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Component Error Representation of Sensor Target Location Errors

by Matthew Banta, Kyle Miele, Marguerite Shepler, and Thomas Koehler

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Executive Summary

Traditionally, when the U.S. Army Combat Capabilities Development Command Analysis Center supplied the target location error (TLE) for various sensors so that the Modeling and Simulation (M&S) community could represent the uncertainty inherent in measuring the location of an object, a single 50% circular error probability (CEP50) value as a function of range was supplied. The CEP50 is not an ideal metric; therefore, the models have been expanded to be able to estimate the downrange, cross-range, and vertical TLE for various sensors including the following: Ground Moving Target Indication and synthetic aperture radar, Laser Rangefinders with electro-optical/infrared sensors, and signals intelligence systems. The models have also been expanded to include TLE with and without self-location error. By including these additional parameters, the M&S community will be able to more accurately represent the TLE of a sensor, and they can expand their efforts to play scenarios that they were previously unable to investigate.

1. INTRODUCTION

1.1 Sensor Introduction

The warfighter uses a variety of sensors to determine the location of objects of military interest. Some of these sensors include radar (both Ground Moving Target Indication [GMTI] and synthetic aperture radar [SAR]), electro-optical/infrared (EO/IR) with a Laser Rangefinder (LRF), and signals intelligence (SIGINT).

Each sensor is designed to detect a different type of object of interest. For example, SIGINT systems listen in, and they can be used to locate a target emitting radio frequency (RF) radiation. These targets of interest include radar systems, RF jammers, radios, and other communication systems. Figure 1 is an image of a SIGINT system.



Figure 1. SIGINT system

The EO/IR systems take images and/or videos of an area of interest. Users can determine the azimuth and elevation to a target of interest in an image by noting the direction that the imaging sensor was pointed to at the time and then by analyzing the location of the target in the image. With the addition of an LRF, these EO/IR systems can determine the range to the target and therefore the location of the target relative to the sensor. These sensors can be used to find the location of targets that are large enough to be visible in the images that the sensor takes of the area of interest. Figure 2 has an image of an EO/IR system as well as a thermal image.

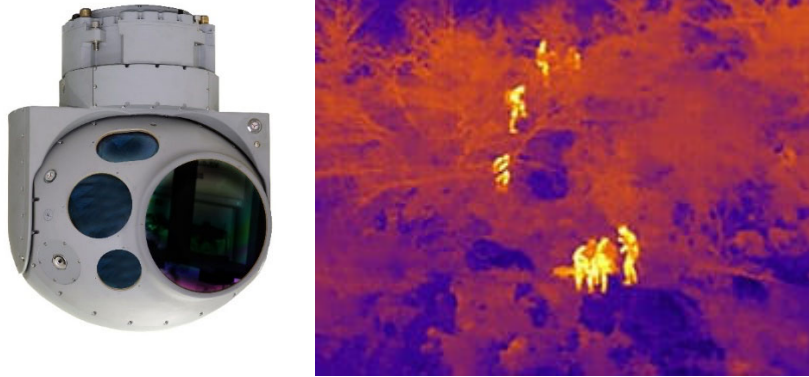


Figure 2. EO/IR system and thermal image

There are many types of radar systems. This report only considers GMTI radar and SAR. GMTI radar can find the location of moving targets, whereas SAR can take images of large pieces of terrain along with the objects and structures that are located on this terrain. SAR typically cannot create images with a resolution as high as that of EO/IR systems; however, SAR can operate even when the targets are obscured by weather and/or other obscurants. Figure 3 is an image from a SAR.

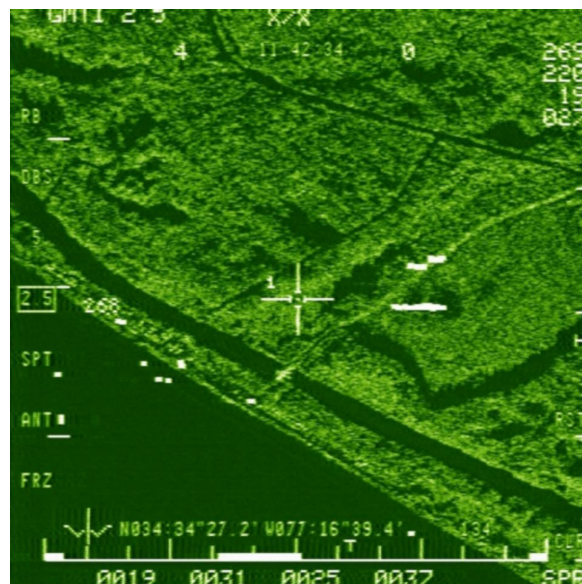


Figure 3. SAR radar image

Whenever a sensor is used to find the location of an object, there will inevitably be an uncertainty in the measurement, called the target location error (TLE). If the TLE is large enough, it may affect the Warfighter's ability to complete their mission. The Army Futures Command needs to study how TLE affects various missions to determine whether current sensor systems are acceptable for the Army of the future.

1.2 Problems with Current Methodology

Traditionally, the U.S. Army Combat Capabilities Development Command (DEVCOM) Analysis Center, known as DAC, supplied TLE as a single 50% circular error probability (CEP50) value as a function of range. The CEP50 is often used to compute the performance of weapon systems. To measure the CEP50 of a system, the weapon system is fired at a target. When a real weapon system performs this experiment, there will be a spread around the target where the projectiles actually land. The CEP50 is the size of a circle drawn around the target where 50% of the projectiles are inside the circle and 50% are outside the circle.

Although CEP50 works fine for weapon systems, it is not an ideal metric to use for sensor TLE because a sensor's TLE is often not circular in nature. Furthermore, users cannot remove the component of the TLE that is due to self-location error—this makes it difficult for the modeling and simulation (M&S) community to model the effects of a loss in global positioning system (GPS) capability.

In addition to CEP50, we expanded the models to estimate the downrange, cross-range, and vertical TLE with and without GPS self-location error for various sensors including GMTI radar and SAR, LRFs and EO/IR sensors, as well as SIGINT systems. By including these additional parameters, the M&S community will be able to more accurately represent the TLE of a sensor and will be able to expand their efforts to play scenarios that they were previously unable to simulate.

2. METHODS, ASSUMPTIONS, AND PROCEDURES

For every type of sensor, there is a different procedure for finding the base TLE. For most sensors, once the base TLE is established, the self-location error can be added to get the total TLE. Below are summaries of how TLE is calculated for each main sensor type as well as how to add the final self-location error to the TLE.

2.1 Target Location Error for Electro-Optical/Infrared Systems

An LRF measures the range to a target by transmitting laser radiation to the target of interest and then usually measuring the time it takes for the radiation to bounce off the target of interest and return to the sensor. Although the range measurement is susceptible to errors caused by such things as having the beam shine on background objects instead of or in addition to the target of interest, the largest source of error in measuring range with a LRF is the uncertainty in measuring the time it takes for the radiation to travel to and from the object. As such, most vendors will supply the uncertainty in measuring range with an LRF as a single standard deviation in the range measurement that does not change as a function of time.

The Joint Fires Integration and Interoperability Team (JFIIT) tested a series of EO/IR systems with LRF and found that at the longest range they tested (5 km), there was sometimes a jump in the uncertainty in measuring range (Spock, 2008). At lower ranges (1 to 2.5 km), however, the uncertainty in measuring range remained relatively constant. In the future, parameters such as range measurement uncertainty could be modeled to be dependent on range, but for the time being, the idea that the range uncertainty remaining relatively constant as the range to the target increases appears to be a reasonable assumption.

To measure the exact location of the target relative to the sensor, LRF sensors are paired with an EO/IR imager to obtain the azimuth and elevation angle. Typically, these imagers are mounted on a gimbal mount that will rotate until the object of interest is within the field of view of the imager. To measure the angle to the target, the sensors need to measure the azimuth and elevation where the camera needs to pan to in order to find the target along with where the target is in the image. Once again, vendors usually specify their uncertainty in measuring the angle to the target as a fixed value that does not depend on range. Moreover, once again, JFIIT tested the performance of several EO/IR sensors as they attempted to find the angle to the target. Sometimes the angle uncertainty did increase at longer ranges; however, for short ranges, the azimuth and elevation uncertainties remained relatively constant as the range to the target changed. For now, it is assumed that these uncertainties will stay the same for all ranges. However, in the future, it might be advantageous to modify the DAC models

such that users can specify that these parameters may no longer remain constant for longer ranges.

If the azimuth, elevation, and range uncertainties are known, then estimating the TLE for this type of sensor becomes a matter of trigonometry. The self-location error needs to be added to get the full TLE for a given sensor.

2.2 Target Location Error for GMTI Radar and SAR

There is one type of radar called GMTI. This radar type uses the Doppler effect to find targets of interest that are moving. There are uncertainties in the range to the target as well as the elevation and azimuth angles when using this type of radar to find the location to a target. As with EO/IR with LRF, finding the total TLE for this type of instrument is a matter of geometry. As in Section 2.1, the self-location error may need to be added to estimate the total TLE for this type of sensor if the asset is being used in a scenario where it is important to know the target location relative to the center of the Earth.

SAR is another type of radar. SAR is a form of radar that is used to create 2-D images or 3-D reconstructions of objects, such as landscapes. SAR uses the motion of the radar antenna over a target region to provide finer spatial resolution than conventional stationary beam-scanning radars. Instead of measuring range, azimuth, and elevation to the target, SAR measures the range, elevation, and range rate for a target of interest. As with GMTI, depending on the scenario, the self-location error may need to be added to determine the total TLE. Note that unlike GMTI radar, SAR may image buildings or other landmarks that may allow them to determine their location relative to the center of the Earth on their own. The exact equations used to find the uncertainties in range, range rate, elevation, and azimuth for radar in SAR or GMTI mode are shown and explained in Appendix A.

2.3 Target Location Error for Signals Intelligence Systems

The SIGINT systems have multiple algorithms that can be used to find the location of an RF emitter. One way in which SIGINT systems can measure the location of a target is by measuring the angle that the radiation hits the SIGINT system's antenna. If multiple sensors are measuring the angle to the target, or if one sensor moves around and measures the angle to a stationary target at multiple locations, trigonometry can be used to find the location of a target. This algorithm is called angle of arrival (AoA). Because there is a limit to the accuracy in which a system can measure the angle of the incoming radiation, SIGINT systems will often combine AoA with other algorithms to more accurately find the location of the target.

Another algorithm SIGINT systems can use to find the location a target is time difference of arrival (TDoA). To use this algorithm, multiple SIGINT systems need to be in the area at the same time. Without knowing the exact location of the target, it is impossible to directly measure the time it takes for a signal to traverse the distance between the target and the sensors. However, it is possible to measure the additional amount of time it takes for the signal to travel from one sensor to another. If there are multiple sensors measuring these times and the location of these sensors are known, it is possible to use these times to determine the location of the target.

Frequency difference of arrival (FDoA) is yet another algorithm that can be used to find the location of the target. The sensors need to be moving to use FDoA. Instead of measuring the different times that it takes for the signal to move from one sensor to another as in TDoA, FDoA measures the difference in frequency caused by the Doppler effect between the sensors. Once again, if the location and velocity of each sensor is known, FDoA can be used to calculate the location of the emitter.

Any textbook on SIGINT systems will derive equations that allow for calculating the location of the emitter if using TDoA, FDoA, or AoA. The problem becomes more complicated if multiple algorithms are combined, or if FDoA is used on an emitter that may be moving. The DAC developed the Multipurpose Universal Simplified TLE Calculator (MUSTC) algorithm to determine the TLE for a SIGINT sensor no matter which algorithm, or combination of algorithms, is used. In addition to SIGINT sensors, the algorithm can be used to find the TLE for just about any sensor or collection of sensors that measure the position, navigation, and timing (PNT) of a target. In fact, the exact algorithm that the sensor uses to find the location of an object is not needed for the MUSTC algorithm to find the TLE for the sensor—all that is required is a model that estimates the raw measurement that the sensor will make. The rest of this section contains a summary of the algorithm, which is explained in more detail in another technical report (Banta, 2022).

Depending on the setup and method being used, it may be difficult to create an algorithm to determine the location of the emitter. The MUSTC algorithm is based on the fact that the location of the emitter is known. It is assumed that the emitter is located at the point where the TLE is being calculated. Instead of estimating the location of the emitter, the uncertainty in location caused by an uncertainty in one of the measurements is determined. To map out how an error in a measurement can cause an error in location, a perturbation is added to one measurement and then a new emitter location is determined that would produce a set of measurements that match the one with the perturbation.

There are multiple optimization algorithms that can be used to find the optimal new location based on a perturbation to one of the parameters. However, to use these algorithms, a cost function must be defined. The input to the cost function will be the location that will produce a set of measurements that match the measurement after the perturbation is added. The output of the function will be a number that rates how closely the actual measurements for the location guess matches the desired set of measurements. The mean difference between the actual and desired measurements for that location is one example of a possible value that can be used for the output of the cost function. Once this cost function is defined, the optimization algorithm can be used to search and then find the location that minimizes the cost function and thus matches the perturbed measurements.

One caveat of using an optimization algorithm to minimize a function is that sometimes a local minimum for the function is found instead of a global minimum. When there is a good initial guess for the optimal location, the chance of hitting a local instead of a global minimum is greatly diminished. If an extremely small perturbation is added first, then it can be assumed that the location that produces the perturbed measurement will be close to the initial location. The initial location will therefore be an ideal choice as an initial guess to give to the optimization algorithm. As larger and larger perturbations are added to the measurement, the previous location that the algorithm found can be used as an initial guess for the next location. In this way, an optimization algorithm can be used to map out how different errors in a single measurement can create different errors in the location measurement. Once this map is established, the following equation can be used to find the uncertainty in location measurement based on an uncertainty in the measurement of a single variable:

$$\sigma_A = \sqrt{\sum_{i=1}^n P_i (\Delta L_i)^2}. \quad (1)$$

Here, ΔL_i is the location error caused by adding the i th perturbation to the measurement, P_i is the probability that the i th perturbation will be the actual error in the measurement (the exact probability density function depends on the variable; however, for most cases, it is safe to use the probability density function of a normal distribution), n is the number of perturbations that were tested, and σ_A is the TLE from the variable being tested. To find the total TLE at a given location, this procedure must be performed for each variable in which there might be an uncertainty that affects the final TLE. If the TLE from uncertainties in some random variables that we can call A , B , and C are known, and the uncertainties in these variables are largely independent, then the total TLE can be estimated using the following equation:

$$\sigma_f \approx \sqrt{\sigma_A^2 + \sigma_B^2 + \sigma_C^2}. \quad (2)$$

Here, σ_A , σ_B , and σ_C are the TLE from variables A , B , and C , and σ_f is the total TLE.

Unlike other sensors whose TLE algorithms are presented in this report, differentiating the self-location error and non-self-location error for SIGINT sensors is not straightforward because SIGINT measurements require multiple sensors whose locations must be known before the location of the target can be determined. The location of the sensor formation relative to the Equator and Prime Meridian and the location of the sensors relative to each other can contribute to the TLE of the sensor system. If the location of the sensors relative to each other is measured independently to the location of the entire formation relative to the Equator and Prime Meridian, then the self-location error will be independent of the base sensor TLE, and these values can be separated in a similar way to how they are separated for other sensors. However, if each sensor has its own GPS and these GPS measurements are how the system determines both the location of the formation relative to the outside world as well as the sensor's locations relative to each other, then it might not be as straightforward to separate the self-location error from the base TLE error.

For now, assume that each sensor has its own GPS and that the GPS is used to measure both the location of the formation as well as the location of the sensors relative to each other. The DAC will supply the TLE with and without self-location error for SIGINT systems as is done for other sensors. However, this may be discontinued because adding a different self-location error to determine how the system will work in GPS denied environments may not be as straightforward for SIGINT systems as it is for other sensor types.

2.4 Adding Self-Location Error to Target Location Error

The “AMSAA Data Request Process Guide for Target Location Error Data for Target Acquisition Sensors” outlines the technique used to add the self-location error to the base TLE for a sensor (Chamberlain, 2013). This technique is used for EO/IR systems with LRF as well as GMTI radar and SAR systems. For SIGINT systems, the self-location error will be included while the algorithm determines the location error caused by uncertainties in all of the variables. This section summarizes the technique used to add this location error.

In general, the self-location error is independent from the base sensor TLE. These uncertainties can be combined by taking the square root of the sum of the squares of the standard deviations. The problem is that not all uncertainties are given via the same coordinate system.

When a GPS gives the location of an object, it typically gives the location as a latitude, longitude, and altitude. In other words, the location, and uncertainty in location, is given via an axis located at the center of the Earth. Sensors, on the other hand, will give the location of the target relative to the location of the sensor. The base sensor TLE will therefore be given relative to an axis located on the sensor. Although the GPS uncertainty is given in spherical coordinates, the sensor base TLE may not be.

To overcome this discrepancy, the algorithm used to add the self-location TLE to the sensor base TLE will simply project all of the sources of error onto the same axis and coordinate system. For completeness, the algorithm will also add other sources of error to find the total TLE such as uncertainties in how the GPS antenna is mounted to the sensor platform. Users may want to estimate how a change in PNT measurement can lead to a change in the total sensor TLE to test how operations must change in a GPS-denied environment. All uncertainties must be given via the same axis, and then users can take the square root of the sum of the square of all the uncertainties to find the total TLE.

3. CONSTRAINTS, LIMITATIONS, AND ASSUMPTIONS

3.1 Constraints

The project had to be completed in 1 year. In addition, there were insufficient resources to test the performance of several sensors. When it comes to adding the sensor parameters, only certain parameters have been published or are known in the community.

3.2 Limitations

Because of limited time, it was necessary to use sensor models that have already been derived and published, and the number of sensors that could be added was limited. These models have their own limitations. Because we only had access to the parameters that have been published, the parameter options available in the model are also limited.

3.3 Assumptions

Several assumptions were required in this effort. The first is that the models are accurate enough to use for the purposes of this effort. Another assumption is that the uncertainty in self-location is independent of the base sensor TLE. Finally, there are assumptions that the parameters that have been published are accurate and appropriate for use.

4. RESULTS AND DISCUSSION

4.1 Software Updates

All of the algorithms discussed in this report, except for the SIGINT TLE algorithm, have been previously implemented via an Excel sheet. Although spreadsheets can be handy for developing and testing a new algorithm, they are not practical when creating a large number of calculations for an external customer.

Excel sheets require data values such as sensor parameters to also be stored in a spread sheet. It is difficult to set up a system where the data values can be tracked and thus ensure that the values are up to date and are derived from the most appropriate source. Even if the sheet is expanded with macros, performing complex calculations with an Excel sheet can often require multiple steps that may make it difficult to train others on how to perform the calculations. The multiple steps can also make these calculations prone to errors because steps can be forgotten or performed out of order.

To better track the sensor parameters and make it easier to perform the calculations that external customers require, a program in C# has been created along with a database to house, update, and track sensors parameters, allowing required calculations to be more easily performed. All equations and procedures in the Excel sheets were converted to C# so that they could be included in the model. Because the MUSTC TLE algorithm had already been implemented in C#, it was easy to include that algorithm as well. Appendix B outlines how to use this program to calculate the data that external customers require.

4.2 Sample Output

The data request program will output a comma-separated value (CSV) file. The CSV files are text files designed to be automatically loaded into Excel by simply clicking on the file. These CSV files can easily be loaded into a variety of different databases and computer programs so that they can be transformed into any type of standard file format (SFF) that is required. Table 1 is a sample of TLE data that were traditionally supplied by our branch.

Table 1. TLE data that were previously supplied (all values are in meters)

Sensor	Range	TLE	Classification
sensor 1	1000	14.53774	U
sensor 1	2000	24.6638	U
sensor 1	3000	35.74288	U
sensor 2	1000	9.707752	U
sensor 2	2000	10.84787	U
sensor 2	3000	12.29187	U
sensor 3	1000	46.53754	U
sensor 3	2000	55.25692	U
sensor 3	3000	64.56688	U

In Table 1, the TLEs listed are the CEP50 in meters. Note that for illustrative purposes, the TLE values in Table 1 were displayed with the same number of significant figures as will be displayed in the SFF file. However, it is extremely unlikely that the model will in fact be able to estimate the TLE with that much precision. These data will continue to be supplied so that the CSV and eventual SFF will be backwards compatible for customers who have not yet updated their software to accept the new values. In some cases, TLE as CEP50 will still be the only TLE values that can be supplied. This is because some parameters that are needed for the models are not available. For some sensors, it may also be necessary to resort to test results or other sources that only supply a single value for TLE. In other cases, TLE may need to be supplied for another type of sensor for which a model has not yet been created that is capable of returning the 3-D TLE.

Notes such as information on when the values were classified and by whom, and the declassification date, are also included as columns within the CSV file. Table 2 shows the additional values that will now be supplied with CEP50.

Table 2. Additional values that will now be included in the CSV (all values are in meters)

Sensor	Range	Downrange TLE	Cross-range TLE	Vertical TLE	Downrange TLE no self-location	Cross-range TLE no self-location	Vertical TLE no self-location
sensor 1	1000	7.215284909	17.889999955	5.206014043	5.201955048	17.17708019	1.45002835
sensor 1	2000	7.215363562	34.71524897	5.774954202	5.202064141	34.35328966	2.889653273
sensor 1	3000	7.21549223	51.77170221	6.615334759	5.202242605	51.52969193	4.331587928
sensor 2	1000	10.91374755	5.779404689	5.177073984	9.701024979	2.898537314	1.342421334
sensor 2	2000	10.9137528	7.651517777	5.669882267	9.701030888	5.791867081	2.673493019
sensor 2	3000	10.91375593	10.02261104	6.407558363	9.701034408	8.68635321	4.007094231
sensor 3	1000	63.89604686	16.21178408	5.241122783	63.7001162	15.42147668	1.571422296
sensor 3	2000	63.89608136	31.24440345	5.897647536	63.70015081	30.8417371	3.127658302
sensor 3	3000	63.8960973	46.53168128	6.853881375	63.7001668	46.26226716	4.687823578

As seen in Table 2, the CSV file now also includes the downrange, cross-range, and vertical TLE with and without self-location error (all in meters). These additional values are in terms of standard deviation and not CEP50. Customers whose programs only accept the TLE as a single value might be able to use these additional values to find a better value to use for their TLE.

4.3 Using the New Values

Users can use the following formula to convert the cross-range and downrange TLE in the form of standard deviation into CEP50:

$$CEP50 = \begin{cases} b (0.609 k + 0.567), & k > 0.3 \\ b (0.844 k^2 + 0.674), & k \leq 0.3 \end{cases} \quad (3)$$

Here, b is the larger of the two standard deviation values (cross-range or downrange TLE) and k is the smaller of the two values divided by the larger of the two values. If the cross-range and downrange are approximately equal (in other words, if the TLE really is circular), then the CEP50 will be approximately 1.18 times larger than the standard deviation TLE.

There may be times when a user will want to use a CEP value that is different from the CEP50 that DAC supplies. For example, there may be instances in which a user will want to use a CEP that more closely matches the uncertainty in the cross-range or downrange direction as opposed to the default CEP50 value that finds an uncertainty that is somewhere in between these values. Users can use Eq. 3 to create a better CEP for a given scenario than the standard CEP50 that the program automatically creates.

Users of the new standard deviation values may need to know how to convert the new standard deviation values into the probability that the sensor will report that the target is at a given location. It is safe to assume that the TLE will fit a Gaussian distribution where the standard deviation in the x direction is given by σ_x , the actual location of the sensor is μ_x , and P_x is the probability that the sensor will measure the location. The probability that the value will be at location x can be estimated using this formula:

$$P_x = \frac{1}{\sigma_x \sqrt{2\pi}} e^{-\frac{1}{2} \left(\frac{x - \mu_x}{\sigma_x} \right)^2} \quad (4)$$

It can be assumed that the probability of measuring a location in each direction is independent; thus, the probability that the sensor will report the target is at location x , y , z will be equal to

$$P = P_x P_y P_z \quad (5)$$

Here, P is the total probability, and P_x , P_y , and P_z are the probability that the location in the x direction will be equal to x , the probability that the location in the y direction will be equal to y , and the probability that location in the z direction will be equal to z .

4.4 Adding A Custom Self-Location Error

As mentioned in Section 2.3, adding a custom self-location error to a SIGINT TLE may not be straightforward because it may or may not include the uncertainty in knowing the location of each individual sensor relative to each other as well as knowing the location of the entire formation relative to the Equator and Prime Meridian. In addition, SAR may gain information on their self-location based on buildings or other landmarks that they are able to image. However, adding a custom self-location error to the other sensor types is straightforward because the uncertainties in knowing the location of the sensor on the surface of the Earth and the location of the target relative to the sensor are independent. Therefore, the total TLE for a sensor can be estimated using the following formula:

$$TLE_i = \sqrt{(TLE_b)^2 + SLE^2}. \quad (6)$$

Here, TLE_i is the target location error in the i th direction, TLE_b is the base sensor TLE (uncertainty in finding the target relative to the location of the sensor), and SLE is the sensor's self-location error. Note that this equation assumes that TLE_b and SLE are using the same coordinate system.

This equation prompts the question of what self-location error should be used for any given situation. The uncertainty when finding a location using GPS depends on the scenario; however, a reasonable rule of thumb is to add approximately 5 m of uncertainty in each direction. However, what value should users select if the Warfighter is in a GPS-denied environment?

The GPS denial is often intermittent. To compensate for this, vehicles often have an inertial navigation sensor (INS) to supplement their GPS self-location measurement. The self-location error when using an INS sensor to find location in lieu of a GPS depends on the amount of time that has passed without a valid GPS measurement. If GPS is denied for long enough, then the Warfighter may have to use a paper map to find their location.

There is a general rule of thumb that when using a 1:50,000 scale United States Geological Survey map, one can find the location of a landmark with a CEP50 of approximately 13.9 m. The Marine Artillery Survey Operations handbook states that a CEP50 value of approximately 54.9 m can be assumed when using a map to find the

location of a target (U.S. Marine Corps, 2002). Actual self-location error while using a map can be much higher if there are no suitable landmarks around; it can grow to many kilometers if, for instance, someone drives into a desert full of shifting sand dunes and no landmarks that can be found on a map.

4.5 Verifying the Results

Because the MUSTC algorithm was originally written in C# and then compiled into a Dynamic-Linked Library, the program can directly use this software to calculate the TLE for SIGINT sensors. Please refer to the separate technical report for the verification and validation of this software package (Banta, 2022).

For other sensor types, the algorithms that are used to find the base sensor and self-location TLEs were initially implemented in Excel and then converted to C# to allow the data request software to implement these algorithms. The C# implementation was verified by feeding both the Excel sheets and the C# program a variety of test sensor parameters and ensuring that when these programs use the same parameters, they return the same TLE result.

5. CONCLUSION AND RECOMMENDATIONS

The DAC reviewed existing error budget models including SAR and GMTI radar, as well as EO/IR sensors with LRF, and SIGINT systems, and noted which could be expanded for component error representation and which needed additional development. The teams worked to integrate these algorithms into a spreadsheet tool to calculate end-to-end TLE, and they collaborated with stakeholders (including System Effectiveness Analysis Simulation modelers and the Long-Range Precision Fires and Assured Positioning Navigation and Timing Cross-Functional Teams) to determine what systems should be prioritized when generating a list of error budget models to develop. The validated models/methodologies have been documented and considered for use in the future.

6. REFERENCES

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Appendix A – Target Location Error for Synthetic Aperture Radar and Ground Moving Target Indication Radar

A.1 Introduction

This section provides a method for computing target location error (TLE) for airborne Ground Moving Target Indicator (GMTI) and synthetic aperture radar (SAR) modes of radar. The method was derived from the method recommendations in “*Radar System Performance Modeling*.”¹ For most systems, both of these radar modes are available with the same suite of software, hardware, and antennal configuration.

There are four quantities that can potentially be measured with the GMTI and SAR modes:

- Azimuth angle
- Elevation angle
- Range
- Velocity (range rate)

The GMTI mode uses a measured range and azimuth angle along with a digital elevation model to measure a target location. In a more complex process associated with Doppler mapping, the SAR mode uses a measured range, range rate, and a Digital Elevation Model (DEM) to measure a target location. In both cases, the DEM and measured range substitute for an elevation angle measurement. These measurements are transformed from a sensor-centric coordinate system to an Earth-fixed coordinate system to compute the TLE.

This appendix provides a means of calculating each of these values and describes which specific measurements are used by both the SAR and GMTI modes of airborne radar systems. This appendix will consider the largest sources of error when calculating the TLE. However, in the future, it may be advantageous to add other sources of error. The inclusion of these sources of error could increase the fidelity of the model. Some of the sources of error that could be considered in the future include the following:

- The location and mounting of the GPS antenna used to find the location of the radar platform
- Impact of Digital Terrain Elevation Data (DTED) (Department of Defense, 2000) errors on target ground range and height estimates
- Refraction effects on slant range estimates for long-range SAR sensors looking at the ground

¹ Curry, R. G. (2004, November 30). *Radar system performance modeling* (2nd ed.). Artech House Inc.

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-
- Aircraft position, speed, and heading errors
 - Radome effects
 - Linear Frequency Modulated (LFM) ambiguity function position shift

A.2 Method

The root sum square (RSS) method is used to estimate error for each measurement. As with all models, this method is imperfect. Some of the imperfections in this model are because errors in one system parameter will result in errors in other radar measurements. For example, antenna pointing errors alter the antenna gain in the direction of the target, in turn altering the receive echo power²—especially in the absence of detailed probabilistic models for each of the error components.² Despite these imperfections, this has been shown to provide a realistic approach. The following sections in this appendix will outline how to estimate the uncertainty in each measurement. All of the sections conform to the following assumptions:

- The fluctuation of target signals can be described by the Swerling models (see “*Principles of Modern Radar: Basic Principles*”² for details).
- Scintillation and glint effects are not included. GMTI’s are being used to track slow-moving ground targets, such as vehicles and dismounts, whose orientation will not change significantly.
- Clutter and multipath effects are ignored. These would be heavily scenario dependent.

A.3 Angular Accuracy: Azimuth Angle

The GMTI mode measures the angle to target. Equation A-1 shows the RSS angular measurement accuracy, σ_A

$$\sigma_A = (\sigma_{AN}^2 + \sigma_{AF}^2 + \sigma_{AB}^2)^{\frac{1}{2}}. \quad (A-1)$$

Here

σ_{AN} = signal-to-noise ratio (SNR)-dependent random angular measurement error

σ_{AF} = angular fixed random error

σ_{AB} = angle bias error.

² Richards, M. A., Scheer, J. A., & Holm, W. A. (Eds.). (2010 May). *Principles of modern radar: basic principles*. SciTech Publishing.

The SNR-dependent error, σ_{AN} , typically dominate radar angular measurements.

Several techniques can be used to compute the angle of arrival. Some example techniques are monopulse, conical scanning, sequential lobing, and angle centroiding for scanning radars. The most commonly used techniques for modern radars are monopulse and angle centroiding, ² for which error formulations are provided in Eq. A-2 and Eq. A-3. An error formulation for interferometers is also provided in Eq. A-4.

$$\sigma_{AN(m)} = \frac{\theta_{3db}}{k_m \sqrt{2SNR}}, \quad (A-2)$$

$$\sigma_{AN(a)} = \frac{\theta_{3db}}{\alpha \sqrt{nSNR}}, \quad (A-3)$$

$$\sigma_{AN(i)} = \frac{1.15\lambda}{2\pi D \cos\varphi \sqrt{nSNR}}. \quad (A-4)$$

Here

θ_{3db} = 3dB radar beamwidth in azimuth or elevation

SNR = SNR for one pulse

n = number of pulses for largely noncoherent radars, or the number of independent looks assuming that the target decorrelates even slightly between looks

k_m = monopulse pattern difference slope

α = 0.339, a constant dependent on the azimuth observation period

λ = wavelength

D = for interferometers, the distance between antennas

φ = radar antenna scan angle off boresight to target.

For a monopulse system, Eq. A-2 can be refined for a system that uses multiple pulses. For radars that use coherent integration and the interference is limited to noise, Eq. A-5 is applicable:

$$\sigma_{AN} = \frac{\theta_{3db}}{k_m \sqrt{2SNR_{CI}}}. \quad (A-5)$$

Here $SNR_{CI} = nSNR$.

For radars that use noncoherent integration and the interference is limited to noise, Eq. A-6 is applicable:

$$\sigma_{AN} = \frac{\theta_{3db}}{k_m \sqrt{1 + 2SNR_{NI}}}, \quad (A-6)$$

where $SNR_{NI} = n \frac{SNR^2}{1+SNR}$. Note that some references suggest that the denominator of Eq. A-6 should be $k_m \sqrt{2SNR_{NI}}$; however, based on recommendations by the subject matter experts, the denominator in Eq. B-6 has been modified.

The angular fixed random error, σ_{AF} , has two components: the radar fixed random angle error and the random angle error. The radar fixed random angle error is a function of the beam-splitting ratio and can be taken to be 1/40th to 1/125th of the beamwidth. Note that these beam-splitting ratios may be optimistic because the model assumes that the monopulse beam cannot be scanned; therefore, there may be some extra losses. For this model, assume the worst case of $\sigma_{AF} = \theta_{3db}/40$. Random angular errors due to propagation are usually small and will be assumed to be 0.¹

The angle bias error, σ_{AB} , has two components: the radar angle bias error and the angle bias error from propagation. The radar angle bias error is a calibration error and is a model input. An angle bias error occurs due to refraction through the atmosphere and is relevant for measuring elevation angles. With Eq. A-7 and Tables D-2 and D-3 in “*Handbook of Radar Measurements*,”³ the angle bias error can be computed as a function of platform altitude and elevation angle.

$$N(h) = 313e^{-0.14386h}. \quad (A-7)$$

Here

h = altitude in kilometers

$N(h)$ = refractive index

A.4 Range Accuracy

Both the GMTI and SAR mode measure the range to target. Equation A-8 shows the RSS range measurement accuracy σ_R :

$$\sigma_R = (\sigma_{RN}^2 + \sigma_{RF}^2 + \sigma_{RB}^2)^{\frac{1}{2}}. \quad (A-8)$$

Here

σ_{RN} = SNR-dependent random range measurement error

³ Barton, D. K., & Ward, H. R. (1984). *Handbook of radar measurements*. Artech House.

σ_{RF} = range fixed random error

σ_{RB} = range bias error.

The SNR-dependent error, σ_{RN} , typically dominates radar range measurements. Equation A-9 should be used for simple uncoded rectangular pulse, and Eq. A-10 should be used for LFM waveform with a rectangular envelope and a known range gate (Richards, Scheer, & Holm, p. 695).²

$$\sigma_{RN} = c \sqrt{\frac{\tau}{8(SNR)B_{IF}}}, \quad (A-9)$$

$$\sigma_{RN} = \frac{c}{\pi B} \sqrt{\frac{3}{8(SNR)}}. \quad (A-10)$$

Here

c = speed of light = 3.0×10^8

τ = pulse width

B_{IF} = receiver bandwidth

B = swept bandwidth for the LFM waveform.

The range fixed random error, σ_{RF} , has two components: the radar fixed random range error and the random range error. The radar fixed random range error is a function of internal noise and can be taken to be 1/25th to 1/80th of the range resolution. The general expression for range resolution is shown in Eq. A-11:

$$\Delta R = \frac{c}{2B}. \quad (A-11)$$

For this model, assume the worst case of $\sigma_{RF} = \Delta R/25$. Random angular errors due to propagation are usually small and will be assumed to be 0.¹

The angle bias error, σ_{RB} , has two components: the radar range bias error and the range bias error from propagation. The radar range bias error is a calibration error and is a model input. Range bias error is usually small and will be assumed to be 0 for this model.

A.5 Velocity Measurement Error

The velocity measurement error, otherwise known as the range-rate error, is important for calculating target position measurement errors for SAR. Therefore, only those quantities for deriving range-rate measurement errors as they pertain to SAR will be shown in this section.

Equation A-12 shows the RSS velocity (range rate) measurement accuracy, σ_V

$$\sigma_V = (\sigma_{VN}^2 + \sigma_{VF}^2 + \sigma_{VB}^2)^{\frac{1}{2}}. \quad (\text{A-12})$$

Here

σ_{VN} = SNR-dependent random range-rate measurement error

σ_{VF} = range-rate fixed random error

σ_{VB} = range-rate bias error.

The SNR-dependent error, σ_{VN} , typically dominates range-rate measurements. Equation A-13 can be used to estimate the range-rate error, where T_{int} is the integration time, and SNR_{SAR} is the SNR attained by a SAR over T_{int} . Equation A-14 shows the calculation of T_{int} :

$$\sigma_{VN} = \frac{\lambda}{\pi T_{int}} \sqrt{\frac{3}{4(SNR_{SAR})}}, \quad (\text{A-13})$$

$$T_{int} = \frac{r\lambda}{2\rho v \cos\theta}. \quad (\text{A-14})$$

Here

r = slant range to target (image point)

ρ = SAR image resolution

v = platform velocity

θ = angle off broadside of radar antenna

λ = wavelength.

The range-rate fixed random error, σ_{VF} , has two components: the radar fixed random range-rate error and the random range-rate error due to propagation; both of these are assumed to negligible.¹ Therefore, σ_{VF} will be assumed to be 0 for this model.

The angle bias error, σ_{VB} , has two components: the radar range-rate bias error and the range-rate bias error from propagation. The radar -rate range bias error is a calibration error, and it is a model input. The range-rate bias error is usually small¹ and will be assumed to be 0 for this model.

A.6 Deriving an Elevation Angle from a Digital Elevation Model

Both SAR and GMTI rely on a DEM to aid in developing a target location in lieu of an elevation angle. Therefore, an elevation angle and error in elevation angle measurement is derived from the intersection of the following:

- A circle with a radius equal to the measured range, centered on the sensor aperture
- A circle with a radius equal to the mean radius of the earth with the added error associated with a DEM
- The distance between the two circles, equal to the mean radius of the Earth plus the DEM error plus the altitude of the sensor

The most commonly used DEMs are the DTED Level 1 and DTED Level 2. According to the performance specification for DTED, the absolute vertical accuracy, 90% linear error for DTED Level 1, is less than or equal to 30 m. If a normal distribution of error is assumed, this translates to a 1-sigma error of 18.24 m. The absolute vertical accuracy, 90% linear error for DTED Level 2, is less than or equal to 18 m. Again, assuming a normal distribution of error, this translates to a 1-sigma error of 10.94 m. For this model, the user will be asked if the sensor is using a DTED Level 1 or Level 2. If a different DEM is being used, then the corresponding 1-sigma value can be provided as input as well.

This model assumes a flat-Earth model. It does not account for actual elevation data nor the horizontal error associated with a specific point of elevation data. The error in the elevation angle is calculated by subtracting the elevation angle, which includes the DEM error from the elevation angle where the DEM error is assumed to be zero.

Appendix B – Data Request Software Overview

B.1 Introduction

This section outlines how to use the Signals, Measurements, and Signatures (SMS) Data Request program to perform the calculations needed to determine the target location error (TLE) in 3-Ds with and without self-location error for different sensor types. The SMS Data Request program is an application written in C# that allows for easy execution of most data requests required by the SMS team. Upon starting the SMS Data Request program, a dialog similar to what is shown in Figure B-1 will be displayed.

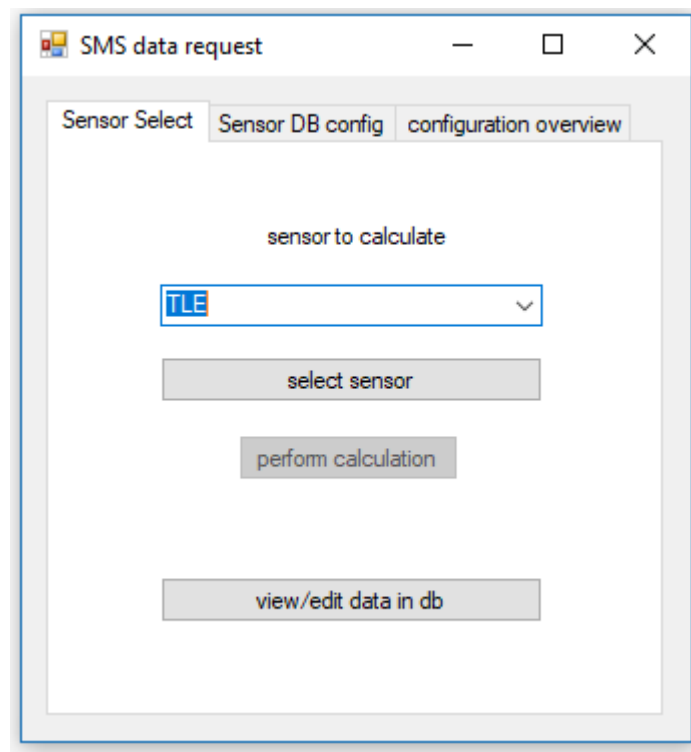


Figure B-1. Dialog that appears when running the SMS data request program

The “sensor to calculate” pull-down menu will be populated with the sensors and/or calculation types that are available to perform calculations. Figure B-2 is a screenshot showing the options available.

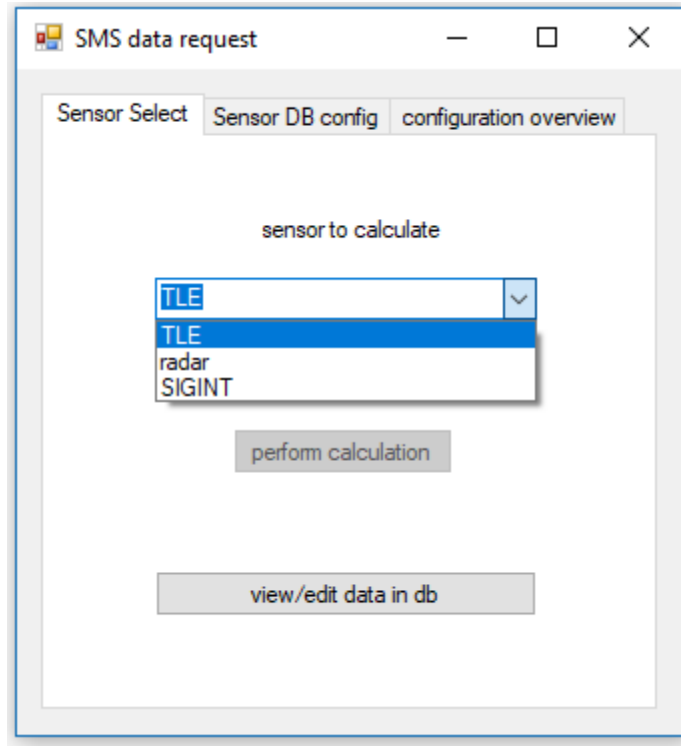


Figure B-2. Screenshot showing sensors that can be selected to perform calculations

Once a sensor is selected, press the “select sensor” button. This will enable the “perform calculation” button. Pressing the “perform calculation” button will open a dialog box that will let you continue entering the request input parameters.

B.2 Target Location Error Calculator

After selecting “TLE” in the dialog in Figure B-2, then pressing the “select sensor” and “perform calculation” buttons, a screen similar to what is shown in Figure B-3 will appear.

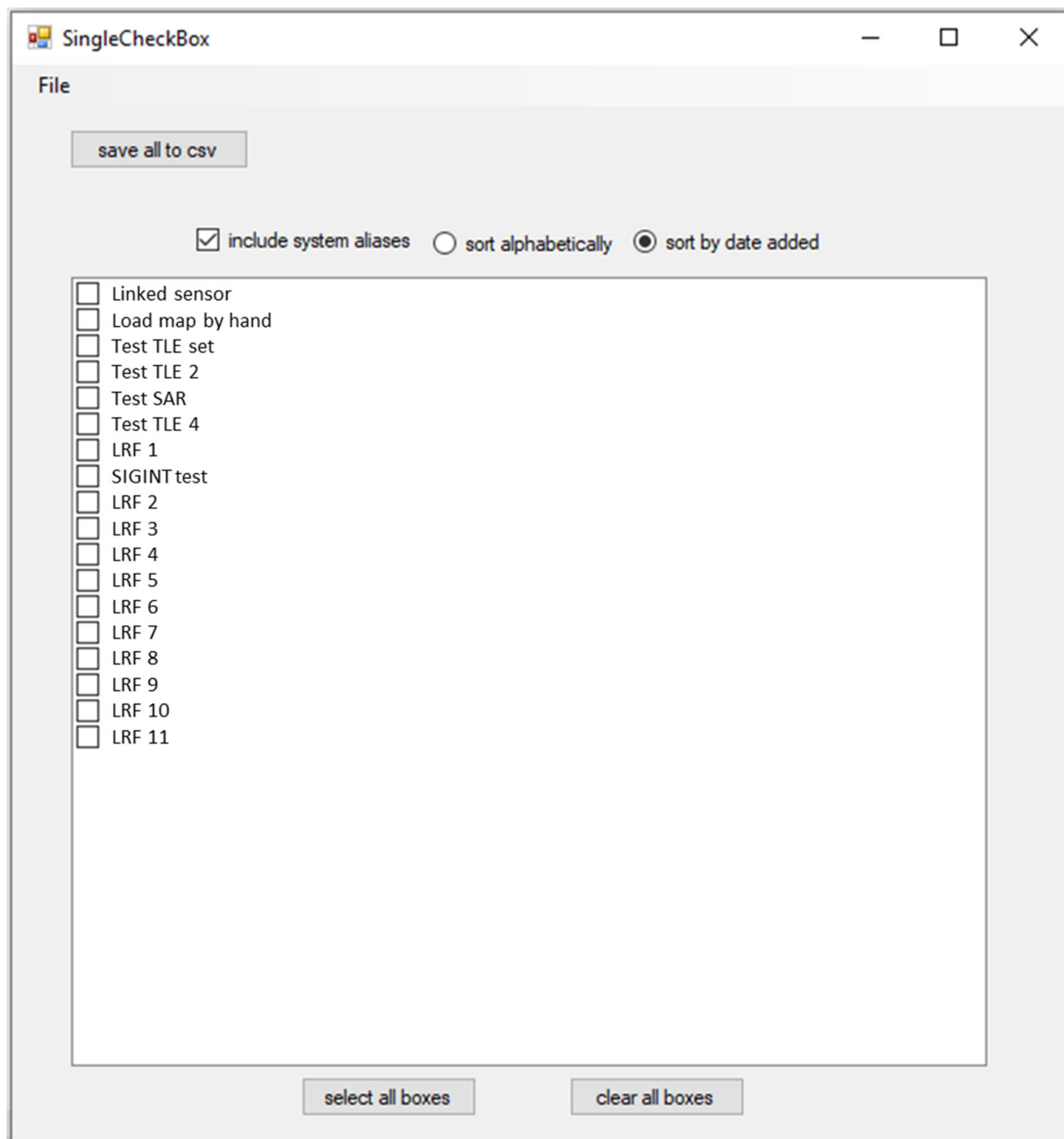


Figure B-3. Dialog that appears when selecting TLE as the sensor type to perform calculations

Figure B-3 shows the sensors that have been loaded into the database that are ready to have their TLE as a function of range values calculated. Click on the check boxes next to the sensor names to have their TLE values calculated. In addition to clicking the boxes by hand, the “File” pull-down menu located in the upper left side of the graphical user interface (GUI) can be used to load a list of sensors from a file.

Once the sensors have been selected, press the “save all to csv” button to have the program perform the calculations. At this point, a dialog box will open to prompt the user to enter the name of the csv file and determine the save location. The csv file will contain, among other things, the TLE as a function of range.

In order for a sensor to be visible in Figure B-3, the sensor must be added into the “TLE” group in the database and explicitly set to be allowed to be used for calculations. Figure B-4 is an image of the database viewer program with the “TLE” group loaded into memory. Users can access the database viewer by pressing the “view/edit data in the db” button in Figure B-2. They can then load a group such as the TLE group by pressing “File->load db data” from the pulldown menu at the top of the SMS database viewer program. Note that Figure B-4 has been transposed so that the rows show the attribute names while the columns are the system names.

SMS DB Viewer

File Edit/search Add new WDB data files Data Requests Interpolation View admin user info

group name: TLE

☒ sort data alphabetically ☐ sort data by order it was added

DEVCOM
COSTUME ANALYSIS
CENTER

click on cell to modify value or to get more info:

	LRF sensor 1	linked sensor	LRF sensor 2	load map by hand	LRF sensor 3	LRF sensor 4	LRF sensor 5
Classified by	value not set	value not set	value not set	value not set	value not set	value not set	value not set
confidence	value not set	value not set	value not set	value not set	value not set	value not set	value not set
confidence rational	value not set	value not set	value not set	value not set	value not set	value not set	value not set
Derived from	value not set	value not set	value not set	value not set	value not set	value not set	value not set
Downgrading	value not set	value not set	value not set	value not set	value not set	value not set	value not set
Linked Platform	system: ground tripod	system: test platform	system: ground tripod	value not set	system: ground tripod	system: ground tripod	system: ground tripod
Linked Sensor	system: LRF 1	system: radar 1	system: LRF 2	value not set	system: LRF 3	system: LRF 4	system: LRF 5
Lined Sensor M...	value not set	GMTI	value not set	value not set	value not set	value not set	value not set
Linked Target	value not set	value not set	value not set	value not set	value not set	value not set	value not set
notes	value not set	value not set	value not set	value not set	value not set	value not set	value not set
pedigree	value not set	value not set	value not set	value not set	value not set	value not set	value not set
REC_SECURITY...	value not set	value not set	value not set	value not set	value not set	value not set	value not set
TLE	value not set	value not set	value not set	value dependent	value not set	value not set	value not set
TLE_YN	value not set	value not set	value not set	value not set	value not set	value not set	value not set

Figure B-4. An image of the SMS database viewer program when the “TLE” group is loaded into memory

Most of the attributes listed in Figure B-4 show values that will automatically be copied into the output csv file. Within the SMS Database Viewer, it is possible to add notes or

edit items such as the pedigree of the calculation (i.e., gold, silver, or bronze) and from where the classification of the values are derived. Consult the database viewer software manual to get more information on how to use the viewer to view and modify values in the database.

There may be some sensors that are in the database, and you might not want to calculate a TLE for them. To turn off the ability to calculate the TLE for a given sensor, set the “TLE_YN” attribute to false and leave most of the other values set to “value not set.” Note that there is also a checkbox in the dialog that lets you edit the name and the metadata for a sensor that also explicitly says that the sensor should not be used for calculations. To set the sensors so that the TLE value as a function of range can be calculated and/or displayed, either leave “TLE_YN” as not set or set it to true, make sure that the flag that says that the sensor cannot be used for calculations is not set, and set one or more of the other attributes in the table.

For some sensors, a model to calculate the 3-D TLE with and without self-location error might not be available. For these sensors, the program should just output TLE as a set of CEP50 values as a function or range. To configure a sensor to just output these CEP50 values, one must set the “TLE” attribute for the sensor. The SMS Database Viewer allows for an attribute to be set as being a function of another variable; the test sensor with the name “load map by hand” shows this feature. Figure B-5 is a zoom-in version of Figure B-4. Note that in Figure B-5, the TLE value for this sensor is highlighted in blue. The system has “value dependent” as the TLE value for this sensor, meaning that the TLE value is dependent on another variable. The fact that the name of the variable has not been set does not matter because the system will assume that the TLE is dependent on range.

ATTRIBUTE	VALUE NOT SET	VALUE NOT SET	VALUE NOT SET	VALUE NOT SET	VALUE NOT SET
pedigree	value not set	value not set	value not set	value not set	value not set
REC_SECURITY...	value not set	value not set	value not set	value not set	value not set
TLE	value not set	value not set	value not set	value dependent	value not set
TLE_YN	value not set	value not set	value not set	value not set	value not set

Figure B-5. Zoom-in version of Figure B-4 where one of the TLE values has been set as a function of another variable

Clicking on a TLE value will produce the display similar to that shown in Figure B-6. These are the TLE values that have been entered. The values on the left side are the range values and the values on the right side are the corresponding CEP50 TLE values. To get a TLE value at a different range, the user will be expected to interpolate or extrapolate to estimate a TLE value.

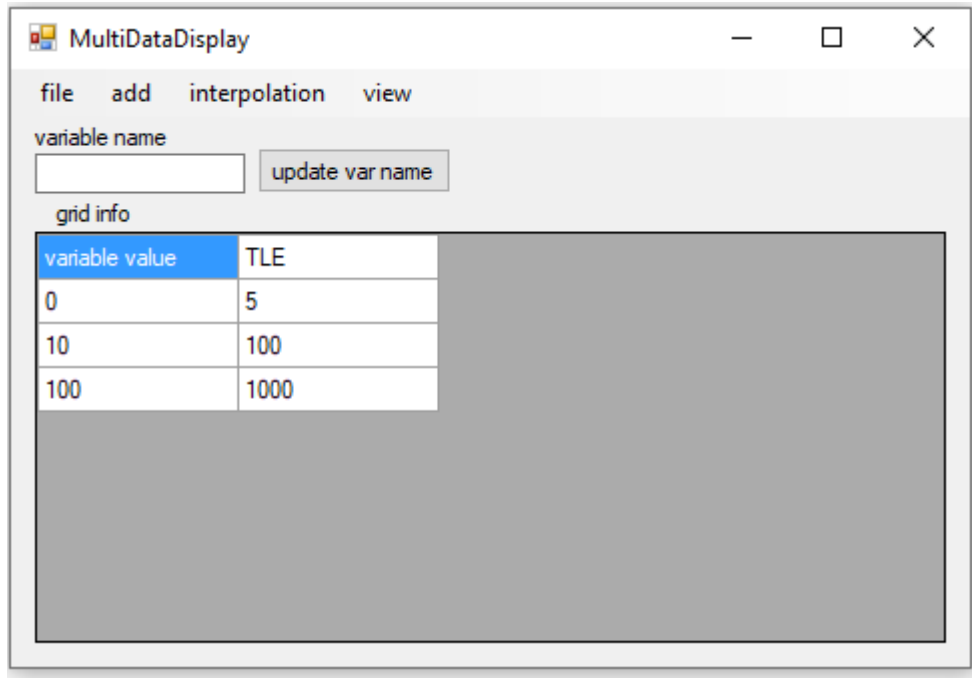


Figure B-6. A display showing how the TLE for a particular sensor is dependent on range

Traditionally, the only TLE values that were supplied were CEP50 versus range. Some customers may not have updated their software to make use of the new TLE values that are supplied as standard deviation in 3-Ds. In addition, there are some sensors where we do not have a model that can calculate anything but CEP50 as a function of TLE. So, the older CEP50 versus range values are always supplied. However, in addition to CEP50 versus range, some customers will be able to make use of the new 3-D TLE with and without self-location error. For most sensors, the parameters in the database should be updated to calculate the new TLE values.

Figure B-7 is a zoom-in version of Figure B-4 that shows the attributes that must be set in order to instruct the program to calculate the TLE and output the new additional 3-D values. Depending on the type of sensor, the "Linked Platform," "Linked Sensor," "Linked Sensor Mode/Parameters," and/or "Linked Target" attributes will need to be set.

Downgrading	value not set	value not set	value not set	value not set
Linked Platform	system: ground tripod	system: test platform	system: ground tripod	value not set
Linked Sensor	system: LRF 1	system: radar 1	system: LRF 2	value not set
Linked Sensor M...	value not set	GMTI	value not set	value not set
Linked Target	value not set	value not set	value not set	value not set
notes	value not set	value not set	value not set	value not set

Figure B-7. Zoom-in version of Figure B-4 showing the attributes needed to explicitly instruct the program to calculate the TLE

The “Linked Platform” attribute must always be set in order to calculate the TLE, and that attribute has been configured so that the only valid values that can be entered are links to systems/sensors from other groups. Even though values for this attribute can be set to be any system from any group, the only systems that make sense are systems in the “TLE Platform” group. Figure B-8 is a screenshot of the SMS Database Viewer after the “TLE Platform” group has been loaded.

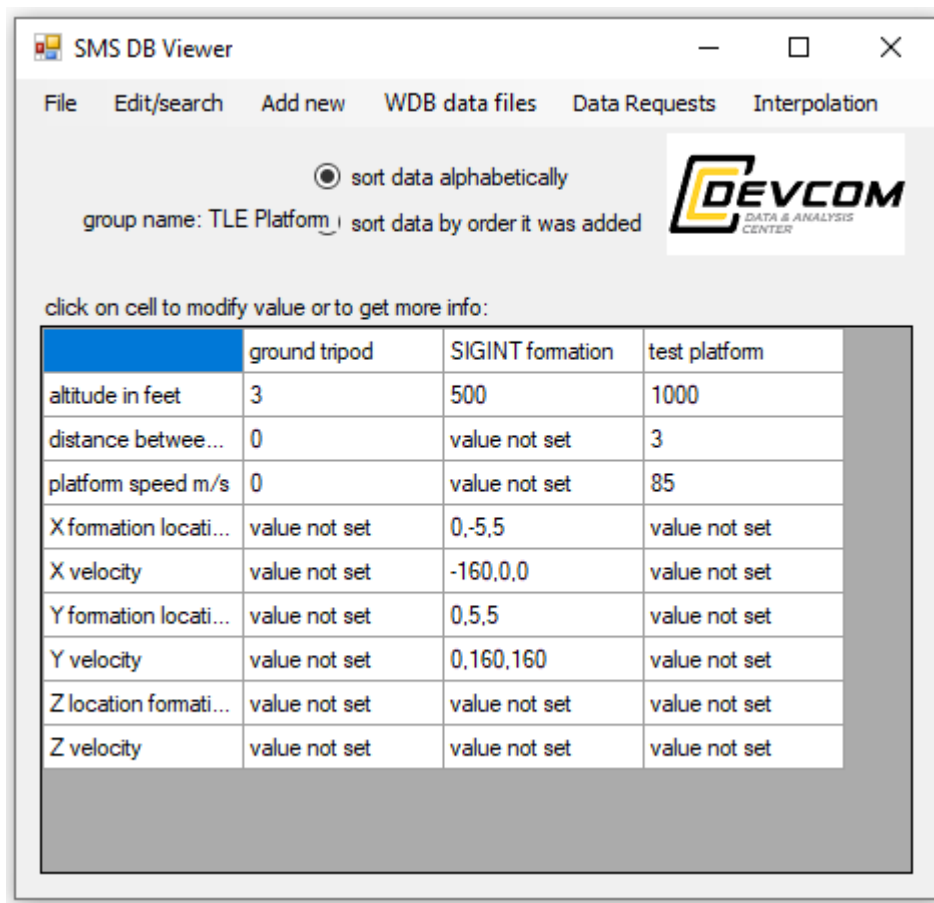


Figure B-8. Image of the SMS Database viewer program after the “TLE Platform” group has been loaded into memory

Figure B-8 shows that three platforms are loaded into the database that can be selected for the “Linked Platform” attribute in the “TLE” group. More platforms can be added to the “TLE Platform” group at any time to provide more options. As seen in Figure B-8, the “TLE Platform” group allows some basic parameters to be set for a platform. The first, and perhaps only, attribute that must be set for a platform is the altitude or height of the platform (in feet). If the platform has more than one antenna (for interferometric measurements) or more than one sensor (for dual signals intelligence [SIGINT] sensors), then the distance between each sensor attribute must be specified. When the platform is a vehicle, the platform speed (in meters/second [m/s]) must be set.

For some sensors, the platform information may need to be more complicated. For example, if the device is a SIGINT sensor, then it may be that the only way get valid measurements is by sending up a group of SIGINT systems on separate platforms to fly in formation. In this case, set the X and Y locations and velocities of the platforms in the “TLE Platform” group. When there is more than one platform in the air at the same time, separate each X, Y, and Z location and velocity with a comma. If the sensors are located on the ground and/or its altitude does not change, leave the Z location and/or the Z velocity as unset and the system will automatically set those values to 0.

Once the “Linked Platform” in the “TLE” group is established, the “Linked Sensor” attribute must be set in order to tell the system for which sensor to calculate the TLE. Once again, the Linked Sensor attribute is configured so that only links to sensors/systems that are part of other groups in the database can be selected. Although the user can select sensors from any group, the only three sensor groups that it makes sense for users to select sensors from are the following: “EO/IR and LRF TLE,” “RADAR,” and “SIGINT Receivers.”

If it is an EO/IR with a LRF that needs the TLE, then once the “Linked Platform” is set, all that remains is to select a sensor from the “EO/IR and LRF TLE” group to be the value of the “Linked Sensor” attribute. At that point, there is enough information to calculate the TLE for that sensor assuming that valid information has been entered for all required attributes for the sensor and platform.

Figure B-9 is a screenshot of the “EO/IR and LRF TLE” group. Figure B-9 is displaying available test sensors and attributes needed to ensure that the system can calculate a TLE. The rows are attributes while the columns show the name of each sensor. Only the azimuth, elevation/tilt, and range uncertainty are required for these sensors.

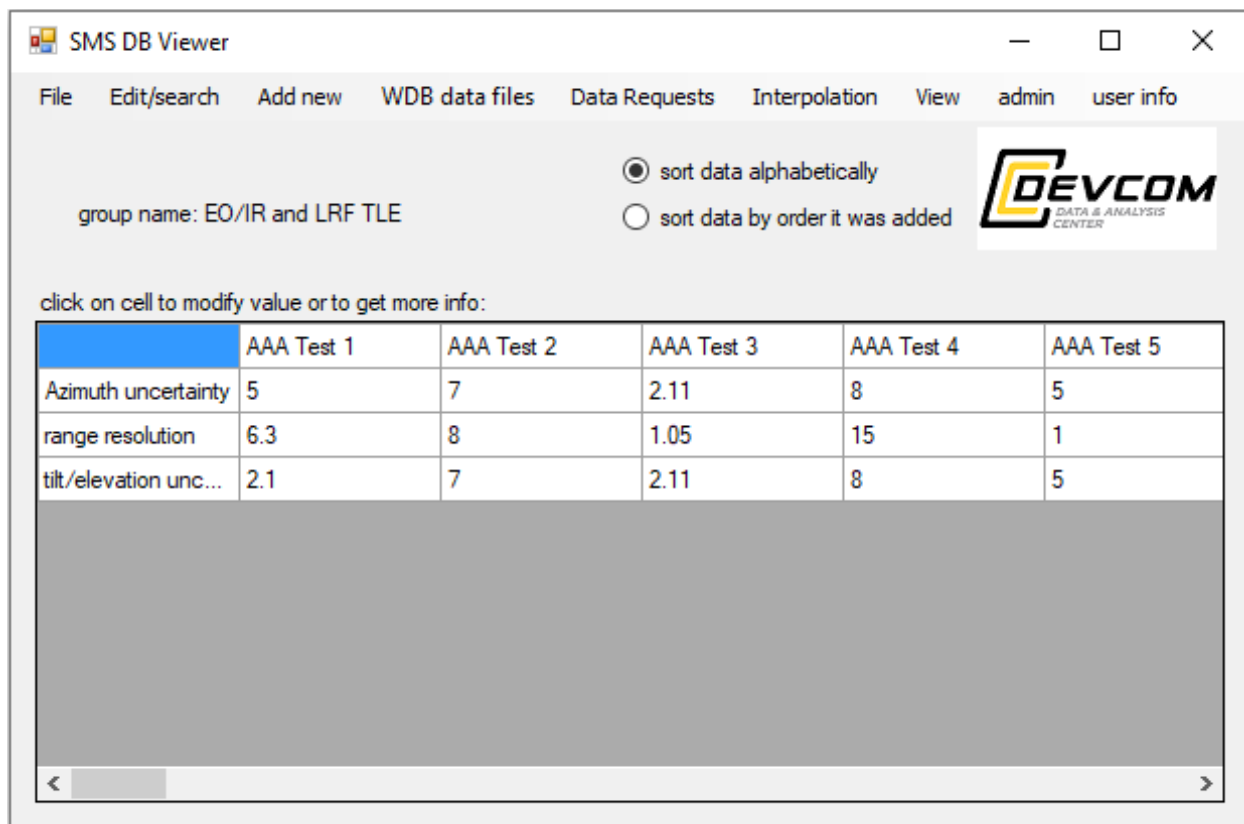


Figure B-9. Screenshot of the database view program after the “EO/IR and LRF TLE” group is loaded in and populated with test sensors

To calculate the TLE for a radar, select a sensor from the “RADAR” group to be the value of the “Linked Sensor” attribute in the “TLE” group sensor. The “RADAR” group is also used to estimate the probability of detection (PD) versus radar cross section (RCS) for radar sensors. Figure B-10 shows the SMS Database Viewer when the “RADAR” group is loaded.

group name: RADAR

☒ sort data alphabetically
☐ sort data by order it was added

click on cell to modify value or to get more info:

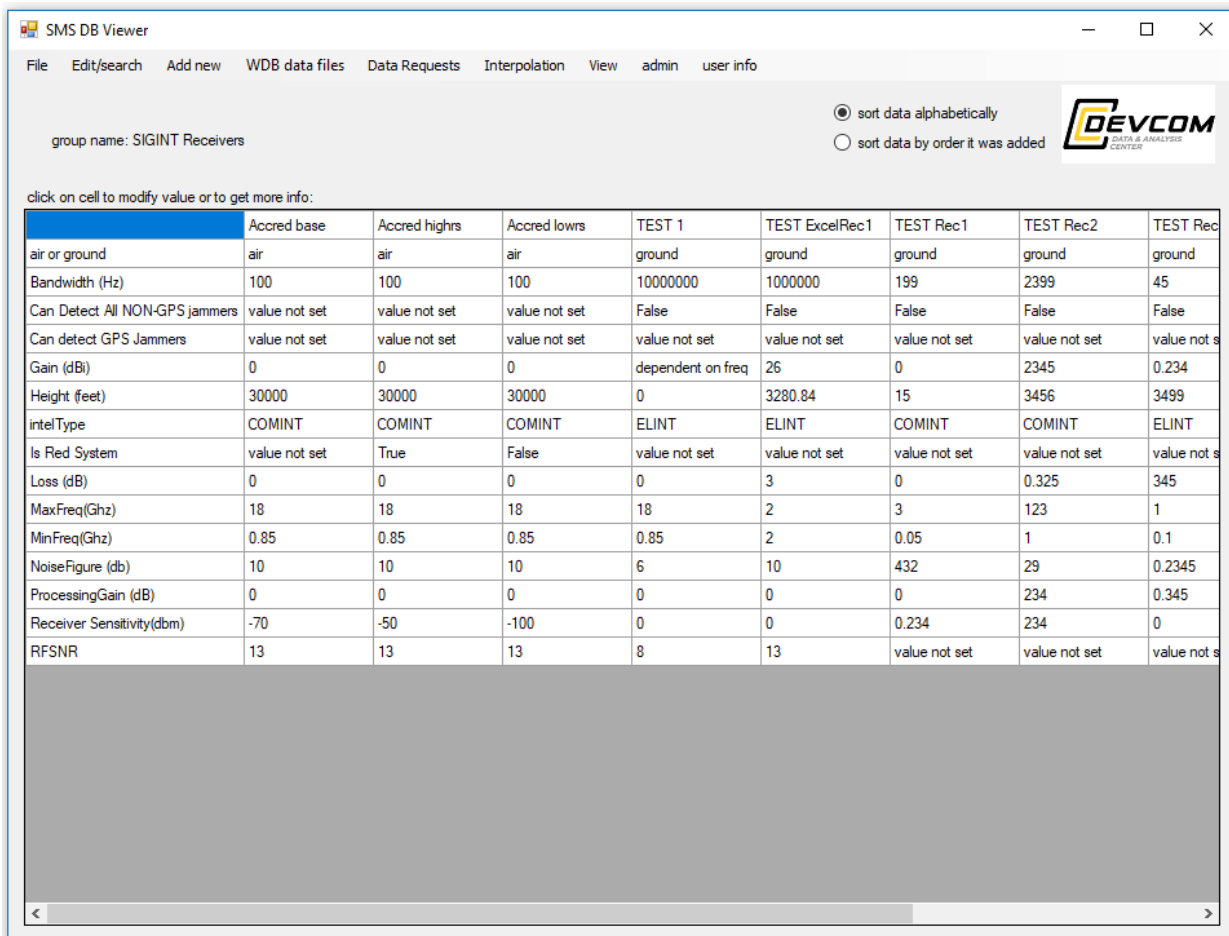
	radar 1	radar 2	radar 3	radar 4	radar 5	radar 6	radar 7
Beam_Width_EL	0	0	0	0	7	0	0
Bn (MHz)	200	200	1	68	3	390	8
Cal Factor	not set	not set	not set	not set	not set	not set	not set
DETECT_DISMOUNTS	not set	not set	not set	not set	not set	not set	not set
DETECT_IJD	not set	not set	not set	not set	not set	not set	not set
f (GHz)	1.2	3.5	90	37	100	90	17.2
FOUAGE_DETECT	not set	not set	not set	not set	not set	not set	not set
FREQUENCY_BAND	not set	not set	not set	not set	not set	not set	not set
Gr (dBi)	19	37	35	19	4	45	24
Gt (dBi)	20	30	35	19	30	45	29
L (dB)	7	15	0	0.6	20	8	11
max az angle	not set	not set	not set	not set	not set	not set	not set
max el angle	not set	not set	not set	not set	not set	not set	not set
Max range (km)	10	12	10	10	9	20	10
min az angle	not set	not set	not set	not set	not set	not set	not set
min el angle	not set	not set	not set	not set	not set	not set	not set
MIN_DIS_VEL	not set	not set	not set	not set	not set	not set	not set
MINIMUM_SLANT_RANGE	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MTI_CLUTTER_ATTEN	not set	not set	not set	not set	not set	not set	not set
NF (dB)	0	0	0	9	0	30	10
NUMBER_PULSES_INTEG	not set	not set	not set	not set	not set	not set	not set
OPERATOR_SET_FOR_AZ	not set	not set	not set	not set	not set	not set	not set
OPERATOR_SET_FOR_EL	not set	not set	not set	not set	not set	not set	not set
PEDIGREE	not set	not set	not set	not set	not set	not set	not set
POLARIZATION	not set	not set	not set	not set	not set	not set	not set
Post detection Gain pu	0	0	0	0	5	0	1
Pre detection pulses In	3000	200	600	4000	20	100	12
PROBABILITY_OF_FALSE	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
Pt (W)	3000	5000	900	2000	100	6000	5000
pulse comp ratio	not set	not set	not set	not set	not set	not set	not set
PULSE_REPETITION_FREQUENCY	0	0	0	0	0	0	0
PULSE_WIDTH	0	0	0	0	0	0	0
RADAR_MODE	not set	not set	not set	not set	not set	not set	not set
RADAR_TYPE	not set	not set	not set	not set	not set	not set	not set
RANGE_GATESIZE	not set	not set	not set	not set	not set	not set	not set
REC_SECURITY_CLASS	U	U	UNCLASSIFIED	U	U	UNCLASSIFIED	U

Figure B-10. Image of the SMS data viewer program when the RADAR group is selected

There are additional attributes that need to be set in the “RADAR” group in order to calculate the TLE as well as to the PD versus RCS (PD vs. RCS is another set of calculations that the SMS team may need to estimate to fulfill a data request). For example, to get the TLE for a GMTI radar, set the “Angle of Arrival Technique” attribute to “monopulse,” “angle centroiding,” or “interferometer.” In addition, set the “Coherent integration” attribute as true or false, and the “Waveform type” attribute to “LFM” or “Rectangular.” To calculate the TLE for a synthetic aperture radar (SAR), set the “Sar

resolution m” (this value should be available in the radar’s specification sheet). The target RCS and the clutter scatter coefficient are needed for both SAR and GMTI radar s, but those are set as global program parameters and will be the same for all sensors. The TLE is different when a radar is operating in SAR mode than when it is operating in GMTI mode, and because some radar systems can operate in either mode, it is necessary to specify either “SAR” or “GMTI” in the “Linked Sensor Mode/Parameters” attribute.

Finally, to calculate the TLE for a SIGINT system, set the “Linked Sensor” attribute to a system/sensor in the “SIGINT Receivers” group. This table is also used to calculate the PD for SIGINT systems (yet another calculation that may need to be performed for a given data request). Figure B-11 is a screenshot of the database viewer with the “SIGINT Receivers” group loaded into memory.



group name: SIGINT Receivers

☒ sort data alphabetically
☐ sort data by order it was added

click on cell to modify value or to get more info:

	Accred base	Accred highs	Accred lows	TEST 1	TEST ExcelRec1	TEST Rec1	TEST Rec2	TEST Rec
air or ground	air	air	air	ground	ground	ground	ground	ground
Bandwidth (Hz)	100	100	100	10000000	1000000	199	2399	45
Can Detect All NON-GPS jammers	value not set	value not set	value not set	False	False	False	False	False
Can detect GPS Jammers	value not set	value not set	value not set	value not set	value not set	value not set	value not set	value not s
Gain (dBi)	0	0	0	dependent on freq	26	0	2345	0.234
Height (feet)	30000	30000	30000	0	3280.84	15	3456	3499
intelType	COMINT	COMINT	COMINT	ELINT	ELINT	COMINT	COMINT	ELINT
Is Red System	value not set	True	False	value not set	value not set	value not set	value not set	value not s
Loss (dB)	0	0	0	0	3	0	0.325	345
MaxFreq(Ghz)	18	18	18	18	2	3	123	1
MinFreq(Ghz)	0.85	0.85	0.85	0.85	2	0.05	1	0.1
NoiseFigure (db)	10	10	10	6	10	432	29	0.2345
ProcessingGain (dB)	0	0	0	0	0	0	234	0.345
Receiver Sensitivity(dbm)	-70	-50	-100	0	0	0.234	234	0
RFSNR	13	13	13	8	13	value not set	value not set	value not s

Figure B-11. SMS database viewer with the SIGINT receiver group loaded

The TLE of a SIGINT receiver can change depending on the target it is viewing so the target must be specified using the “Linked Target” attribute; users must set it to a sensor/system in the “SIGINT Transmitters” group. Figure B-12 is a screenshot of the Database Viewer when the “SIGINT Transmitters” group is loaded into memory.

group name: SIGINT Transmitters

☒ sort data alphabetically
☐ sort data by order it was added

click on cell to modify value or to get more info:

	sensor 1	target 2	sensor 3	radar 10 linked	Test 1	Test 2	Test 3	Test 4	Test 5
air or ground	ground	ground	ground	air	air	air	ground	ground	air
classification	U	U	UNCLASSIFIED	U	U	U	U	U	U
extra	value not set	value not set	value not set	value not set	value not set	value not set	value not set	value not set	value not set
f Ghz	12	12	10	5	11	2	2	0.2	5
Frequency hopper	value not set	value not set	TRUE	FALSE	value not set	value not set	value not set	value not set	value not set
Gt (dB)	10	10	20	30	5	19	20	12	10
height m	0	0	0	100	50	1000	1	4	0
Jams GPS	value not set	value not set	value not set	value not set	value not set	value not set	value not set	value not set	value not set
Lt (dB)	0	0	0	3	1	0.8	0	0	0
max freq Ghz	12	6	10	5	5	1	2	0.1	1
Max Pt (W)	100	10	50	1000	32	20	6	7	4
minFreq Ghz	12	18	10	5	17	3	2	0.3	9
type	radar	radio	radar	radar	jammer	radio	radar	jammer	jammer

Figure B-12. SMS database viewer when the SIGINT transmitter group is loaded in

Not all SIGINT sensors can detect all SIGINT transmitters; for example, a transmitter may output radiation with a wavelength outside of the range for which a SIGINT receiver is searching. The SIGINT sensors also come in Communications Intelligence (COMINT) and Electronic Intelligence (ELINT) types where COMINT systems are designed to search for things such as radios, whereas ELINT systems are designed to search for things such as radars. When a SIGINT transmitter is paired with a noncompatible SIGINT receiver, the resultant calculated TLE may not make sense.

Often, SIGINT systems must fly in a formation in order for them to work. The “TLE Platforms” group is used to add a specific flying formation, and the “Linked Platform” attribute will need to be set to that system to use the formation.

There are multiple algorithms that SIGINT systems use to find the location of a target, including the following: angle of arrival (AoA), time difference of arrival (TDoA), and/or frequency difference of arrival (FDoA). To specify which algorithm the system is using, enter “AoA,” “TDoA,” and/or “FDoA” into the “Linked Sensor Mode/Parameters” attribute of the “TLE” group. A system can use one or more of these algorithms at the same time to increase accuracy or receive a valid 3-D measurement of the location of an emitter when there are only two SIGINT systems in the air. If a SIGINT is using more than one algorithm at once, specify this by listing them all in the “Linked Sensor Mode/Parameters” attribute and separating them using a comma.

In addition to the parameters described above, there are other parameters that affect how the program calculates TLE. For example, the program’s global parameters can be used to set the minimum, maximum, and step between each range measurement that the system will use when calculating range versus TLE. Because these values do not usually need to be modified, setting the “TLE” group to the values specified in this section will allow the system to calculate the TLE for a wide range of different sensors and sensor types.

LIST OF ACRONYMS

2-D/3-D	Two-Dimensional/Three-Dimensional
AoA	Angle of Arrival
CEP50	50% Circular Error Probability
COMINT	Communications Intelligence
CSV	Comma-Separated Value
DAC	DEVCOM Analysis Center
DEM	Digital Elevation Model
DEVCOM	U.S. Army Combat Capabilities Development Command
DTED	Digital Terrain Elevation Data
ELINT	Electronic Intelligence
EO/IR	Electro-Optical/Infrared
FDoA	Frequency Difference of Arrival
GMTI	Ground Moving Target Indication
GPS	Global Positioning System
GUI	Graphical User Interface
INS	Inertial Navigation Sensor
JFIIT	Joint Fires Integration and Interoperability Team
LFM	Linear Frequency Modulated
LRF	Laser Rangefinder
M&S	Modeling and Simulation
MUSTC	Multipurpose Universal Simplified TLE Calculator
PD	Probability of Detection
PNT	Position, Navigation, and Timing
RCS	Radar Cross Section
RF	Radio Frequency
RSS	Root Sum Square
SAR	Synthetic Aperture Radar
SFF	Standard File Format
SIGINT	Signals Intelligence
SLE	Self-Location Error
SMS	Signals, Measurements, and Signatures

SNR	Signal-to-Noise Ratio
TDoA	Time Difference of Arrival
TLE	Target Location Error

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