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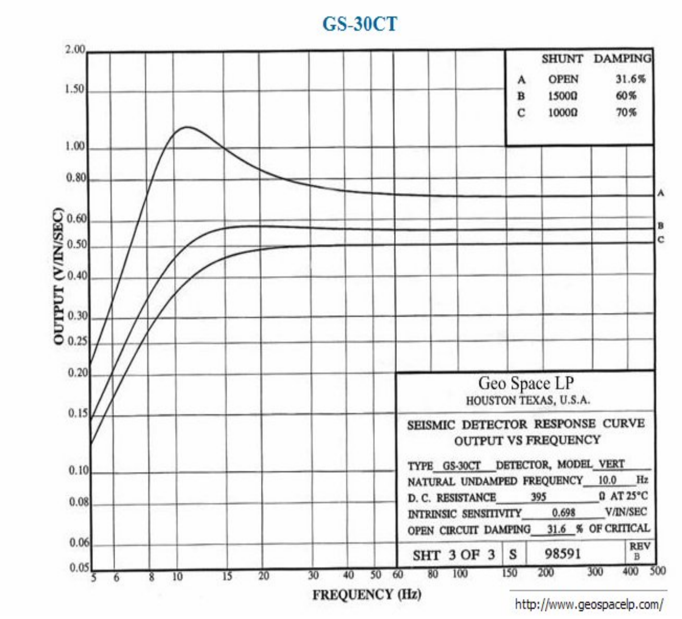
This article is prepared by Norman M. Cooper of Mustagh Resources Ltd. as part of a report on available instrumentation.

Excerpt from recent report on instrumentation:

Several systems have been developed using “Digital” Sensors. Typically, digital sensors use moving parts with stiff springs. Feed-back circuits apply discrete steps of force in an attempt to keep the moving part in a neutral position relative to a moving case or frame. The discrete feedback steps are applied through a delta-sigma network at a high cycle rate. The average of the over-sampled feedback steps forms a high-precision digital measurement of the sensor motion. Also, because of the stiffness of the springs, the output is usually proportional to sensor acceleration. Due to the stiffness of the springs, measurements of seismic frequencies are made below the resonant frequency of the sensor and the response is relatively flat even in to very low frequencies.



It is often claimed that analog geophones are the reason that we have not been able to recover very low frequencies in seismic data. We feel this is a very misleading comment. While it is true that a digital sensor will have a relative amplitude about 12 db stronger than an analog sensor at 5 Hz, this is not an insurmountable loss. Deconvolutions routinely recover high frequencies that are attenuated by 30-40 dB by attenuation. It is reasonable to assume the same deconvolutions can recover our low frequencies even if they have been attenuated by 12 to 24 dB (5 Hz or 2.5 Hz).

What many authors forget is that in order to recover the amplitude and phase of low frequencies, we typically depend on deconvolution algorithms. These algorithms use auto-correlations and cross-correlations in the design of wavelet stabilization operators. It is well known that auto-correlations and cross-correlations require at least 6-8 cycles of input signal in order to have meaningful output. Imagine a geologic section with typical reflectivity (perhaps the section of Cretaceous rocks, for example). If this section has a two-way time thickness of 1.2 seconds, and if we require a minimum of 6 cycles of signal to represent this geologic section, then the period of each signal would be a maximum of 200 ms. This corresponds to a frequency of 5 Hz. For this reason, it is unlikely that we will be able to process stable seismic signals for typical geologic sections at frequencies less than 5 Hz. Therefore, at ***useable*** seismic frequencies, there is not a significant difference between digital and analog sensors with respect to low frequency recovery.

Digital sensors are more sensitive than analog geophones. However, our limit in recovering weak signals is normally the level of ambient and source-generated noise. Noise levels in normal seismic data are typically 40 to 70 dB below peak signal levels, while the dynamic range of either digital or analog geophones lies far below that (more than 100 dB). Therefore, the sensitivity of our sensors is not the limiting factor in signal recovery and differences in sensitivity between digital and analog sensors will not have a significant impact on our results.

The mass of the moving components of an analog sensor is quite large compared the mass of the moving wafer in a digital sensor. This means that the motion of an analog coil has greater momentum and inertia compared with a digital sensor. A small mass (such as a drop of dew) hitting a geophone will cause a relatively long duration pulse (perhaps 40 ms) of low amplitude. The same small impact on a digital sensor will result in the same energy over a very short period of time. On digital sensors, droplets of dew falling on the sensor can cause very high amplitude spikes that last only one or two sample intervals. It has been demonstrated many times that digital sensors can be very noisy in some environments, partly due to low-inertia phenomenon.

Analog sensors are usually used with several sensors connected in a series-parallel configuration along a wire. This allows us to use large receiver intervals suitable for capturing signal wavelengths. Typical apparent wavelengths of signal are 60 meters to infinity and 20 to 30 meter recorded trace intervals are sufficient to preserve such wavelengths for processing. However, we also observe much shorter wavelengths of noise due to interacting reverberations and scattered surface waves. Overall, various noise modes tend to occur over a range of wavelengths from infinity down to very short wavelengths (less than 2 meters). If short wavelengths of noise are not properly measured and filtered, then they will alias around the Nyquist wavelength of [2 x recorded trace interval] and will contaminate our desired reflection signals. The distributed analog array serves to sub-sample the normal receiver interval sampling and the averaging of the outputs of the array elements creates a filter that attenuates shorter wavelengths that would otherwise alias. The use of an analog array of elements is an extremely important part of discrete sampling of earth signals. If distributed arrays are replaced by single sensors or bunched geophones, then the recorded receiver interval must be reduced to avoid aliasing of poorly sampled short wavelengths of noise.

Jon Tessman and others have shown that recording 3-component sensors, even though at sparse intervals, will allow adaptive filtering of ground roll because it has a recognizable signature of changing shear and compressional behavior. This is generally true, but it only applies to complex waves such as ground roll (which is relatively long-wavelength). The same algorithms are not effective for single mode noise waves such as compressional direct waves, shear direct waves or air blast. Nor are these algorithms effective to suppress short wavelength interactions and chaotic scattered waves.

Our recommendation is that if single-sensor recording is implemented then planned receiver intervals must be reduced by at least a factor of 3. For example if arrayed geophones are used to produce a recorded trace at a 30 meter receiver interval, then single sensors should be used only if the recorded trace interval is 10 meters or less.

One of the modern recording systems that is in popular use in the Middle East is WesternGeco's Q-Land system and its more recent evolution, the Uni-Q system. The latter system can record up to 150,000 channels. The sensors are digital output units consisting of 18Hz stiff-spring accelerometers with an electronic feed-back loop to produce digital output signals. Each sensor is recorded as a single sensor and no analog arrays are used. However, their digital sensors are usually deployed with 6.5 meter in-line spacing with 4 parallel lines staggered and separated by 6.5 meters. Later, in processing they perform digital group forming, producing a single trace every 25 meters. However, in the digital group forming, they use the closely spaced individual sensors to first perform noise suppression and correct for elevation statics, then they do the array forming. Again, sub-sampled groups are used to manage the noise, and then form larger trace intervals suited to the expected longer wavelengths of signal.

One other consideration is the coupling of the digital sensors. Usually a small gas-powered drill is required to pre-drill a hole in the ground where the sensor will be planted. (Note that this process offsets some of the perceived benefit of lighter sensors and faster planting.) The hole is slightly smaller than the sensor. The sensor is then pressed into the hole. While this procedure often produces good coupling, we must remember that coupling is a function of mass per unit of surface area in contact with the ground. Some sensors are made light in weight for easier transportation when hand-carried. The contact surface area of the digital sensors is considerably larger than for conventional geophones with spikes. Better coupling will be obtained due to the increased surface area, only provided that the weight of the sensor increases at least proportionally or if the pressure of pressing the sensor in the under-sized drilled hole exceeds the force of the equivalent weight. This will not happen in very soft earth or water-saturated materials.

Therefore, if digital sensors are to be a part of the equipment mix purchased by a company, then we strongly encourage the use of much smaller receiver intervals for the portions of lines where digital sensors are to be used. This will require the purchase of more channels.

For more information, we encourage the reader to review two recent articles in the CSEG Recorder (March 2010, Volume 35, Number 3). These articles will soon be available in digital form from the CSEG website (www.cseg.ca). One shows the value of recording short-wavelength noise and is entitled “Looking beneath the noise: experience with high-resolution seismic acquisition and pre-stack processing” by David Henly, Malcolm Bertram and Kevin Hall of the University of Calgary. The other article of interest in the same issue is “The influence of spatial sampling on resolution” by Mark Egan, Joe Seissiger, Atoun Salama and George El-Kaseeh.