Addendum 1

- **Comments on Processing Frequency Selection Effects on Array Size and the Presence of Background Noise**
- **Adaptive Spatial Processing vs. Conventional Beam forming**
- **Tri-axial UGS sensor vs. Army Boomerang sensor unit for SBIR TOPIC NUMBER: H-SB011.2-001**

Summary: Determining the bearing and elevation of a target at lower frequencies with the same accuracy as can be done at slightly higher frequencies in a lower noise field comes at the expense of larger arrays and more signal processing. Signal loss due to spreading and absorption may be significantly less at frequencies below 500 Hz, but there is significant impact in the assumption holding the array gain constant when deciding to process this frequency range. Field data taken against ultra-light aircraft to date indicate there are significant, higher frequency source levels above 500 Hz which are far more practical to exploit for added array gain and smaller element spacing.

Discussion on Processing Frequency Selection Effects on Array Size and the Presence of Background Noise: Figure 1, derived from ISO 9613-1 and ISO 9613-2 data, indicates that for a given source level at various frequencies, one would expect significantly longer detection ranges when monitoring lower frequencies when the array gain (element spacing and array size are consistent with frequency) is held constant.

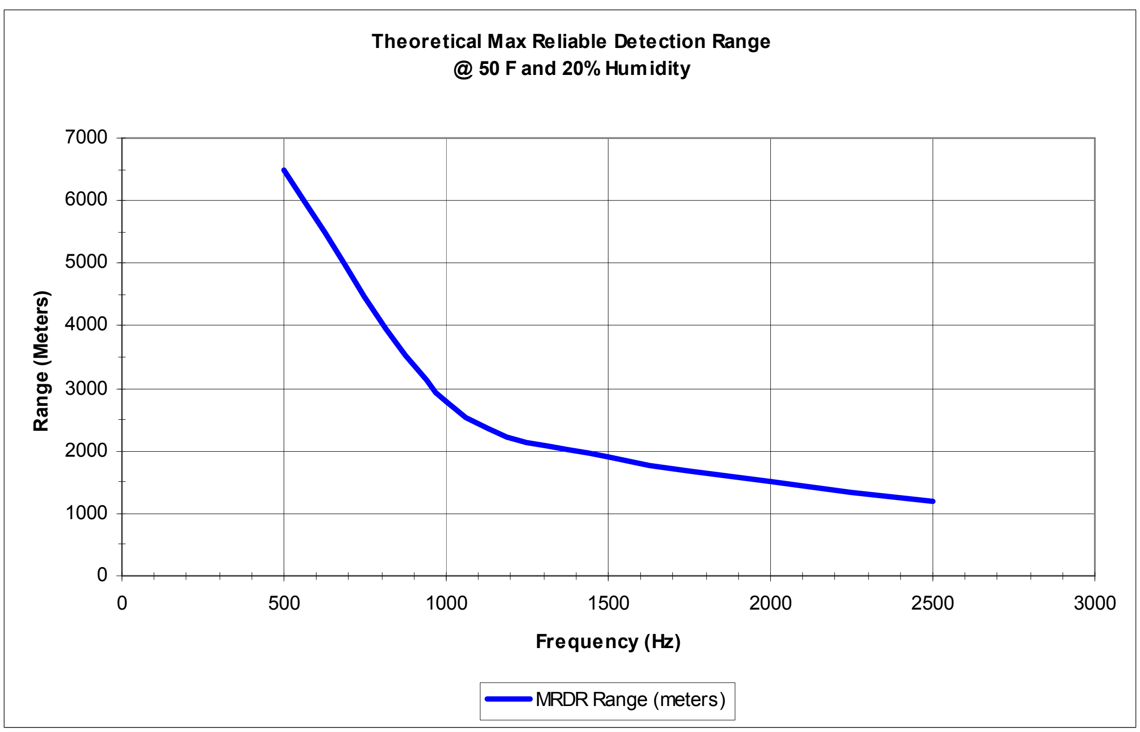

Figure 1 – Maximum Reliable Detection Range given constant array gain vs. Frequency

This chart is based on the assumptions that source levels at the various frequencies are uniform, with uniform temperature and humidity, and the same array gain at each frequency. It also assumes the noise field across the acoustic spectrum from below 500 Hz to above 3000 Hz is uniform. This background noise assumption is known *not* to be true, as there is significant wind and other environmental noise at frequencies below 500 Hz that is not present at slightly higher frequencies.

One of the most significant assumptions in the chart in Figure 1 is the assumption regarding uniform array gain in terms of the practical impact on the size of a fielded unit. As the frequency becomes lower, with longer wavelengths, the array elements must be spaced at greater distances apart to maintain the same array gain with an equal number of elements present. For example, the SAS-1 traffic sensor used for the initial field studies has an array aperture sized for a 6000 Hz response with approximately 1" microphone spacing. This 8" x 10" array provides 16 dB of gain. At 500 Hz, the aperture for the same amount of array gain would be 96" x 120", and would double again in size to similarly process 250 Hz. Arrays this large are not practical to field in a portable fashion.

Even in the face of the significant background noise field due to wind and other environmental sources below 500 Hz, one could argue that eliminating array elements and shrinking the array to practical size, while significantly reducing the potential array gain, may be allowable given the significant margin available from lower absorption and spreading losses. Detection, meaning determining that a potential source level is above the detection threshold, is only part of the problem. As important is rapidly developing a target track, as the target movement can be used to quickly determine the validity of the target vs. false detections. This is where the advantage of adaptive spatial processing (SAS-1 Patent) compared to conventional beam forming proves to be of great importance. The proven technique of adaptive spatial processing enables longer range detections at higher frequencies, and far more accurate bearing and elevation resolution, using smaller arrays.

Comparison of Conventional processing vs. Adaptive Spatial Processing

In Figures 2 and 3, the conventional beam patterns developed by processing the signals from three separate sources (potential targets or interferers) are shown in red for 2000 Hz and 1000 Hz. Given a desire to provide as small an array size as possible, the array number of array elements is cut down and the spacing is optimized for the respective frequency.

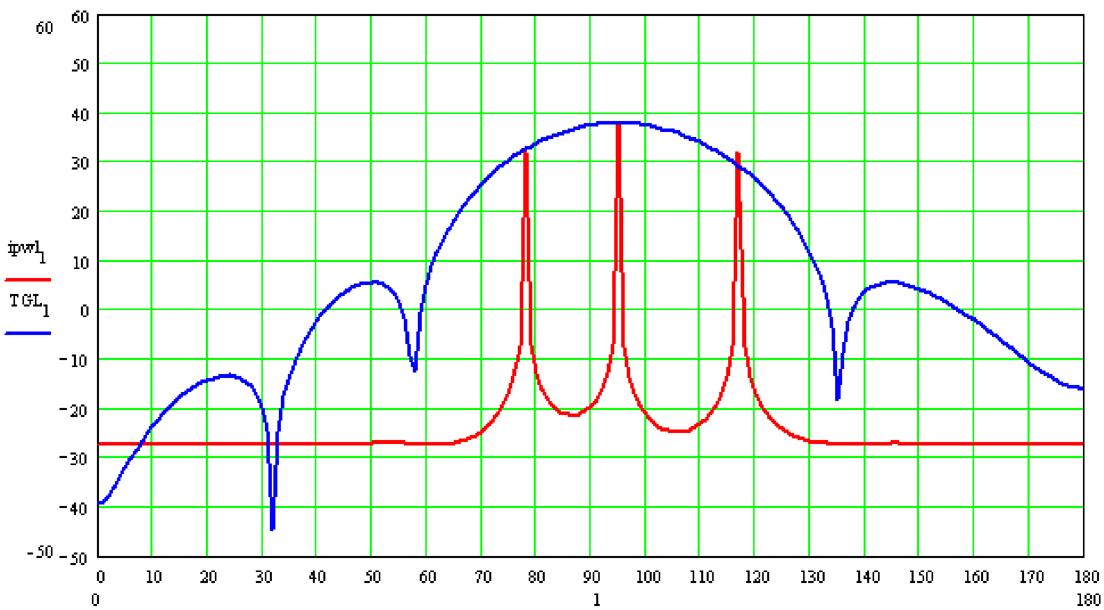

Figure 2: Three sources at 2000 Hz using an 8 element array with 3 inch spacing. The Blue curve is shows results of conventional beam forming; the Red curve shows results of patented adaptive spatial processing

For a 2000 Hz array, the array elements would have to be three times farther apart than the 6000 Hz array used in SAS-1. **Figure 2** shows the conventional response pattern to the three sources given eight elements with 3" spacing reflecting the longer wavelengths present at 2 KHz. Notice that the blue curve showing the main response to the three contacts is over 70 degrees wide, with none of the 3 contacts individually identifiable within the 70 degree main lobe. Contrast that with the very distinct response to the three sources centered at approximately 78 degrees, 95 degrees and 117 degrees, respectively shown on the adaptive spatial processing curve at the same source level and distance. A track can quickly be developed on three separate targets using this data while the conventional processing response in almost useless for other than a general sector alert.

Keeping the same array size by using 4 elements with 6" spacing when processing the three sources at 1000 Hz provides the blue curve in Figure 3. Notice the very broad response over the 180 degree aperture. Essentially, the only real information gained would be the knowledge that there is something above background level in the frequency of interest on a particular side of the array.

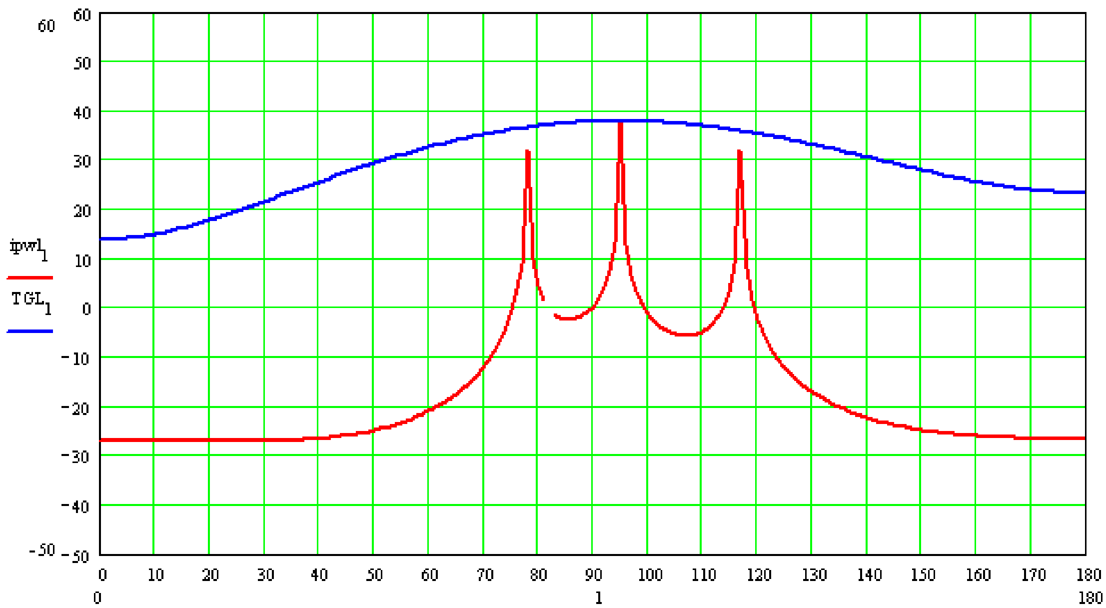

Figure 3: **Three sources at 1000 Hz** using a 4 element array spaced at 6 inches, blue conventional beam forming, and red adaptive spatial processing.

The red adaptive spatial processing curves in the two charts clearly show the respective bearings for each of the three separate sources. Notice that the "look directions" developed are about a degree wide compared to the very broad lobes of the conventional processing. This is true not only at 2000 Hz, but for the three sources at the lower 1000 Hz as well.

Though suffering some signal gain loss due to the smaller number of elements at the lower frequency, **Figure 3** clearly shows distinguishable sources against the background levels which are at least 35 dB less than the conventional signal processing.

With inputs from adaptive spatial processing, one can rapidly develop a track to targets of interest at lower frequencies given a smaller aperture and fewer elements than conventional beam forming would allow. Holding the frequency above 1000 Hz also allows us to significantly reduce the effects of wind and other environmental noise present at lower frequencies without additional signal processing.

UGS Low Power, Tri-axial Acoustic Sensor: The discussion of the SBIR topic in DHS Science and Technology (S&T) Directorate SBIR TOPIC NUMBER: H-SB011.2-001, with the objective to develop an affordable directional acoustic sensor that can be employed with a UGS unit to track targets of interest, has comments about the need to have line of bearing and track information integrated into the current UGS units. The task description contains the following comments:

> With the current deployment of single channel microphone UGS units, tracking information would have to be realized from the use of multiple UGS units and correlation of the individual information from them. Deploying multiple UGS

> units entails an operational impact and it is desirable to be able to develop a track solution from a single UGS.
>
> A low cost, low power, acoustic sensor that can provide directional information in both heading and altitude (for aircraft) and which can be integrated with existing UGS units is desired. It should be noted that the acoustic signature of some types of targets is narrowband in nature such that correlation processing of multiple acoustic sensors at the UGS site is not deemed viable (i.e., Army's Boomerang sensor unit).

One of the questions and responses to the DHS SBIR TOPIC NUMBER: H-SB011.2-001 was a Question 18 dated 6.14.2011:

> Question: With regard to the tri-axial acoustic sensor topic, what is the total frequency range of interest to be covered by such a system?
>
> Answer: The frequency band of interest is <500 Hz.

Inherent in the response to the question regarding the signal band of interest may be an assumption that there is significant ULAD target signal level at less than 500 Hz to be exploited. This has neither been confirmed nor denied by our testing to date. Knowledge of environmental factors gained from highway and other application processing told us not to develop a target data set for this frequency range. We have purposely heavily filtered this lower frequency range due to the significant noise field present below 1000 Hz and the significant array size reduction accomplished by using slightly higher frequencies and adaptive spatial processing. Sources levels may be higher or lower than the mid-level bands tested to date for the targets of interest. Given the potentially longer propagation ranges present at lower frequency, the uninitiated would argue that this band should be used. We have found the appropriate array design for mid frequencies exhibited by the ULAD targets allows for a very small array to be fashioned to exploit the target signature, and the practical experience dictates that these potential longer ranges suffer from similar line of sight and interference issues one encounters by using high frequency radar against such low-cross sectional area targets of interest flying close to the surface of the earth.

Narrow Band tracking comment: For those individual frequencies that may be exploited from a known target signature, the general narrow band detection and tracking problem adds additional signal processing and target track development time when used. Given the existing timelines to detection of ultra-light aircraft carrying contraband short distances over the border, there may not be time to develop significant target alerts and tracks using automatic narrow band tracking algorithms.

Our understanding of the Boomerang processor is that it does not have the elements necessary for the adaptive spatial processing described above, nor the array gain or spacing for significant low frequency directional processing. The comment about the undesirability of correlation processing of multiple acoustic sensors in the DHS SBIR TOPIC NUMBER: H-SB011.2-001 request is well founded, and in effect, confirms the discussion of large aperture requirements necessary for conventional beam forming to be viable in the field processing environment. The correlation processing mentioned is at the price of a significant power, inter-unit communications or processing budget that is not required when a properly sized array designed for adaptive spatial processing is present. The request for a

> A low cost, low power, acoustic sensor that can provide directional information in both heading and altitude (for aircraft) and which can be integrated with existing UGS units is desired. . . . . A tri-axial acoustic sensor would provide the desired functionality for operating near the border. In order for a tri-axial acoustic sensor to be reasonable for employment, the cost of the sensor can't greatly increase the overall cost of a deployed UGS units. Commercially available UGS units may range in cost from $2K-$10K depending upon the vendor. A tri-axial acoustic sensor also should not increase the power consumption of the UGS markedly either. Sensor power consumption should be on the order of three times that of a microphone sensor (ignoring increased processing requirements) when all three channels are used. The bandwidth of the directional acoustic sensor should be great enough to capture the acoustic signature of the different types of targets.. . .

is essentially for development of a sensor similar to the SAS-1 in its current form to provide a module for "line-of-bearing and track information in near real time . . . for the Border Patrol (BP) to determine where a target engaged in illegal activity may be headed." Adaptation of the front-end array (microphone elements) of the SAS-1 processing capability is essentially the description of what is necessary to accomplish what is necessary in the DHS SBIR request.