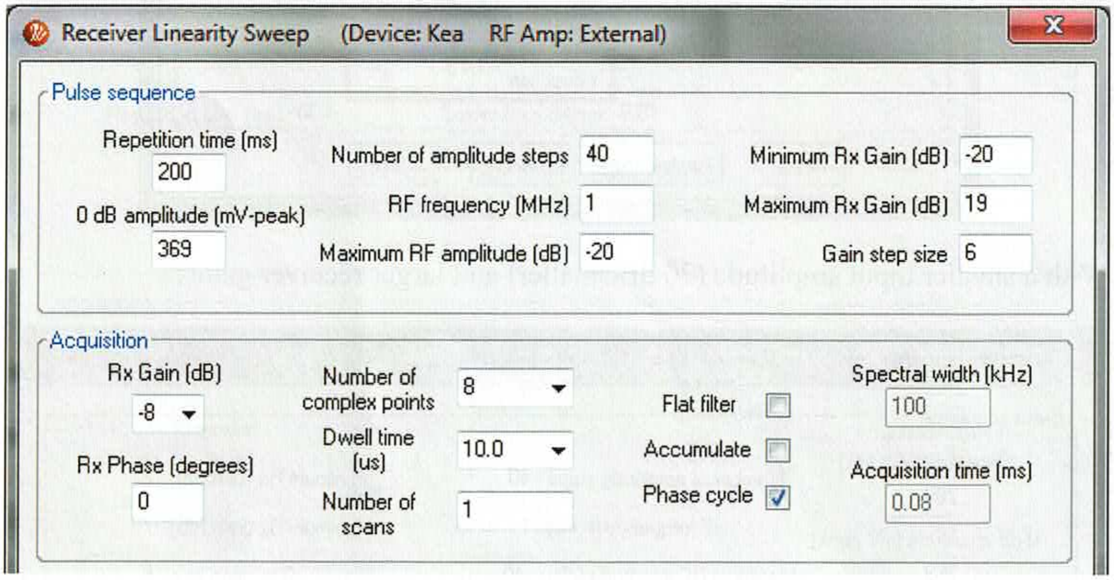
Receiver amplifier frequency response

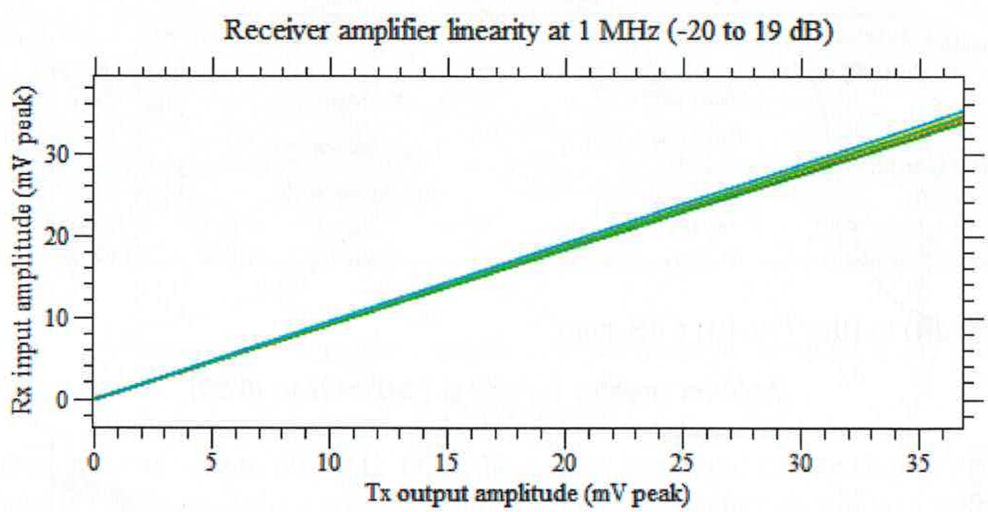


-3dB frequency bandwidth is 20 kHz to 6 MHz.

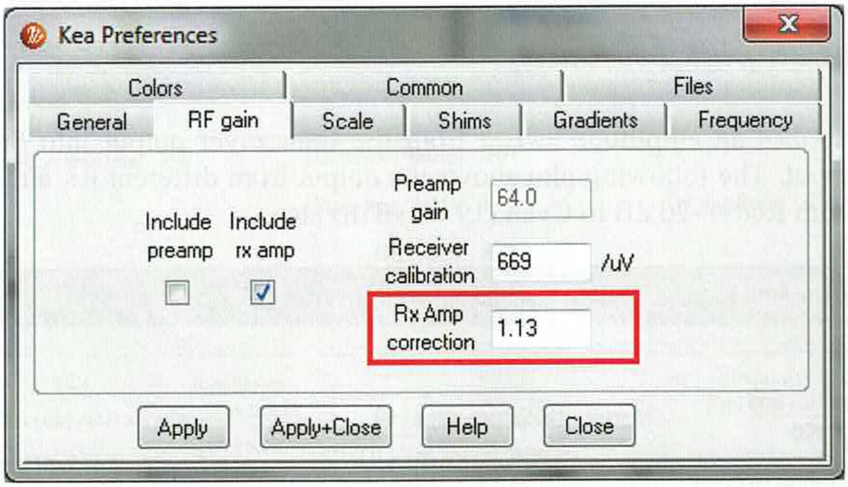
Receiver amplifier linearity

This test applies an amplitude sweep from the transceiver output into the receiver amplifier input. The following plot shows the output from different Rx amplifier gain settings. From Red = -20 dB to Cyan (19 dB) 6 dB steps.

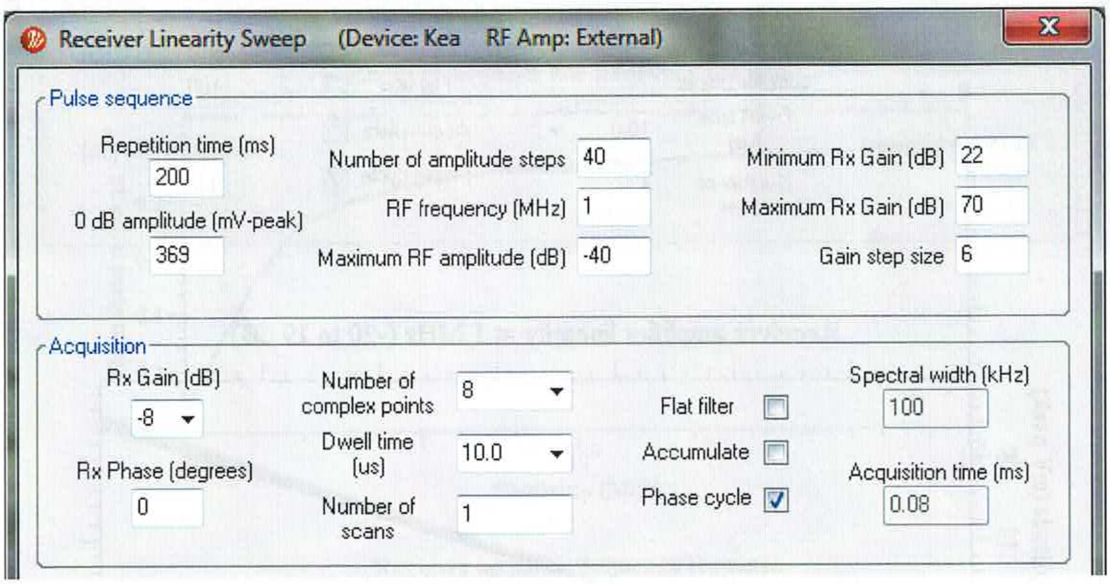




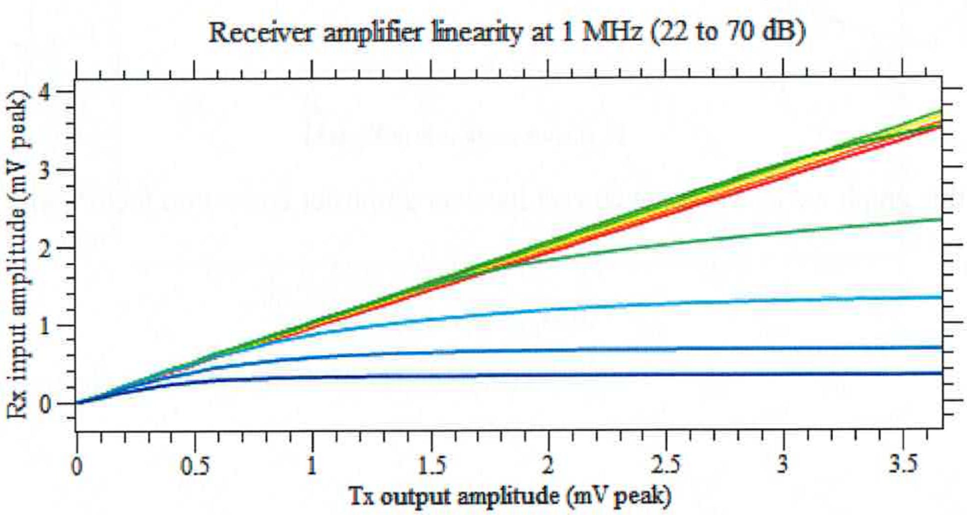
From this graph we find that the correct receiver amplifier correction factor is 1.13



With a smaller input amplitude (20 dB smaller) and larger receiver gains:



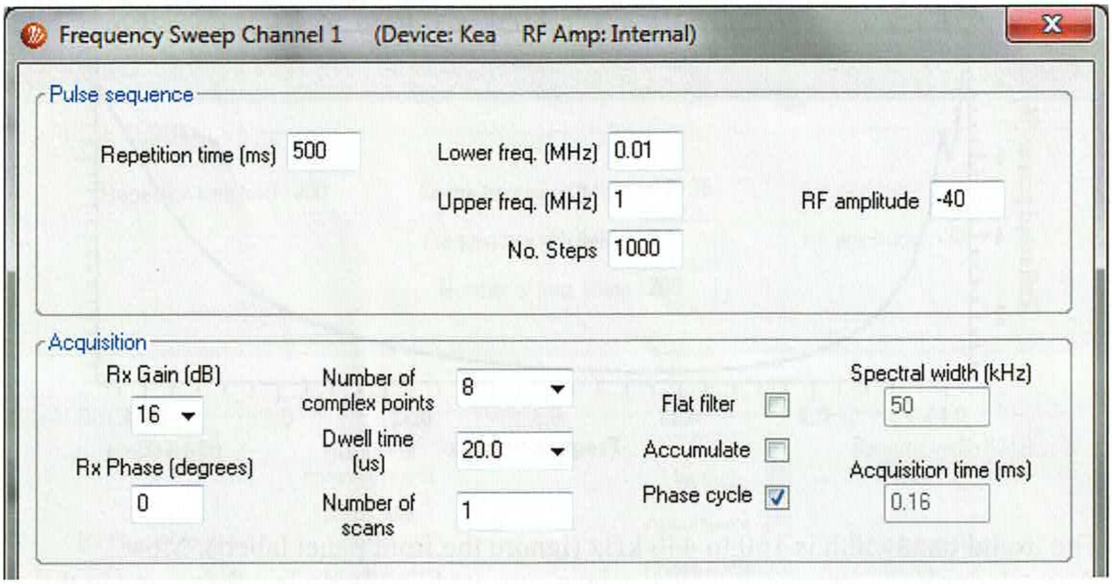
Red (22 dB) to Blue (70 dB) 6 dB steps.

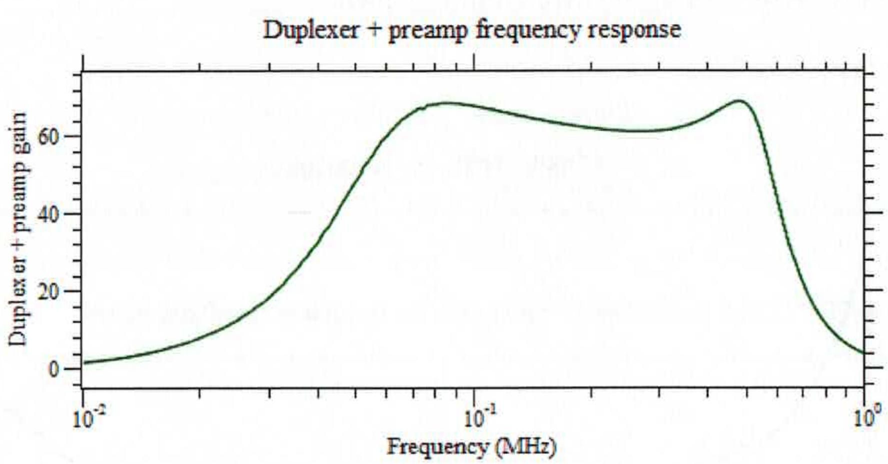


This curve shows the importance of using the correct Rx gain to prevent receiver overflow. *Gains above 40 dB should generally be avoided.*

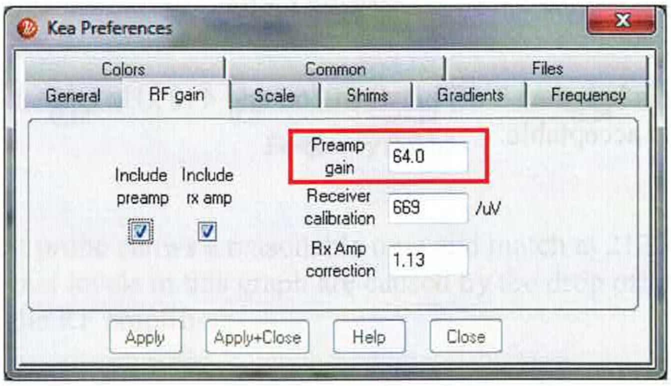
'40-400 kHz' duplexer Gain vs frequency

This shows the frequency response of the duplexer unit in receive mode i.e. when the input power is small.



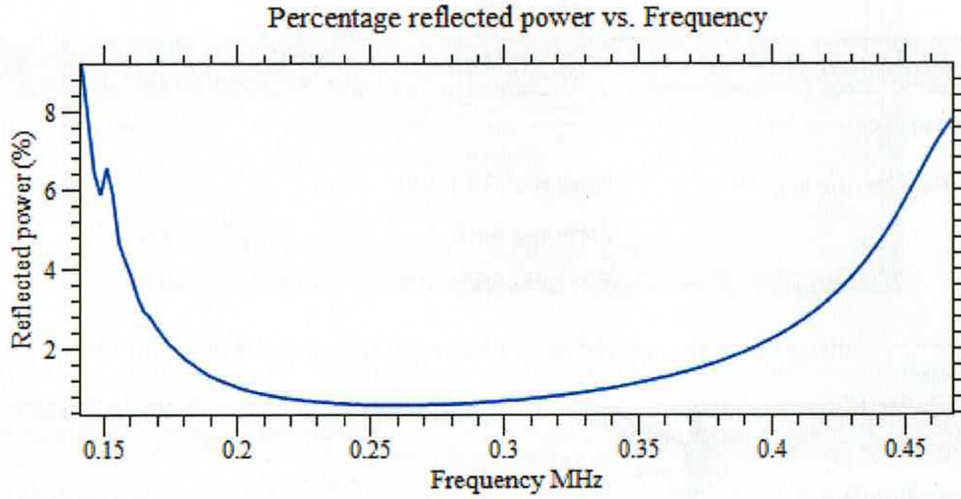


Bandwidth is 46 kHz to 600 kHz. Over the central region the gain averages about 64. For correct calibration the actual gain at the working frequency should be entered into the Kea Preferences->RF Gain tab (preamp gain).



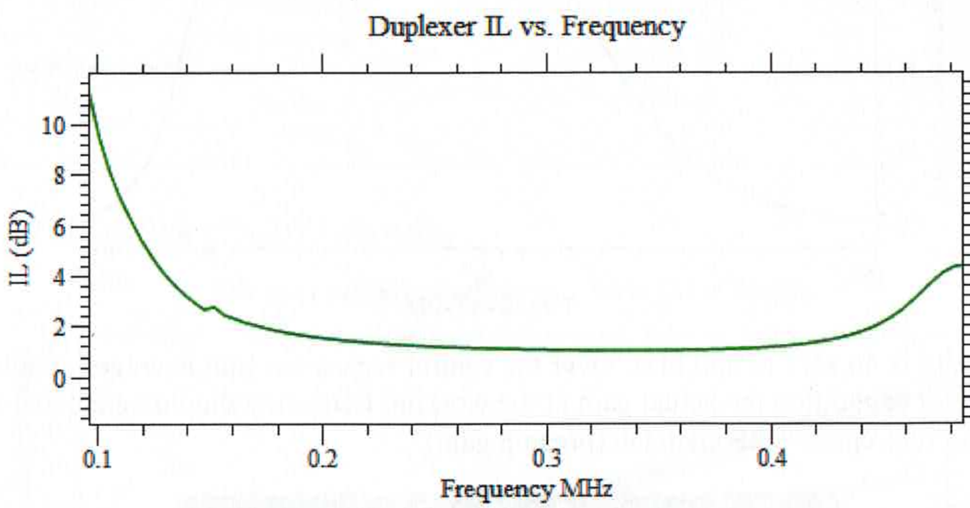
'40-400 kHz' duplexer in transmit mode

Reflected power



The useful bandwidth is 160 to 440 kHz (ignore the front panel label!). Most Magritek duplexers can work over 1 octave surrounding the central frequency in this case ~300 kHz surrounding 300 kHz central frequency.

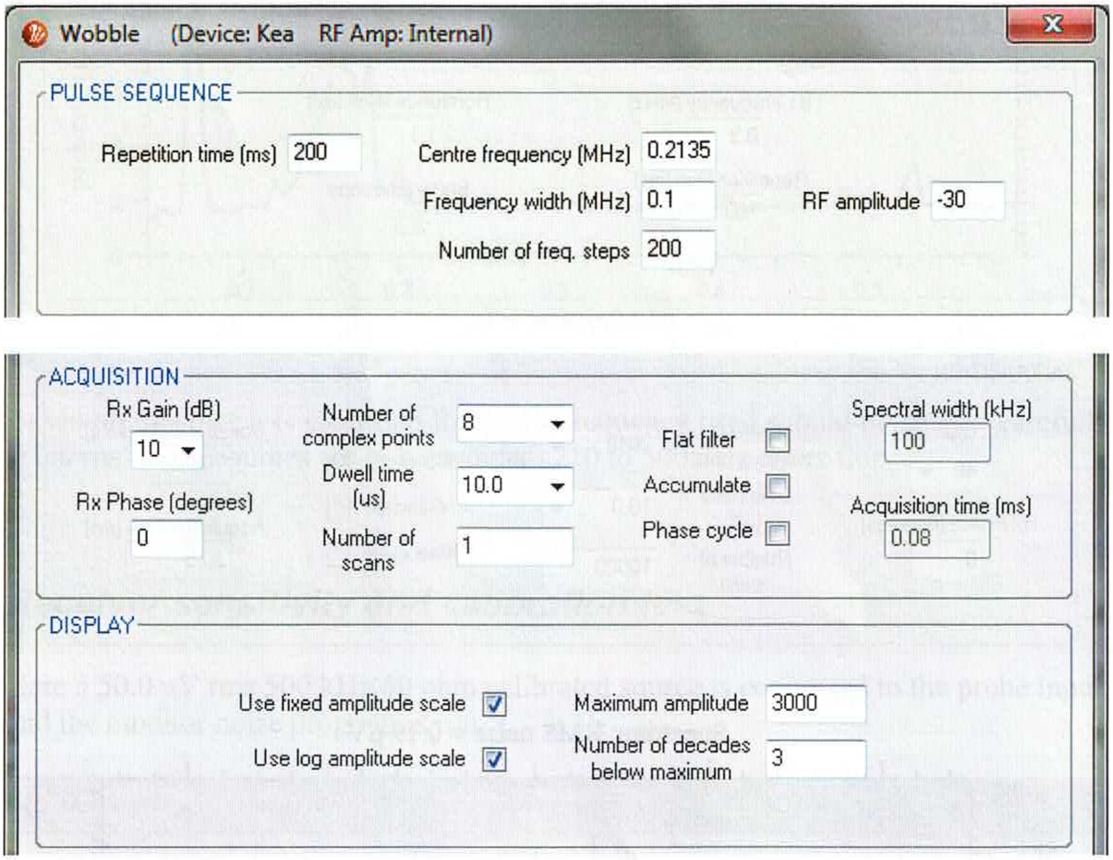
Insertion loss

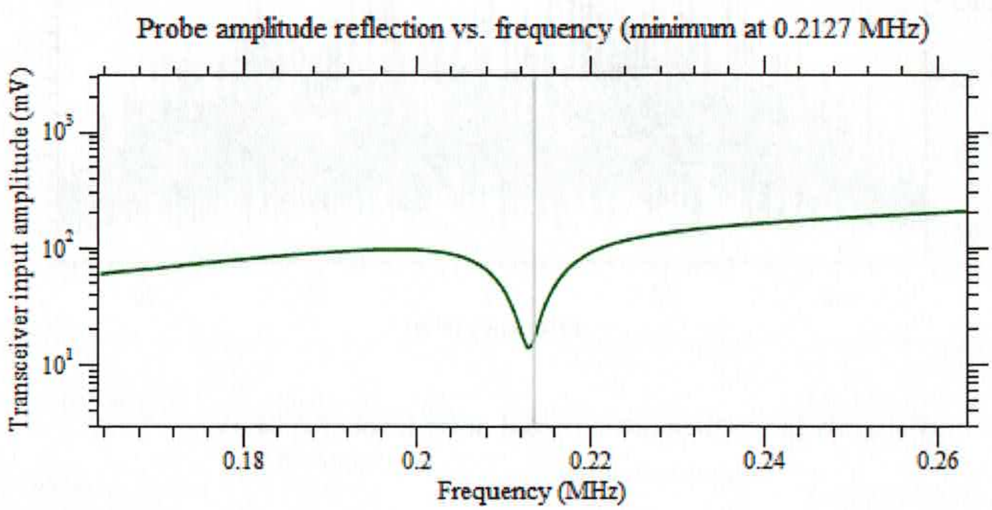


The insertion loss is less than 3 dB between 160 and 440 kHz and ~1 dB at the central frequency which is acceptable.

Wobble test

Here the directional coupler which is part of the duplexer is tested. You will hear a click as internal relays switch to the wobble mode. The Wobble function is used to tune and match an attached probe.

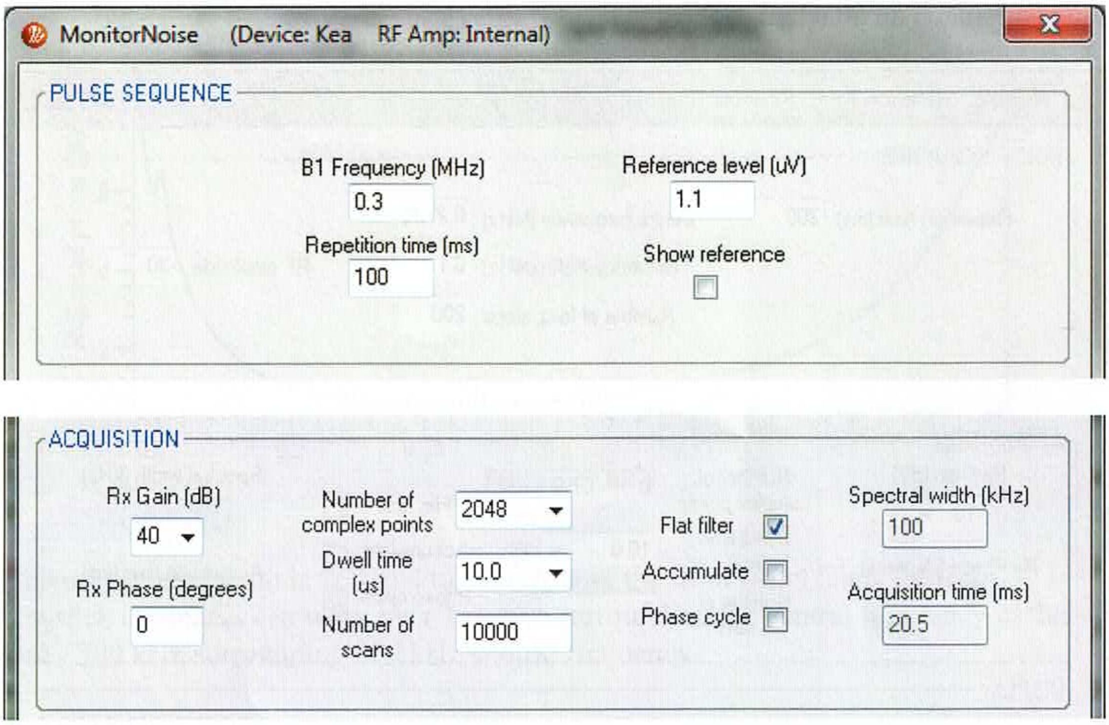


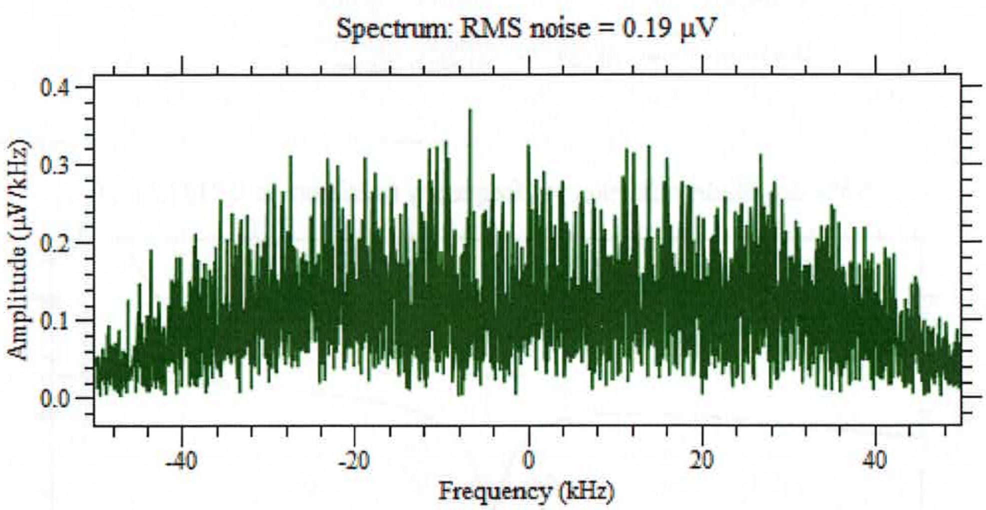


In this case the test probe shows a reasonable tune and match at 212 kHz. The sloping nature and low signal levels in this graph are caused by the drop off in power at lower frequencies from the RF amplifier.

Duplexer noise

The observed RMS noise from a 50 ohm resistor connected to the probe input at 300 kHz is shown below. The bandwidth is ~ 100 kHz

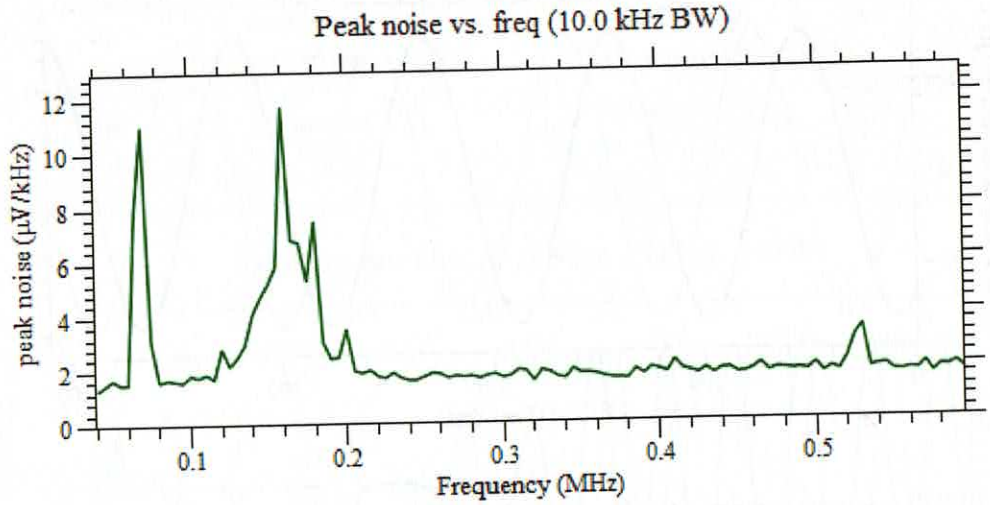




This is only slightly larger than the expected noise level of 0.14 uV.

Noise spectrum

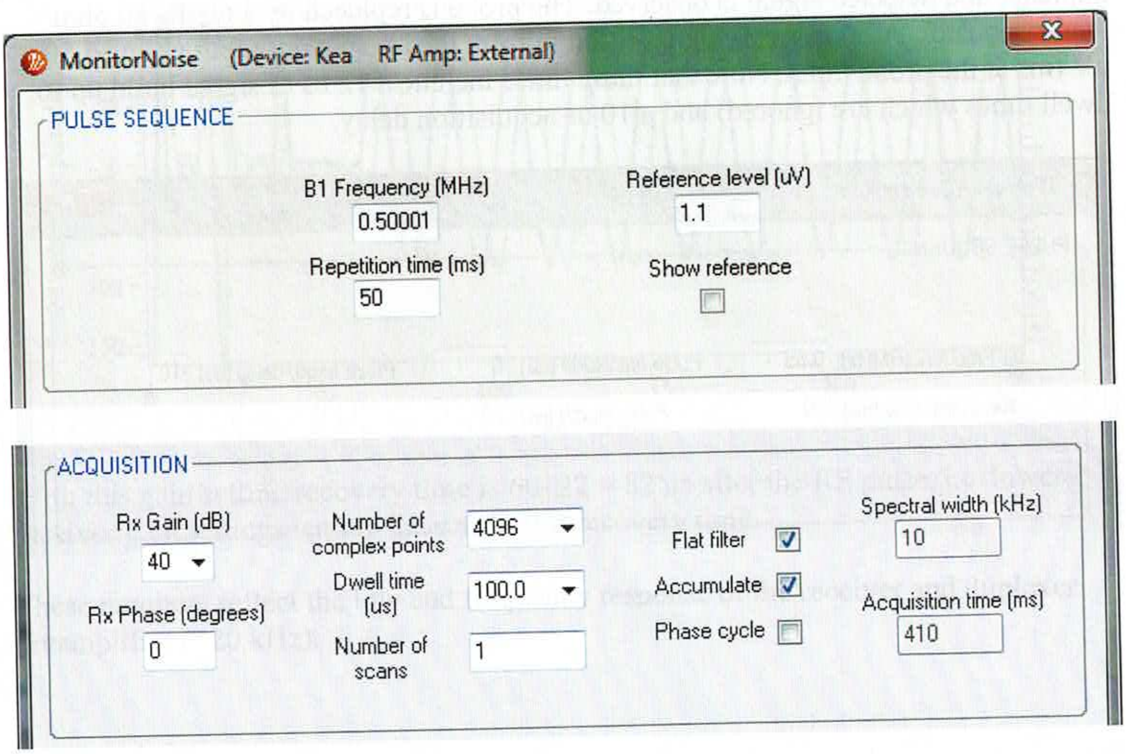
Although <0.2 uV was measured at 300 kHz, the noise will vary across the 40-600 kHz spectrum because this Kea is not designed to work below 1 MHz and so various power supply noise frequencies will be evident. The following plot shows the peak frequency domain noise over a range of frequencies for a stepped 10 kHz bandwidth.

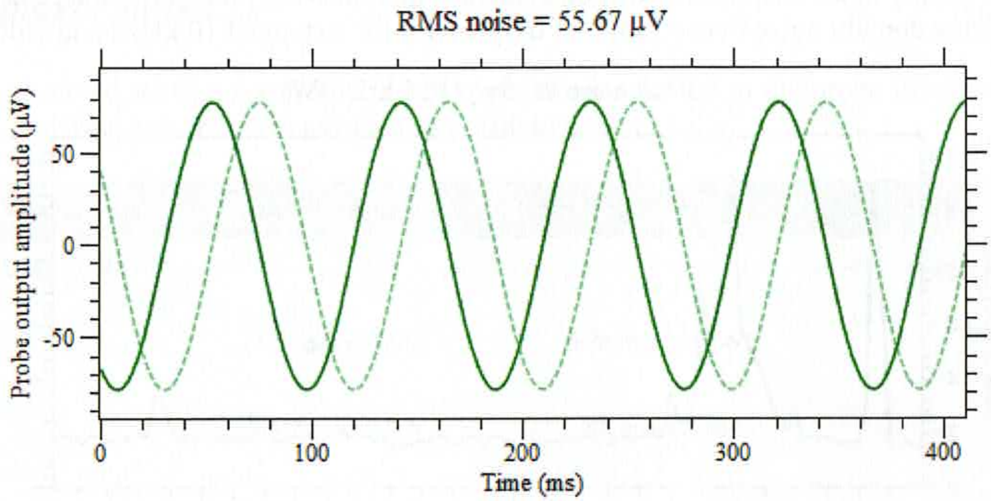


Based on this plot it is clear that the NMR frequency used should be chosen carefully if internal noise sources are to be avoided. 210 to 500 kHz looks fine.

Receiver sensitivity and calibration test

Here a 50.0 uV rms 500 kHz 50 ohm calibrated source is connected to the probe input and the monitor noise program is run.



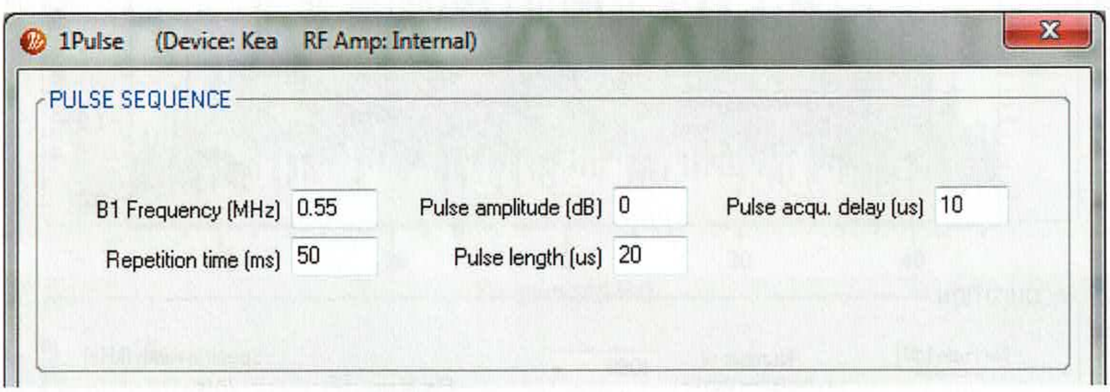


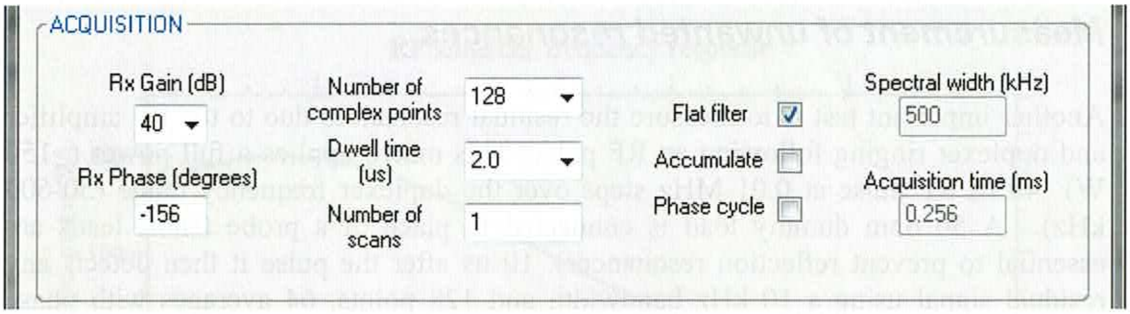
The 10% discrepancy from 50 uV is probably due to slight impedance differences between the duplexer input and the calibrated source (Keysight 33600A waveform generator + 20 dB attenuator)

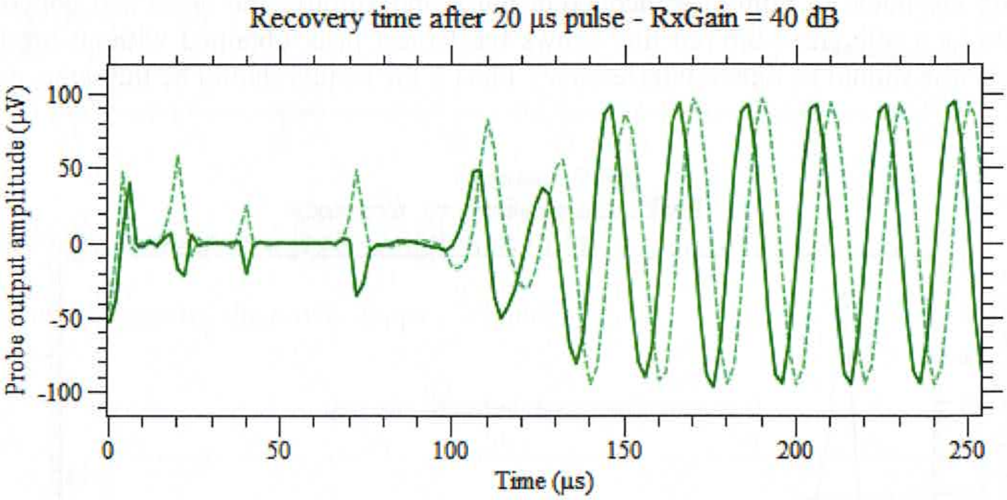
Receiver recovery time test

The recovery time for the receiver is the amount of time required following the RF pulse before an NMR signal can be detected without distortion. This is a combination of duplexer and receiver amplifier delays.

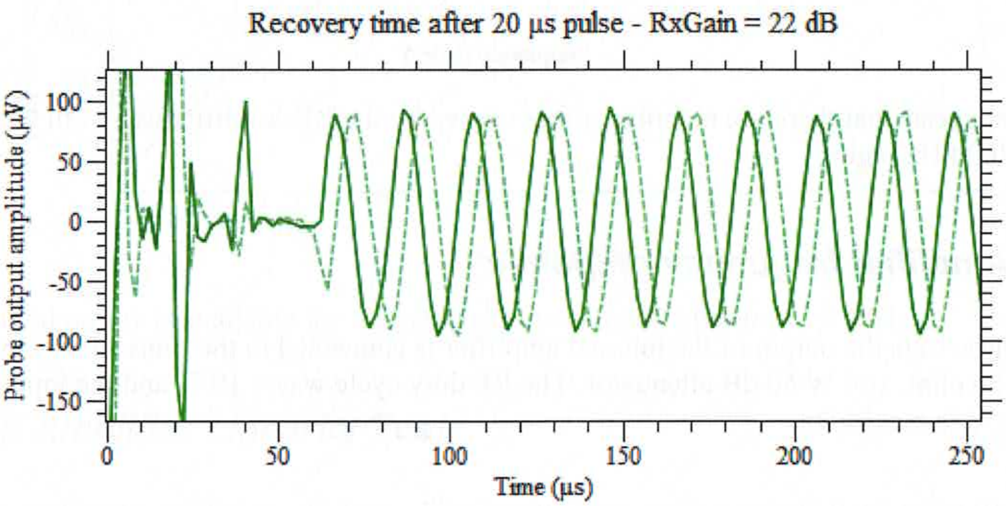
To measure the recovery time a 0 dB 20 us 500 kHz RF pulse is applied to the duplexer and detected signal is observed. The probe is replaced by a 60 dB 50 ohm load/attenuator. A 50 mV rms signal is fed in from the attenuator output giving a 50 uV rms at the probe input. Note that these times include a 12 us of signal build up (6 dwell times which are ignored) and a 10 us acquisition delay.







Here the recovery time is 140+22 = 162 us after the RF pulse

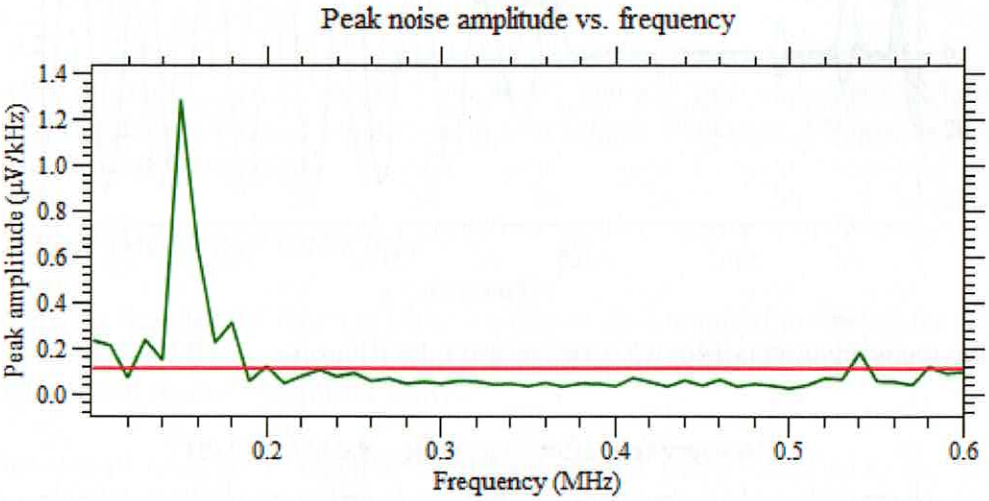


With this gain setting recovery time is 60+22 = 82 us after the RF pulse. i.e. lower receiver gain settings tend to have a shorter recovery time.

These numbers reflect the low end frequency response of the receiver and duplexer preamplifier (~20 kHz).

Measurement of unwanted resonances

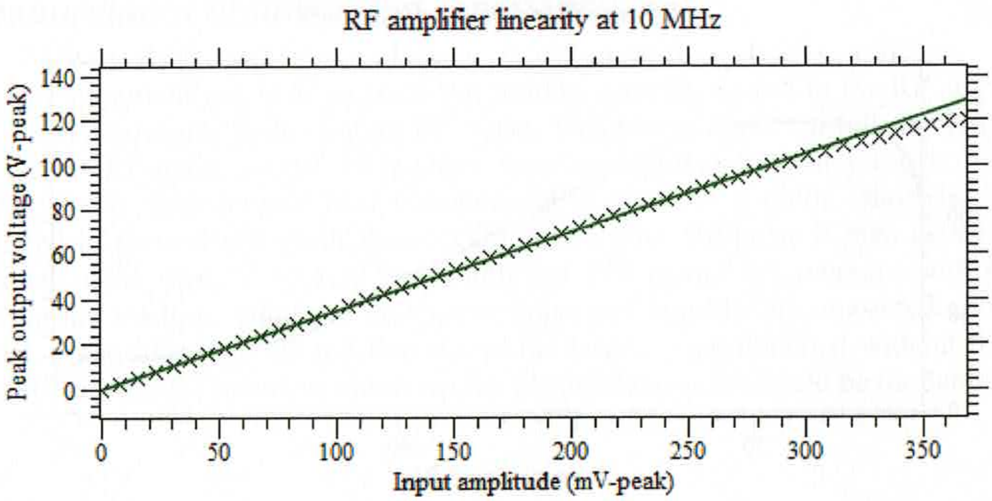
Another important test is to measure the residual resonances due to the RF amplifier and duplexer ringing following an RF pulse. This macro applies a full power (~150 W) 40 us RF pulse at 0.01 MHz steps over the duplexer frequency range (50-600 kHz). A 50 ohm dummy load is connected in place of a probe (short leads are essential to prevent reflection resonances). 10 us after the pulse it then detects any residual signal using a 10 kHz bandwidth and 128 points. 64 averages with phase cycling are made to minimise incoherent noise and amplify the unwanted coherent signal. As a reference, the red line shows the largest peak obtained without the RF pulse (these should be due to interference). Ideally the results should be the same.



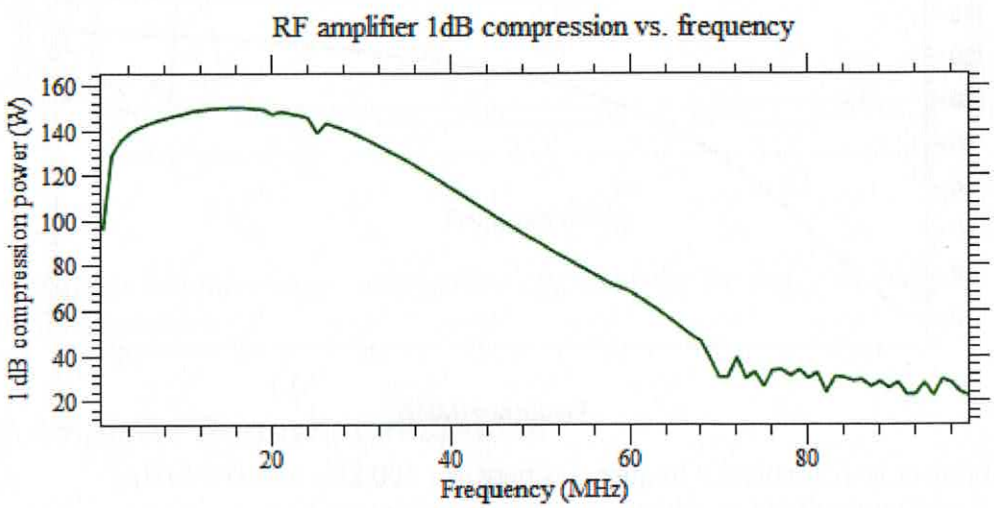
This suggests that there are no noise spikes caused by the RF amplifier except in the 100-200 kHz region.

RF Amplifier frequency response

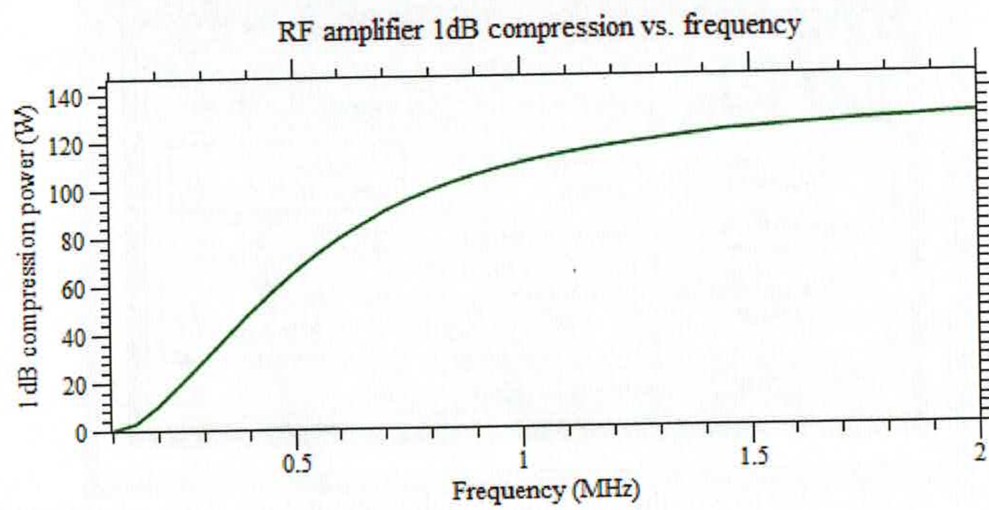
For these tests the output of the internal amplifier is connected to the transceiver input via a 50 ohm, 100 W 60 dB attenuator. The RF duty cycle was < 10 % and the input power was maximum.



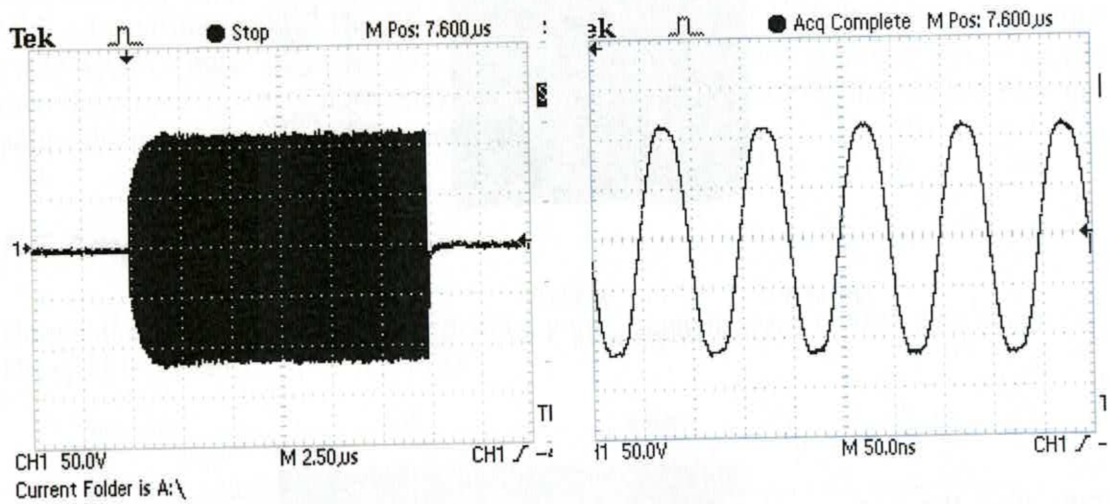
The output is reasonably linear for all input levels. Linearity at lower frequencies tends to be reduced and the 1dB compression points (i.e. when the RF amplifier gain drops by more than 1 dB from the linear fit) are shown below:



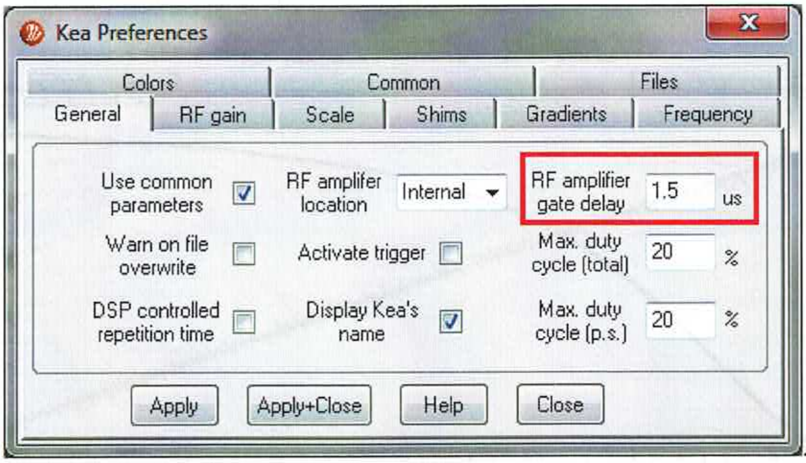
Again at low frequencies this drops off rapidly



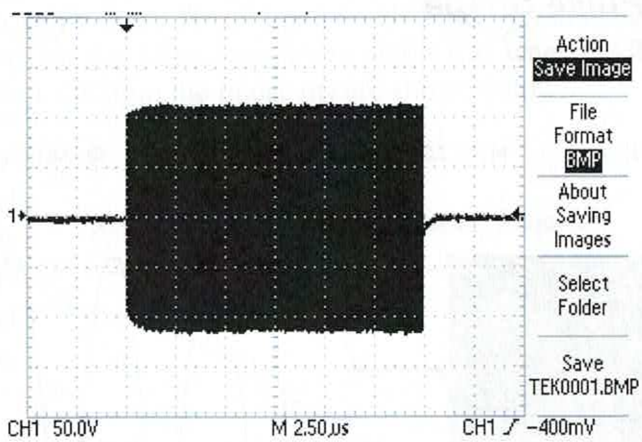
RF Amplifier Pulse Shape



This is the shape of a 15 us 10 MHz pulse (and zoom) as measured using a 100 W 50 ohm load with 40 dB attenuation. Input amplitude is 0 dB and output power is about 150 W. RF gate delay (pgo) is 1.5 us. Rise time is about 2 us.



By increasing this delay to 5 us the rise time (which is about 2 us) can be significantly reduced:

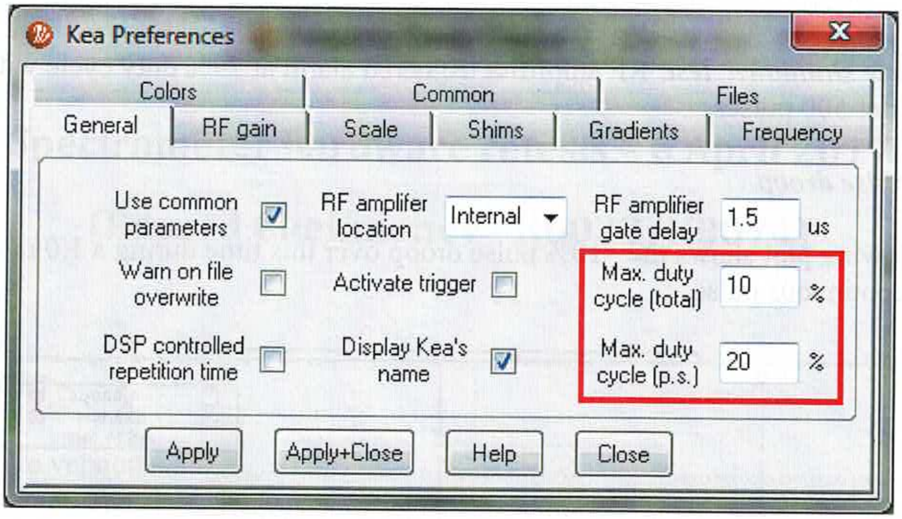


Pulse shape with 5 us RF gate delay

RF Amplifier Protection

Internally there is a 1.7 dB attenuator connected to the RF amplifier output which should protect it from large VSWR (e.g. open or short circuited output) if the duty cycle is low, however you should always endeavour to present a 50 ohm load to the amplifier by careful probe tuning.

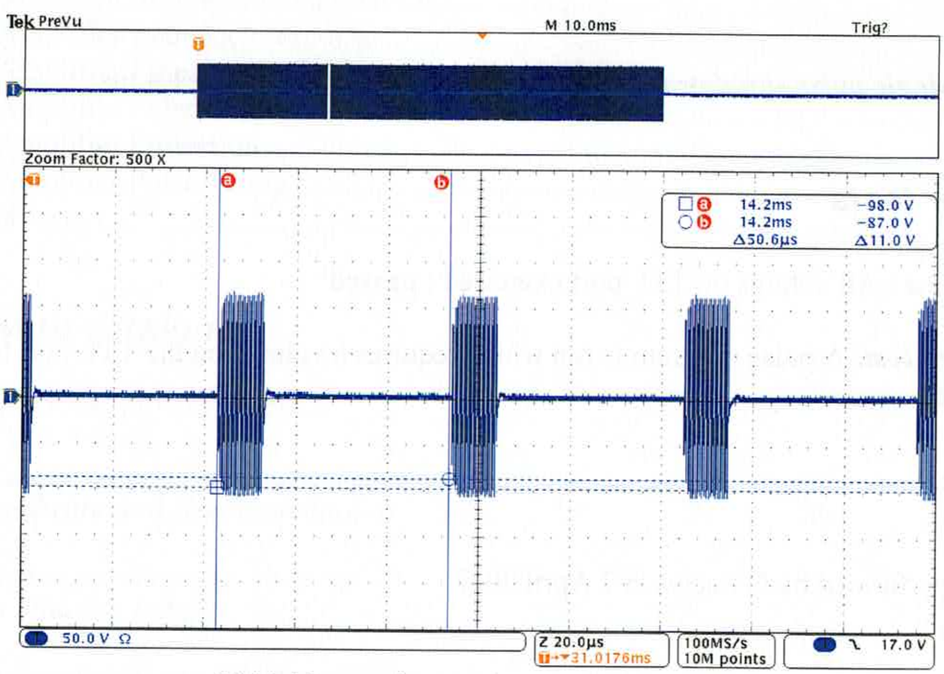
The *average* duty cycle should be kept below 10%. Higher duty cycles at high powers may cause the amplifier to overheat or shut down. A user defined maximum duty cycle can be set in the Kea preferences macro:



The RF amplifier has a built-in over-temperature switch. If the heat sink goes above 60 degrees C it will switch off the unit. If you suddenly find you have lost RF power and you have been running a high powered high duty cycle experiment for a while then this may be the reason. Just leave the Kea to cool for a while and then try again with a lower duty cycle. The RF amplifier also has a duty cycle detector. If the duty cycle within a pulse sequence goes over ~35 % or if any pulse is longer than ~ 1.3 ms then the output will shut down and a (loud!) alarm will sound. Switch off the Kea and adjust the pulse sequence to prevent this from reoccurring.

RF Amplifier Pulse Droop

Here is the RF amplifier output with 1000 pulse 10 us pulses at a 20 % duty cycle. Droop is less than 1% over this time

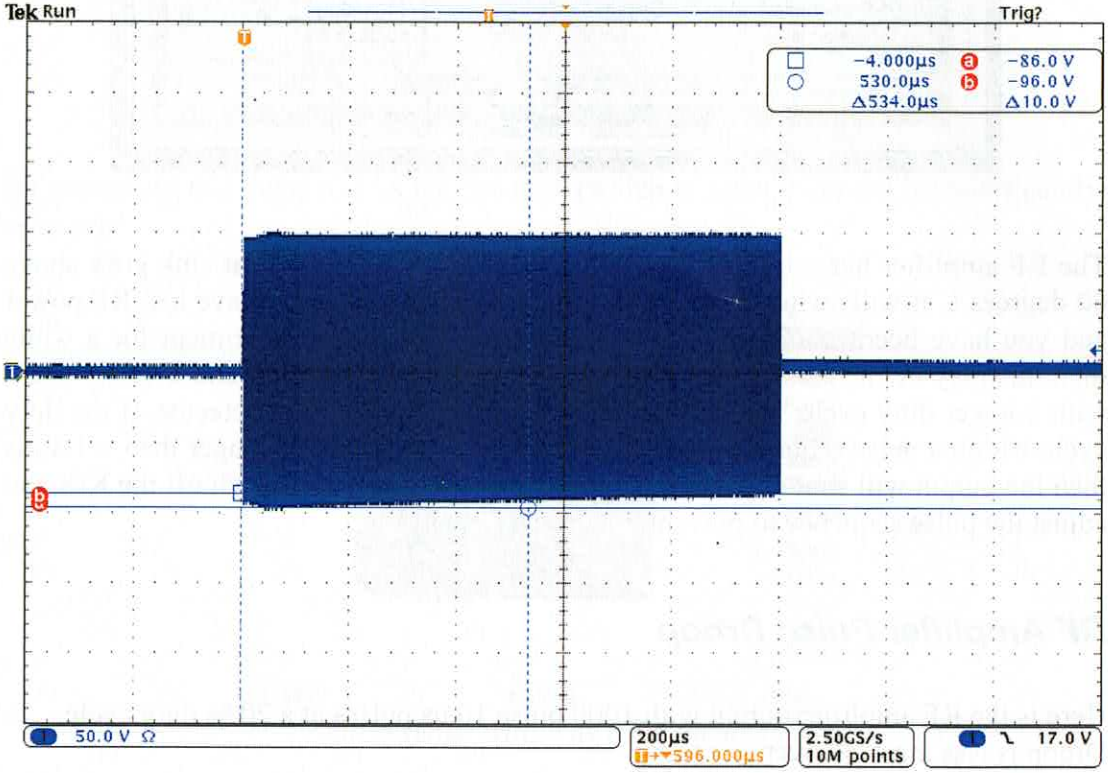


1000 10 us pulses and an enlarged view

Duty-cycle shutdown test: RF amplifier triggered alarm at 29% duty cycle with 20 us pulses after 500 pulses.

Single pulse droop

The following plot shows the ~10% pulse droop over this time during a 1.0 ms 1 MHz 100 W continuous pulse.



Long single pulse shutdown test: RF amplifier triggered alarm at 1.4 ms

Other tests

TTL Test : All outputs on TTL port exercised : **passed**

Trigger Test: A pulse program is run which requires a voltage on the TTL port to start : **passed**

Tests performed by C Eccles, 6/7 April 2017