High Range Resolution Profile Generation Using Sensor And Signature Simulation

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Abstract

Sensor and Signature Simulation (SASS), is a simulation which was developed for the National Missile Defense (NMD) Ground Based Radar-Project Office (GBR-PO) to produce Radar Cross Section (RCS) and target signatures. It is utilized within the NMD-GBR Hardware in the Loop (HWIL) Test-bed, as well as the THAAD Radar Test-bed. Target High Range Resolution (HRR) profiles generated by SASS are used to emulate and execute tactical radar operations. Target models are built up from simple component types, such as flat plates, frustums, spheres/spheroids and fins whose known radar signature is characterized in terms of scattering centers. The radar signatures of the complete target model are determined by reducing the target to a list of effective scatterers. In this paper, we will show how to build and execute targets using SASS, and how to generate the corresponding HRR Principle Polarization (PP) and Orthogonal Polarization (OP) range profiles. Comparisons with real world, and other models (such as Xpatch), will be used as a means of validation. The most important attribute of SASS is speed of execution. Additionally, it is quite easy to build and execute targets using SASS. Wide Band (WB), NB, and HRR -PP and -OP profile examples will be used.

I. NMD GBR HWIL Test-bed Block Diagram [1]

Figure 1 shows a block diagram for the NMD-GBR HWIL Test-bed.

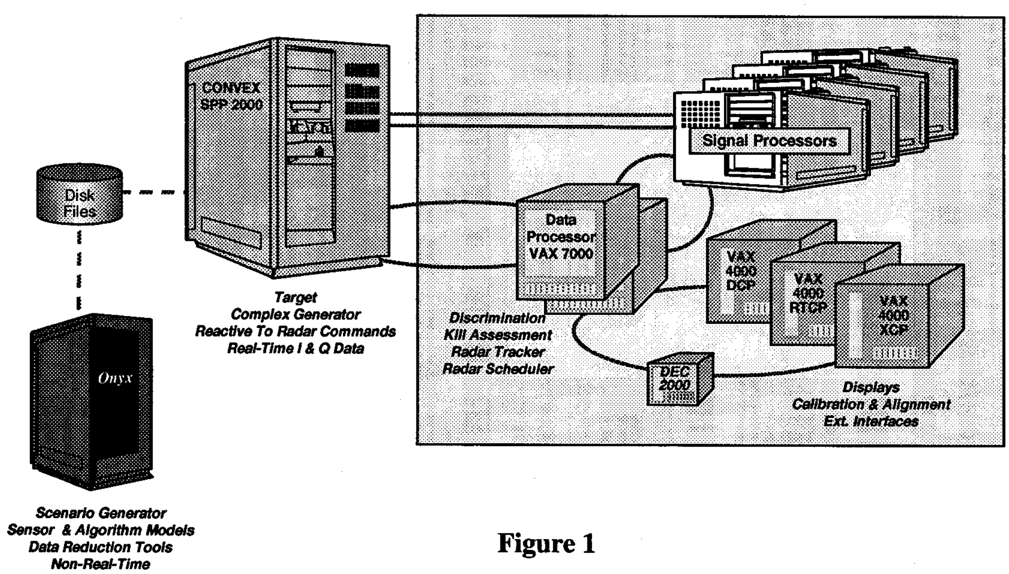

Figure 1

The Target Complex generator (TCG) was developed to digitally simulate the antenna, Beam Steering Generator (BSG), transmitter, waveforms, receiver and Analog to Digital (A/D), of the tactical radar in all three monopulse channels. The TCG provides the required signals to the Data Processing Equipment (DPE), via a Fiber optic Digital Data Interface (FDDI), and to the Signal Processing Equipment (SPE), via a High Performance Parallel Interface (HiPPI).

II. SENSOR AND SIGNATURE SIMULATION (SASS) [2-5]

SASS contains models of the GBR radar signal and data processors to provide for an all digital simulation of the radars. SASS provides high fidelity representation of modern high frequency, coherent chirp radar. All digital models within SASS are systematically constructed and executed, through a user friendly set of graphical user interfaces (GUIs). The GUIs also allow for extensive generation and graphical display of targets, engagement and signatures. This includes, three-dimensional (3-D) static and dynamic target representation, target scattering static patterns, radar engagement (range, altitude, aspect angle, etc.) histories, RCS and phase histories, stacked narrow band, medium band and wide band compressed pulse shapes and measurements. Sensor error analysis are also available. Figure 2 contains SASS external interface block diagram and shows the host and interfaces for the SASS application.

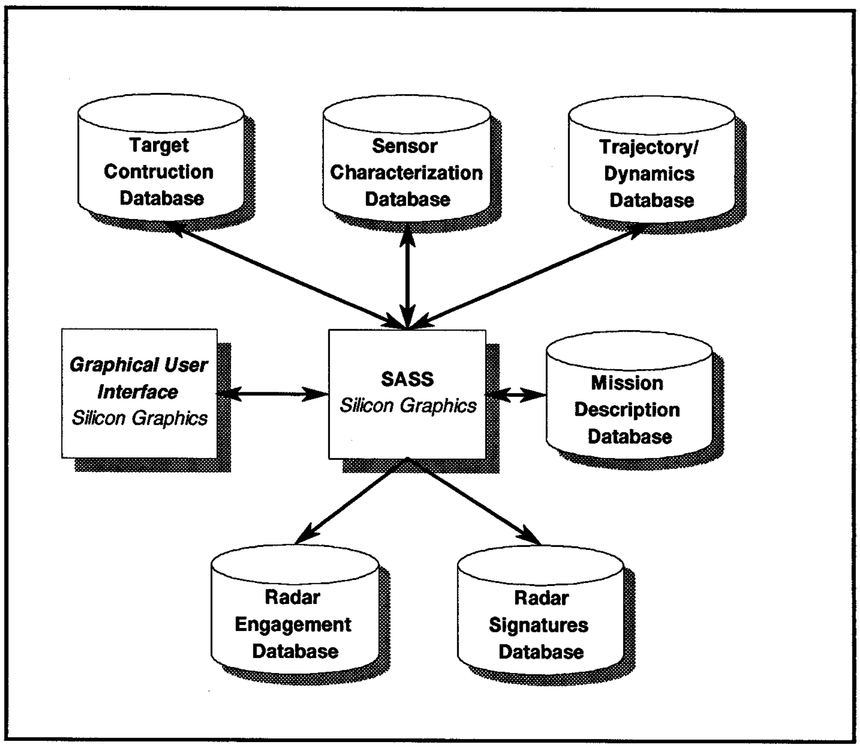

Figure 2

Target models are built up from simple component types, such as flat plates, frustums, spheres/ spheroids and fins whose known radar signature is characterized in terms of scattering centers. The radar signature of the complete target model can then be determined by reducing the target to a list of effective scatterers, complex amplitudes and their positions as projected along the radar line of sight. The most important attribute of SASS is speed of execution. For example, using a Silicon Graphics O2 machine SASS produces an output in less than three seconds, even for the most complex targets. Additionally, it is quite easy to build and execute targets within SASS

Scattering center characterization describes the processing necessary to determine where the effective scattering centers of the target are located and in what manner they contribute to the radar signature. This capability involves the determination of visible scattering centers and the corresponding complex electromagnetic scattering amplitude. This characterization calculates the complex electromagnetic scattering amplitude using an extension of the scattering center approximation developed by Crispin and Maffet. In this approximation the targets are first broken up into geometrical sub-elements, then Physical Optics (PO) is used to calculate the contribution from surface returns of the sub-elements and the Geometrical Theory of Diffraction (GTD) is used to calculate the diffraction contribution from the joints and edges of these sub-elements. The PO returns are calculated for surfaces perpendicular to the line-of-sight, where PO is a good approximation, and GTD is not. For the other cases, GTD is used. Since our radar has a monostatic arrangement, the GTD returns come only from points on the edges where the edge is perpendicular to the line of sight. Thus, both the PO and GTD returns are equivalent to returns due to effective scattering centers, located at the surface edges for PO contributions and located at the edges/joints nearest to the radar for GTD contributions. With SASS, the calculations are taken one step further, the remaining unshadowed scattering centers are then summed coherently (taking into account the distances from the radar of each scattering center along the radar line-of-sight), giving a total complex scattered return towards the radar. From this, the target RCS is calculated.

Figure 3.a shows a typical generic target (Re-entry Vehicle (RV)) constructed using SASS, while Figure 3.b shows the corresponding Narrow Band (NB) RCS (dBsms) at X-Band versus aspect angles (degrees). Figure 3.c Shows the corresponding Wide Band (WB) target signature at the same frequency.

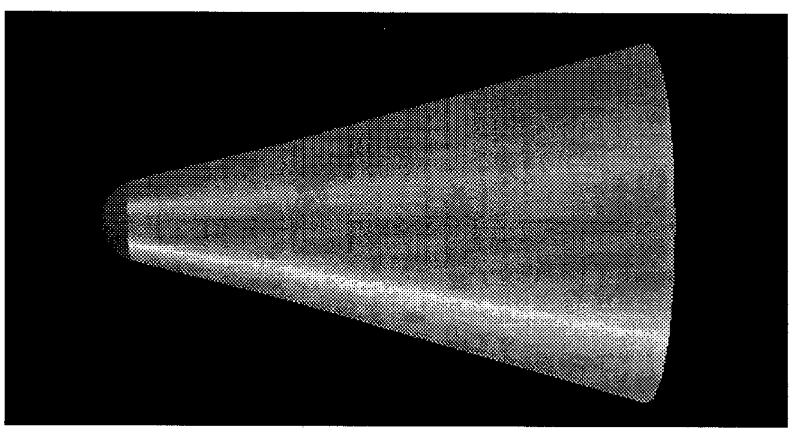

Figure 3.a

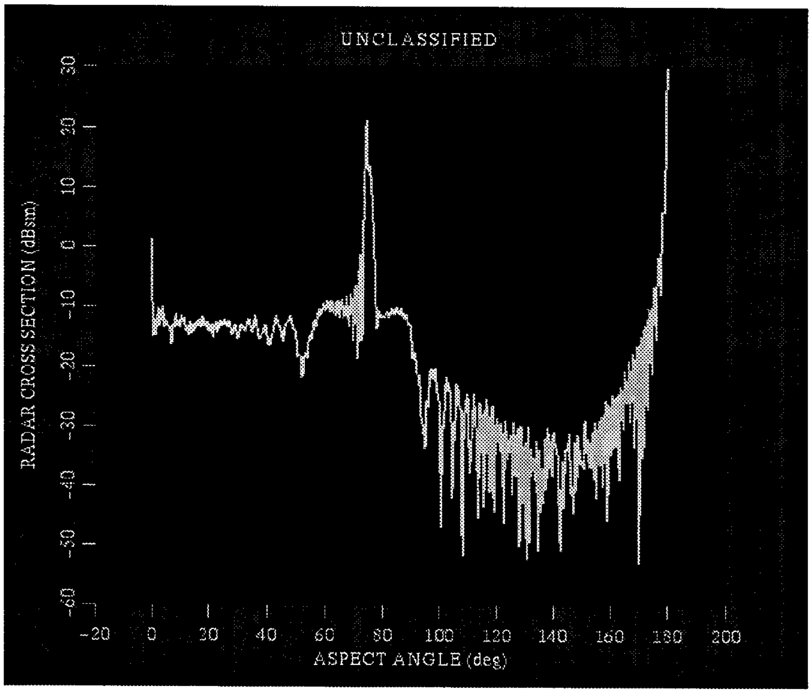

Figure 3.b

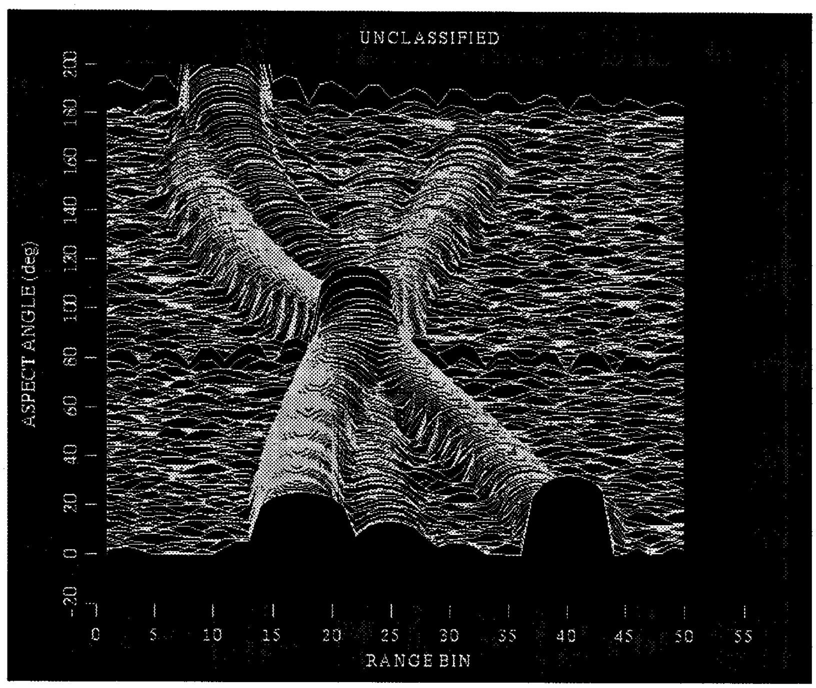

Figure 3.c

III. Stepped Frequency Waveforms and High Range Resolution Profiles [6-8]

Discrete Fourier Transform (DFT) processing of a series of I and Q samples collected on a pulse by pulse basis can be used to generate a high resolution range profile of an isolated target. This can be accomplished by transmitting a sequence or burst of Narrow Band (NB) monotone pulses that are stepped in frequency. Such pulses are referred to as Stepped Frequency waveforms (SFWF). These pulses illuminate a target located in the far field, and after the radar receiver collects a burst of echo pulses, the radar processor Fourier transforms the signal into a target range profile. The processed target range resolution is $c/(2N\Delta f)$ where c is the speed of light, N is the number of steps in the burst, and Δf is the frequency step size.

In general, the Pulse Repetition Frequency (PRF) for a SFWF, during the nth step, can be expressed as

$$f_n = f_0 + n\Delta f \qquad \text{(EQ 1)}$$

where f_0 is the radar operating frequency and Δf is the frequency step. Assuming returns form a stationary target at range R, then the nth video quadrature components for a processed SFWF are

$$x_I^n(t) = C_n \cos\psi_n \qquad \text{(EQ 2)}$$

$$x_Q^n(t) = C_n \sin\psi_n \qquad \text{(EQ 3)}$$

where $\psi_n = (-4\pi R f_n)/c$, C_n is the amplitude for the nth return. The complex video signal is then given by

$$x_n(t) = x_I^n(t) + j x_Q^n(t) = C_n e^{\left[j\left(\frac{4\pi R f_n}{c}\right)\right]} = C_n e^{j\psi_n} \qquad \text{(EQ 4)}$$

It follows that the sampled quadrature components are made of discrete samples the target reflectivity in the frequency domain. And hence, this information can be transformed into range refelcivity series by using the Inverse DFT (IDFT). More precisely, the synthesized range profiles is given by,

$$H_l = \sum_{n=0}^{N-1} \frac{1}{N} C_n \, e^{\left[j\left(\frac{4\pi R f_n}{c}\right)\right]} \, e^{\frac{j2\pi n l}{N}} \qquad ;(0 \le l \le N-1) \qquad \text{(EQ 5)}$$

The instantaneous frequency of the nth video signal can be evaluated as

$$f_d = \frac{2R}{c}\dot{f}_n + \frac{2f_n}{c}\dot{R} \qquad \text{(EQ 6)}$$

where the first term of the right hand side of (EQ 6) corresponds to the frequency change associated with changing the transmitted frequency and range to the target. Alternatively, the second term is associated with the targets induced Doppler due to its motion.

The unambiguous range associated with a SFWF can be found to be

$$R_u = \frac{c}{2\Delta f} \tag{EQ 7}$$

and the corresponding range resolution is

$$\Delta R = \frac{c}{2N\Delta f} \tag{EQ 8}$$

As indicated by (EQ 8) the total number of frequency steps and the step size determine the final synthesized range resolution. Thus, one can perhaps conclude that by increasing the step size then range resolution can be improved. This is true, however, in order to avoid aliasing one must choose the frequency step so that

$$\Delta f \leq \frac{c}{2E} \tag{EQ 9}$$

where E is the target extent in meters. Additionally,

$$\Delta f \leq \frac{1}{2\tau} \tag{EQ 10}$$

where τ is the pulse width.

IV. Utilization of SFWF within SASS

We developed a SFWF processing module within SASS in order to generate HRR profiles of SASS targets. For this purpose, each sub-pulse within a burst is Linear Frequency Modulated (LFM), where the bandwidth corresponds to Δf. The choice of the number of steps within a burst and the step size, are dynamically computed on the basis of the target extent and the desired bandwidth. Further more, HRR profiles for SASS targets are produced for both Principal Polarization (PP) and Orthogonal Polarization (OP). Both PP and OP signatures along with their ratio, are then stored in binary format, for later use in the GBR HWIL test-bed.

The NMD-GBR-PO requested that all of the HWIL entities, including SASS, undergo a Verification, Validation, and Accreditation (VV&A) process. The guidelines established for the VV&A process include: (1) SASS output comparisons with real-world data produced from static range measurements and flight tests; and (2) Touchstone / simulation comparisons. The touchstone model chosen for SASS comparisons is Xpatch Comparisons with, real world, and other models (such as Xpatch) have been used as a means of validation. However, because of the security classification nature of these analysis, we will not show these results.

Figure 4.a shows a typical synthetic HRR PP signature produced by SASS. In this case, the generic RV shown in Figure 3.a was used for demonstration. The center frequency is $10GHz$, and the bandwidth is equal to $4GHZ$. The frequency step is $\Delta f = 35MHz$. The generic RV is $1.75m$ long, with base radius equal to $0.57m$. The nose diameter is $0.26m$. Figure 4.b shows the corresponding OP signature.

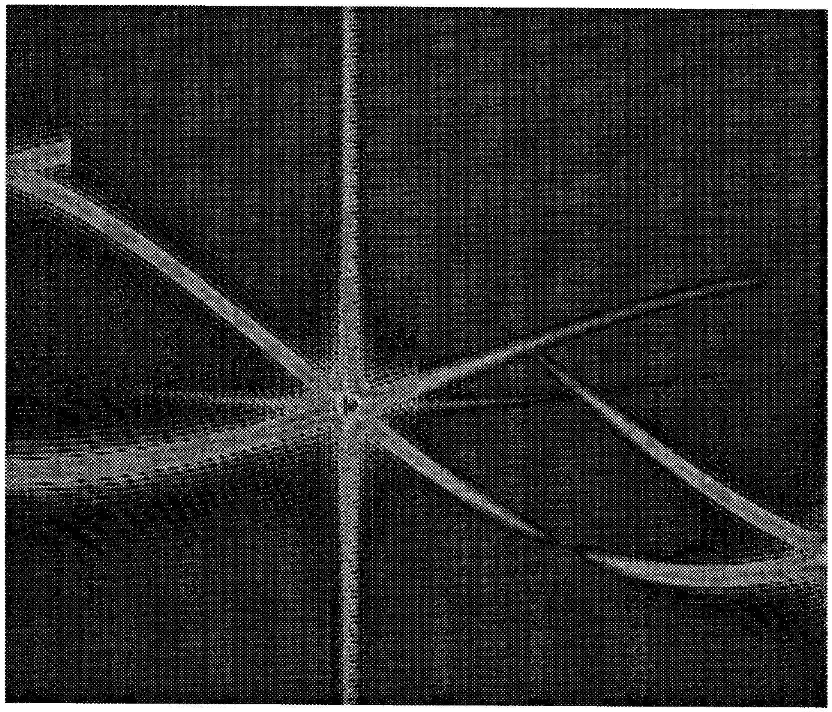

Figure 4.a

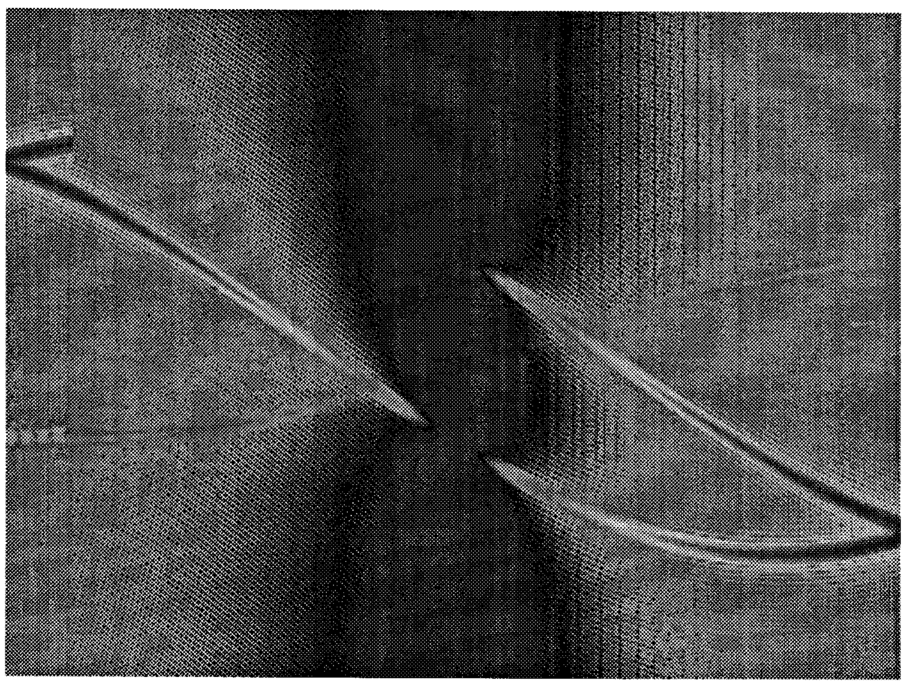

Figure 4.b

V. Conclusions

A very fast running simulation, entitled Sensor and Signature Simulation (SASS) was developed, validated, verified, and utilized for use within the NMD GBR HWIL test-bed, as a means for radar RCS and target signature generation. Narrow band, wide band target signatures are only two of the many outputs SASS can produce. A synthetic High Range Resolution (HRR) module was also developed and tested. In this case, each of the SFWF sub-pulses is LFM modulated and pulse compressed in order to synthesize the desired target signature. Both PP and OP signatures as well as their respective ratio are calculated and stored in binary format for use with the test-bed. For illustration, a typical sub-set of SASS outputs is presented in this paper.

VI. References

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