Analysis of Readout Amplifier voltage and current noise.
SCUBA2 Multichannel Electronics Technical Report.

Mark Halpern, 6 Sept. 2003
Last Edit, October 1, 2003

Summary There are two plausible suggestions for a readout card preamplifier component, the AD797 which has a fast response time, but slightly high current noise, and the LT1128, which has lower current $1/f$ noise but is quite slow. Because Cable Johnson noise dominates the noise budget above 100Hz, and subtraction of the dark pixel signal eliminates $1/f$ noise below 100 Hz, the noise performance of these two amplifiers will be nearly indistinguishable in *SCUBA2*. The AD797 is therefore strongly preferred.

Introduction This note describes the noise performance of several brands of amplifier which have been proposed for use as the front end of the analog portion of the SCUBA2 Readout Cards. These preamplifiers will be at the front end of the Readout Cards, connected via approximately 2.5 metres of cryogenic cabling to a row of the SCUBA2 detector array. The detectors themselves are low impedance, but the round trip resistance of the cryo-cables is expected to be 350 Ωs, including a bit from the squid array output impedance. This is *not* a small number in this context. The output of the amplifiers is fed to a 14-bit analog-to-digital converter which operates at 50 MHz without interruption. The amplifiers should not dominate the noise budget.

In normal operation, a new column of the array is addressed every 1200 ns, switching the input to the preamp. This time is shorter than in the early designs of SCUBA2 in order to reduce sensitivity to out of band thermal noise. Digital samples collected during the system settling time are discarded. The remaining samples are co-added to form a single reading of a given detector pixcel. It is important that the amplifier has s settling time which is much shorter than 1200 ns. By settling time, we mean that the difference between a reading and the eventual value has dropped to be less than the noise. We believe that a settling time of 400 ns or less will be sufficient.

Ideally, these requirements would be captured in the MCE interface control document (ICD), but noise analysis of the whole system is not complete, and the effects of cable impedance were not included. Further, the readout timing has changed since the ICD was drafted. The ICD was written to require an amplifier with a performance at least as good as that of the *voltage noise* of the LT1028. (Actually, the LT1028 is not suited to non-inverting operation, so the LT1128 is evaluated below.) Because of the high cable resistance and the fact that the $1/f$ knee associated with current noise is typically quite high, only the amplifier *current noise* is important, combined with the Johnson noise of the cable itself. We have measured the response time of the LT1028, even at low gain, to be over 700 ns, so that amplifier is not suitable. For all these reasons, a quantitative analysis of preamp noise is called for.

Noise Model The LT1128 is a low noise amplifier with a $1/f$ knee in the voltage noise of a few Hz in selected units and a reasonably low current noise. The AD797 is a very fast low voltage noise amplifier with a higher $1/f$ knee, and higher current noise. It is widely used as a squid preamplifier, including its use in the NIST electronics. The noise parameters of these amplifiers are listed in Table 1.

Table 1: **Noise Properties of 'typical' LT1128 and AD797 units.**

Amplifier	Voltage Noise $nV/Hz^{1/2}$	$1/f$ knee Hz	Current Noise $pA/Hz^{1/2}$	$1/f$ knee Hz
LT1128	0.85	5	1.	250.
AD797	0.9	35.	2.	200.

The $1/f$ knee is the frequency at which the *noise squared* is twice the high frequency value, and we take the noise spectrum to be $1/\sqrt{f}$,

$$e^2(f) = e_o^2[1. + f_{knee}/f]. \tag{1}$$

The amplifier input current noise is converted to an equivalent voltage noise by the 'DC' resistance of the cryo-cables,

$$e^2_{current}(f) = i^2(f)R_{cable}. \tag{2}$$

Because of the high current $1/f$ knee, this term is the dominant low frequency noise.

In addition to these two terms, there will be thermal noise from the DC resistance of the cable. Only that portion of the cable which is warm, *ie* well above 4K, contributes thermal voltage noise. However, the thermal profile of the cables is such that *most* of the cable is nearly room temperature. We have taken the crude estimate that the thermal noise of the cables is that of a room temperature resistor 70% that of the cable itself.

$$e^2_{thermal} = 0.7 \times 4kTR_{cable} \tag{3}$$

where k is Boltzman's constant and T is room temperature. This term provides several nano-volts of noise and dominates over preamp *voltage* noise above 5 Hz. Without including this term, *neither* amplifier meets the ICD requirement for a low $1/f$ knee.

In the accompanying figure, voltage noise spectra are plotted for each amplifier type. These are much lower than the full noise estimates and are therefore nearly irrelevant for performance evaluation. The full noise estimates are also shown. They are essentially cable Johnson noise at high frequency and amplifier $1/f$ current noise at low frequency. The effective $1/f$ knees of the total noise curves are located at 7Hz for the LT1128 and 20 Hz for the AD797. For comparison, the equivalent voltage noise of a one volt, 14-bit AD conversion at 20 kHz is shown, assuming a total preamp gain of $G = 100$.

Every row of pixels contains a 'dark' pixel which is not exposed to the sky. Because this pixel is sampled within 25 μs of any other pixel in its row it contains an *identical* $1/f$ voltage. Subtracting the signal of this pixel eliminates $1/f$ noise, but adds Johnson noise in parallel since the cables associated with the pixels are different. A solid horizontal line in the noise spectrum indicates where, at low frequencies, subtracting the signal from the dark pixel improves noise performance. If there is any hesitation about 'using up' the dark pixel monitor in this way, a low frequency average of the whole row can be accumulated in firmware and passed to the DACs for this purpose.

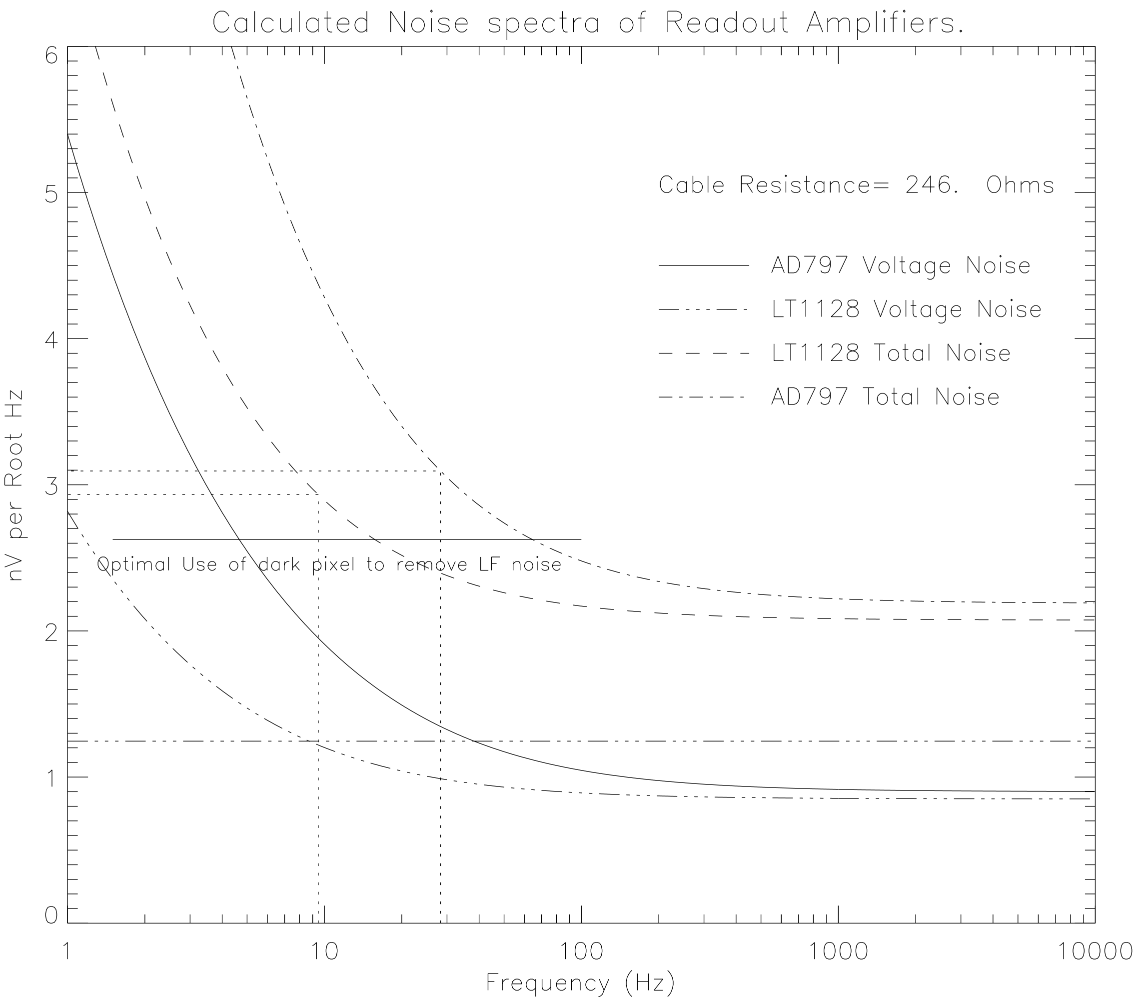

Figure 1: **Amplifier Noise** The models of voltage noise and of total combined noise as described in the text are plotted for LT1128 and AD797-based preamplifiers. The combined noise includes $1/f$ noise in voltage and current, amplifier white noise and thermal noise generated in the cryo-cable resistance. Because of the large cable resistance, thermal noise dominates at high frequencies and current $1/f$ noise dominates at low frequencies. The effective $1/f$ knees are at 9 Hz and at 28 Hz. The horizontal solid line near 2.5 nv/$\sqrt{\mathrm{Hz}}$ shows the upper limit to low frequency noise *after* using the 'dark' pixel to cancel amplifier noise. At high frequencies, where the noise lies below this level, signals from the dark pixel ought not to be subtracted from the other pixels.The horizontal dot-dashed line near 1.3 nv/$\sqrt{\mathrm{Hz}}$ is the power spectral density associated with a 1 Volt, 14-bit AD converter operating at 20 kHz after a gain of 100. It is shown for reference.