TECHNICAL REPORT

Munitions Classification Library Update and Expansion
Blossom Point Data Collection Report

ESTCP Project MR-201424

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Nagi Khadr
Craig Murray
Parsons

D. A. Steinhurst
Naval Research Laboratory

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6. AUTHOR(S) Nagi Khadr*, Craig Murray*, D. A. Steinhurst†	**5d. PROJECT NUMBER** MR-201424 **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**

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Parsons
1776 Lincoln Street
Denver, CO 80203

Naval Research Laboratory
Code 6110
4555 Overlook Avenue, SW
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

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9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Environmental Security Testing and Certification Program
4800 Mark Center Drive
Suite 17D08
Alexandria, VA 22350-3605

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*Parsons, 1776 Lincoln Street, Denver CO, 80203

†Nova Research, Inc., 1900 Elkin Street, Suite 230, Alexandria, VA 22308

14. ABSTRACT

Advanced geophysical classification data were collected for 66 example munitions at the Blossom Point test facility using three sensors: the Modified Portable Decoupled Electromagnetic Induction Sensor (MPEDEMIS), the Time-domain Electromagnetic Multi-sensor Towed Array Detection System (TEMTADS) 2x2, and the MetalMapper. These data were inverted to determine primary axis polarizabilities for the example munitions. The inversion results were converted to Hierarchical Data Format version 5 (HDF5) and Geosoft Oasis Montaj formats to be used as libraries for future advanced geophysical classification projects. The process and requirements for data acquisition were documented in an attached standard operating procedure (SOP) to facilitate library additions by other technology users.

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ACRONYMS

Abbreviation	**Definition**
AOL	Advanced Ordnance Locator
CRREL	Cold Regions Research and Engineering Laboratory
EMI	Electro-Magnetic Induction
ESTCP	Environmental Security Technology Certification Program
HDF	Hierarchical Data Format
ISO40	Industry Standard Object (Schedule 40)
ISO80	Industry Standard Object (Schedule 80)
MEC	Munitions and Explosives of Concern
MM	MetalMapper
MPV	Man-Portable Vector
MTADS	Multi-sensor Towed Array Detection System
NAVSEA	Naval Sea Systems Command
NRL	Naval Research Laboratory
OD	Outer Diameter
PEDEMIS	PortablE Decoupled ElectroMagnetic Induction Sensor
MPEDEMIS	Modified PEDEMIS
PVC	Poly Vinyl Chloride
RX	Receiver
SERDP	Strategic Environmental Research and Development Program
SNR	Signal-to-Noise Ratio
SOP	Standard Operating Procedure
TEM	Time-domain ElectroMagnetic
TEMTADS	Time-domain ElectroMagnetic mTADS
TX	Transmitter
USACE	US Army Corps of Engineers
UXO	Unexploded Ordnance

1.0 INTRODUCTION

Ninety percent of excavation costs on most UXO/MEC projects are related to removing scrap metal that does not represent an explosive hazard. Advanced time-domain electromagnetic induction (TEM) systems and response modeling software – both developed under SERDP and ESCTP research efforts – offer to significantly reduce the quantity of scrap metal that needs to be removed during a MEC cleanup project. This generally comes about by using the system response model to extract parameters characteristic of the metal item being measured by the sensor and comparing these to a library of munitions parameters. If a good match ensues, the item is classified as munitions and flagged for excavation. Otherwise, the item is either classified as clutter and deemed safe to leave in the ground or flagged for further scrutinization.

1.1 BACKGROUND

With ESTCP support, Geometrics has already commercialized an advanced TEM system called the MetalMapper (MM) [1] and is currently undergoing a mass production phase that will include other advanced TEM systems, such as the TEMTADS 2x2 [2] and the MPV2 [3]. Historically, all these systems were developed by Dave George of G&G Sciences, Inc (through NAVSEA, SERDP and ESTCP support) with various alliances (CRREL, NRL, Geometrics, etc.) and are all based on similar hardware and electronics components, but in differing quantities and configuration. Using a standardized modular approach, Geometrics is aiming to have a product list of advanced TEM sensors – including custom configurations – that will operate using a common set of acquisition parameters. The expectation is that there will be a couple of standard settings for these parameters, depending on whether the instrument is used in cued/static mode or in survey/dynamic mode. In addition, an advanced mode option will be available for the customization of the acquisition parameter settings. The expectation is also that the output data will be standardized and exported in the form of an HDF5 file [4].

UX-Analyze [5] is an add-on to Geosoft's Oasis Montaj geophysical processing environment and its development has also occurred with support from ESTCP. In its current form, it can handle cued data from the MM and TEMTADS 2x2 systems, with dynamic data handling for these systems on the horizon. Using UX-Analyze, a data processor can apply physics-based models to measured sensor responses due to buried objects and estimate principal axis polarizability curves to compare with a library of known munitions curves. Geophysical contractors applying classification typically use the UX-Analyze software to extract the polarizability curves from collected sensor data to produce prioritized dig lists. To accommodate the next generation Geometrics systems, the expectation is that these systems' output HDF5 data files will be accepted for import into UX-Analyze.

The existing libraries in UX-Analyze have been successfully utilized in classification efforts to date. However, deficiencies do abound and this project addresses some of the more important shortcomings to these libraries. Specifically:

1. Until very recently, UX-Analyze dealt exclusively with cued data, and so classification capabilities using survey data were not an option. Since dynamic data handling is now in

the pipeline, there will be great interest in exploiting classification based on dynamically collected data using the next generation Geometrics advanced TEM sensors. For this purpose, a munitions classification library applicable to the proposed standard dynamic mode acquisition parameters setting will be crucial.

2. The existing libraries consist of two separate libraries each dedicated to a specific sensor – the MM and the TEMTADS. This division is artificial and based solely on the legacy choice of acquisition parameter settings for each system. The TEMTADS was designed based on the desire to allow the body eddy currents to more fully develop and decay in larger munitions items. For this reason, longer on and off times were specified for the transmit coil current excitation. A more natural division for the libraries should be based on these on and off times instead. Figure 1.1 shows the resulting polarizations for a 57mm projectile with three different transmit on and off times (a duty cycle of 50% ensures that the on and off durations are the same). Here, the 25 ms decay would belong to the current TEMTADS library, and the 8 ms decay to the current MM library (using the expected standard static mode setting). The 2.7 ms decay would belong to the munitions classification library applicable to the expected standard dynamic mode setting.

3. The libraries include all the common munitions items, but are missing many less common items.

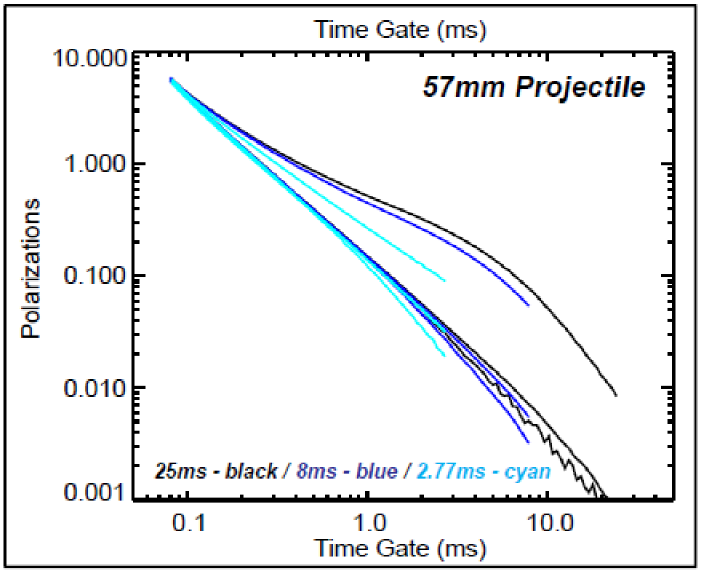


Figure 1-1 – Polarizations for a 57 mm projectile for different transmit coil current on/off times

1.2 OBJECTIVES OF THE DATA COLLECTION

Based on the observed shortcomings listed in the previous section, the objectives of the data collection are to:

1. Produce three classification libraries of polarizability curves for common munitions, each with a different decay length – i.e. 2.7 ms, 8.3 ms and 25 ms. The libraries of 2.7 ms and 8.3 ms decay length will be applicable, respectively, to data collected using the standard dynamic and static mode settings proposed by Geometrics for their advanced TEM systems. The library of 25 ms decay length polarizability curves will be applicable to data collected using a customized set of acquisition parameters that have traditionally been the standard static mode settings for the TEMTADS. The libraries can then be used by all advanced TEM sensors – past and future – with the particular library being used depending on the acquisition parameters chosen during data collection.

2. Acquire data over less common munitions to expand the existing libraries' munitions inventory.

3. Develop a standard operating procedure (SOP) that will allow members of the community to make their own additions to any, or all, of the classification libraries.

2.0 TECHNOLOGY

Three different sensor systems were used during the initial phase of the data collection: a modified PEDEMIS [6]; a TEMTADS 2x2; and a MM. All systems are based on hardware technologies developed by G&G Sciences over the years through NAVSEA, SERDP and ESTCP funding. The PEDEMIS was modified specifically for this project so that it effectively acts as a TEMTADS 3x3. The added spatial coverage that the 3x3 offers over the 2x2 (i.e. by the extra five transmitter/receiver sensor combinations) provides additional "look angles" to the target which will help determine whether there are sufficient differences in the estimation of polarizability curves for the larger munitions items to warrant use of the 3X3 for the remaining phases of the data collection.

2.1 TECHNOLOGY DESCRIPTION

2.1.1 Advanced TEM Sensor Components

2.1.1.1 Transmitter Coils

There are currently two types of transmitter (TX) coils. The larger TX coils are 1 m square loops with 10 turns and are part of the MM design (see Figure 2-5). The smaller 35 cm square TX coils with 25 turns are shown in Figure 2-1 with an inset Styrofoam mold for snug placement of a tri-axial receiver (RX) cube at the center. Both the modified PEDEMIS (MPEDEMIS) and the TEMTADS 2x2 use this TX/RX coil combination as the basic building block for their systems.

Figure 2-1 – TX/RX coil combination that forms the basis for both the MPEDEMIS and the TEMTADS 2x2

2.1.1.2 Tri-axial Receiver Cubes

Each tri-axial RX cube has three orthogonal coils all of slightly different sizes and number of turns (see Figure 2-2 for a close up). The number of turns of each coil varies so that the difference in size is compensated for and there is no difference in the effective gain between the coils. The latest RX cubes are similar in design to those used in the second-generation Advanced Ordnance Locator (AOL) [7] and the first generation Geometrics MM system but with dimensions of 8 cm rather than 10 cm.

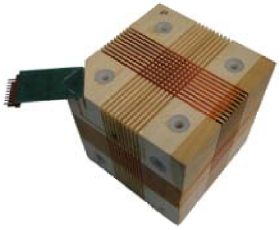


Figure 2-2 – A close up of the tri-axial RX cube

2.1.2 PEDEMIS

The original configuration of PEDEMIS, as shown in Figure 2-3, consisted of a coplanar 3x3 array of 34 cm square TX coils with a separate movable 56 cm square array of tri-axial RX cubes. The vertical non-metallic handle on the RX array is there to facilitate maneuverability. The TX array has a center-to-center distance of 40 cm yielding a 120 cm square array. The RX array schematic representation shows a 3x3 configuration with 20 cm center-to-center spacing. The modification simply dismantles the RX array and fixes each RX cube in the center of each TX coil, as discussed in Section 2.1.1.1. The default dataset for this system is composed of 9 transmitters x 9 receivers x 3 components, or 243 secondary magnetic field decays. The start and end times of the decays, as well as number of gates, will depend on the specifics of the acquisition parameter settings.

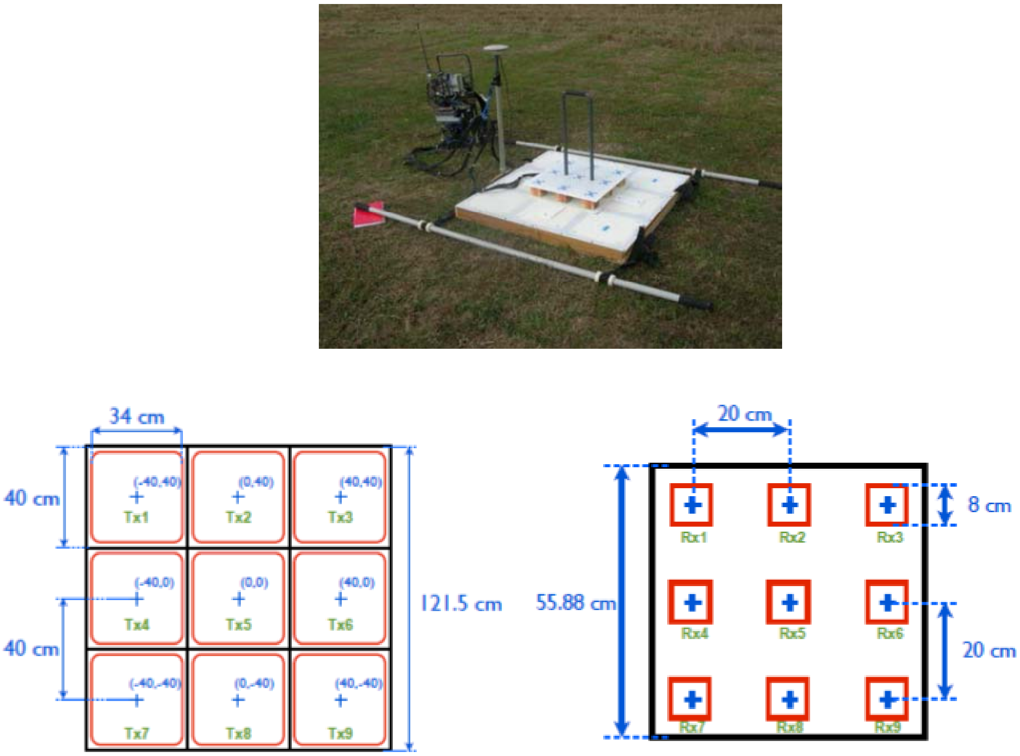


Figure 2-3 – The original PEDEMIS with schematics showing the TX array (left) and the RX array (right). The modification dismantles the RX array and fixes each RX cube in the center of each TX coil.

2.1.3 TEMTADS 2x2

The TEMTADS 2x2 is a man-portable system comprised of four TX/RX combination sensors as discussed in Section 2.1.1.1 and arranged in a 2x2 array as shown schematically in Figure 2-4. The center-to-center distance is 40 cm yielding an 80 cm square array. The system is fabricated from PVC plastic and fiberglass with the array typically deployed on a set of wheels resulting in a sensor-to-ground offset of approximately 18 cm. The transmitter electronics and the data acquisition computer are mounted in the operator backpack. The default dataset for this system is composed of 4 transmitters x 4 receivers x 3 components, or 48 secondary magnetic field decays. The acquisition parameter settings will determine the start and end times of the decays, as well as number of gates recorded.

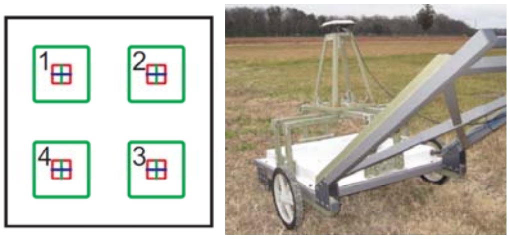


Figure 2-4 – The TEMTADS 2x2 with schematic

2.1.4 MetalMapper

The MM consists of three larger TX coils (as discussed in Section 2.1.1.1) oriented orthogonally to each other and aligned in a manner consistent with the tri-axial RX cubes. Referring to Figure 2-5, the Z (horizontal) TX coil is the bottom coil and contains the RX cubes within the box frame. The schematic shows the location of the RX cubes which are spaced every 13 cm perpendicular to the line of travel. The bottom coil is the only TX coil that is required during dynamic data acquisition. The X and Y TX coils are the vertical coils and are of slightly different size in order to fit together. The default static dataset for this system is composed of 3 transmitters x 7 receivers x 3 components, or 63 secondary magnetic field decays. Again, the

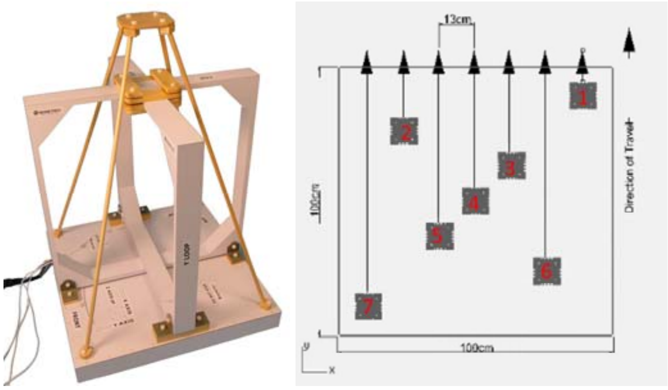


Figure 2-5 – The MM with a schematic showing the positions of the RX cubes within the bottom Z TX coil box frame acquisition parameter settings will determine the start and end times of the decays, as well as number of gates recorded.

3.0 PERFORMANCE OBJECTIVES

Performance objectives for the data collection are given in Table 3-1. These provide the basis for evaluating whether or not the data collected is successful in meeting the project objectives. The first three performance objectives ensure that the requisite amount of data is collected for each munitions item on the library inventory list. The fourth applies to all data sets collected specifically for the purpose of extracting polarizability curves (or βs – see Section 5.2) to add to the libraries and ensures that these estimated curves are sufficiently accurate. The fifth performance objective applies to ensuring that the system remains stable throughout the collection period (i.e. repeatability). The sixth applies towards validating the expected operation of the sensor used (i.e. calibration and inter-sensor comparisons). Finally, the last performance objective is a qualitative one: it ensures that the SOP – that allows any geo-technician to add their own items to the classification library – is clear and easy to follow.

Table 3-1 – Performance Objectives

	Performance Objectives	**Metric**	**Success Criteria**
	For each munitions item		
1	Were the complete metadata collected?	Table 1 in Appendix A of SOP (Appendix B); photograph(s)	Table completed & photograph(s) taken
2	Were data at all three decay length settings collected?	Library checklist	All libraries addressed
3	Were all required data collected?	Step **3.6**C of SOP (Appendix B)	*At a minimum*, 3 required orientations at two depths
	For each data set collected for extraction of βs		
4	Was inversion successful?	Fit coherence (with sanity check of position & orientation parameters)	Fit coherence > 0.98 (with X,Y,Z to within +/- 10 cm and Tilt & Azimuth to within +/- 30^{o})
	Repeatability: Daily QC data		
5	Medium ISO80 data βs	β fit results	βs ± 10%
	Calibration/Validation		
6	Inter-system βs comparison (for identical TX on/off durations)	3-β match	UX-Analyze 3-β match metric > 0.9

3.1 OBJECTIVE: COLLECT COMPLETE METADATA SET

It is important that all the munitions items in the classification libraries are as completely described as possible. This metadata will accompany the library classification data and be an embedded part of it.

3.1.1 Metric

The checklist, as given by the row entries of Table 1 in Appendix A of the SOP (Appendix B), represents all the useful descriptive information that can be obtained for a munitions item.

3.1.2 Success Criteria

Success will be achieved – for a given munitions item to be added to the classification libraries – when all the row entries have been addressed. The entries of the table must be addressed by a UXO technician.

3.1.3 Results

All metadata were measured and recorded by a UXO technician. Photographs were taken of all items included in this phase of the project.

3.2 OBJECTIVE: COLLECT DATA WITH ALL THREE DECAY SETTINGS

Recall that the main objective is to produce three classification libraries of polarizability curves for common munitions, each with a different decay length – i.e. 2.7 ms, 8.3 ms and 25 ms.

3.2.1 Metric

The checklist, as given by the acquisition parameter settings for the three decay lengths for the sensor being used (Tables 4-2 – 4-4).

3.2.2 Success Criteria

Success will be achieved – for a given munitions item to be added to the classification libraries – when data is collected for all three decay length settings.

3.2.3 Results

Data were collected with all three decay length settings for all items included in this phase of the project.

3.3 OBJECTIVE: COLLECT DATA FOR MINIMUM ITEM CONFIGURATIONS

The goal of the library polarizability curves is to provide a means of classifying the metallic objects that are encountered when conducting geophysical surveys. Sometimes, however, and especially for compound or extended munitions, more than one set of polarizability curves are necessary to globally characterize the item. In order to collect sufficient data to begin to address this issue, a minimum of six data sets – i.e. three distinct item orientations at two different ranges – must be collected. In addition, before and after background data sets are also necessary.

3.3.1 Metric

The checklist, as given by step **3.6**C of the SOP (Appendix B), represents the minimum recommended background and item configuration data sets needed to ensure global characterization of the item.

3.3.2 Success Criteria

Success will be achieved – for a given munitions item to be added to the classification libraries – when step **3.6**C of SOP (Appendix B) has been completed. Time permitting, and whenever there exists great variability in the polarizabilities across the different item configurations, more ranges and orientations should be added to the list.

3.3.3 Results

Data were collected with three orientations (horizontal, vertical nose-up, and vertical nose-down) for all items at two ranges. Additional ranges were used when the polarizabilities at the two initial ranges were inconsistent.

3.4 OBJECTIVE: POLARIZABILITY ESTIMATION ACCURACY

The polarizability curves that populate the libraries are estimated from collected data using a dipole model inversion process discussed in Section 5.2.

3.4.1 Metric

The fit coherence, as defined in Section 5.2, presents a measure of how well the model agrees with the data. In addition, the position and orientation fit parameters must be checked to ensure convergence to the proper solution.

3.4.2 Success Criteria

The fit coherence can range from 0 to 1, with 1 occurring when the model matches the data perfectly. Success will be achieved if the fit coherence > 0.98. This must be accompanied by a sanity check of the position and orientation fit parameters, where X,Y & Z are to be within +/- 10 cm of the item placement location and the tilt & azimuth are to be within +/- 30^o of the item placement orientation.

3.4.3 Results

The inversion results for all data collected generally fit the model with a coherence of at least 0.98. The exception to the rule occurred predominantly for the MPEDEMIS on items of large aspect ratio (i.e. greater than 6) where SNR was either low or where the item (horizontally configured, in most cases) had to be brought much closer to the sensor than the recommended starting point of the largest item dimension, L in order to increase the SNR. The majority of the exceptions had a fit coherence greater than 0.97 with some above 0.96 and the worst being above 0.93 for the 2.36in M6 item (aspect ratio of 9) at all three decay lengths configured horizontally at a depth of ~L/2.

All fit locations matched the X and Y coordinates within +/- 10 cm of the placement location with the exception of just three misses for the 120mm M931 munitions item. The three misses were collected using the MM over the item oriented horizontally at the larger of the two depths and put the Y coordinate to within just under -12cmThe same item at the shallower depth, along with the data collected by the MPEDEMIS at two depths show the Y to be within a consistent -8.4cm – -9.5cm range which already comes close to the bound limit of -10cm. This may suggest a need to relax the X, Y location criteria for larger composite items to +/- 15 cm.

The fit locations matched the Z coordinate within +/- 10cm of the placement location generally only for small and medium items, and for horizontally oriented larger items. The larger items in a vertical orientation had the most difficulty with the largest miss being just under 30cm.

The reported angles were generally all within +/- 30^{o} of the item placement orientation. The exceptions to the rule occurred for the larger munitions items (e.g. the 8in M106, 155mm M107 and the BDU33 MK76) and the smaller composite items (in particular, the 20mm TP with cartridge), but not necessarily consistently from one sensor to the other. For example, for the 20mm TP with cartridge placed horizontally in an across-track configuration, the MPEDEMIS fits wanted to consistently orient the dipole horizontally in an along-track direction for all decay lengths. The MM, however, had no trouble orienting the dipole along the item's primary axis for the same configuration case. In a different flavor, the 155mm M107 experienced the same symptom for the MM but at only the 2.7ms decay, with the longer decays having no trouble and the MPEDEMIS and TEMTADS experiencing another symptom also at only the 2.7ms decay. Indeed most of the orientation discrepancies occurred for only the 2.7ms decay fits. The latter phenomenon is likely a result of the way eddy currents form and evolve within the item due to it's excitation by the specific sensor, with the longer decays allowing the body currents to settle along a preferred direction (i.e. the primary axis of the item, in most cases).

3.5 OBJECTIVE: COLLECT DAILY ISO80 DATA FOR SYSTEM(S) USED

It is important to demonstrate that all systems used in collecting library-quality data are stable. This means that data collected over identical objects under similar circumstances should provide reproducible results. If a system is only used for one day, than both a start of day and end of day measurement is needed to show system stability.

3.5.1 Metric

The three βs for a medium Schedule 80 Industry Standard Object (ISO80).

3.5.2 Success Criteria

Success is achieved if the estimated βs for the medium ISO80 are consistently within a ± 10% envelope.

3.5.3 Results

The daily datasets collected over a medium ISO80 were consistently within a ± 10% envelope.

3.6 OBJECTIVE: INTER-SYSTEM POLARIZABILITY COMPARISON

An equally important objective is to demonstrate that all systems used in collecting library-quality data are operating as expected and agree with each other. This is done by comparing the extracted βs for data collected over a medium ISO80 across the advanced TEM sensors.

3.6.1 Metric

The 3-β library match metric is a metric used in UX-Analyze to compare the βs estimated from collected data over an object with any other set of βs (i.e. from a library, or estimated from other data collected over the object). It is based on using all three βs to compare size and shape aspects of the object.

3.6.2 Success Criteria

A 3-β match metric of 1 will occur when the object βs match the other βs perfectly. Generally, anything greater than 0.9 is considered a good match.

3.6.3 Results

All βs extracted from datasets collected over a medium ISO80 matched each other with a metric of greater than 0.9. This was true regardless of the advanced TEM sensor that was used to collect the data from which the βs were derived.

4.0 DATA COLLECTION

4.1 CONCEPTUAL DESIGN

Two phases of data collection were envisioned to achieve the objectives outlined in section 1.2. The first phase – which this report describes – entails data collection over common munitions items addressing: (1) the viability of using one advanced TEM sensor to produce the three classification libraries to be used by any advanced TEM sensor; and (2) the development of a SOP that will allow members of the community to make their own additions to any, or all, of the classification libraries. The next phase entails data collection over less common munitions items.

Data were collected with the MPEDEMIS over all the unique items in the existing collection at the Blossom Point Army Research Laboratory facility over a period of three weeks. The items are listed in section 4.2 in Table 4-1 with descriptor columns detailing the exact type and condition of each item, as well as whether they were also measured using the MM and TEMTADS 2X2. An additional week was spent measuring 44 of the items with the MM and an additional 2 days were spent measuring 20 of the items with the TEMTADS 2X2.

The question of whether different advanced TEM sensors respond to an object in the same way is answered affirmatively in section 4.4 (for a medium ISO80) and section 4.6 (for a couple of example items). The SOP was drafted early in the data collection with the MPEDEMIS and subsequently exercised and revised during data collection with the MM. The current working version is in Appendix B.

The current final data product is an HDF5 file for every unique munitions item for one of the three classification libraries as specified in section 5.2. These contain as many library entries of βs as necessary to globally characterize the item, as well as the item metadata. The criteria by which the entries are selected are discussed in section 4.6.

The goal of the next phase of the data collection is to expand the library by collecting data over additional munitions. The list of munitions to include in the expanded library was developed by surveying geophysicists from the NAOC technology committee, USACE geophysicists, and representatives of the Navy and Air Force. Ten individuals responded requesting 116 additional items (including multiple variants for several items) be added to the library. Project personnel are contacting the curators of several munitions museums and collections to find examples of the requested items and arrange for data collection visits in 2015.

4.2 MEASURED ITEMS

Table 4-1 – The 66 unique items (58 munitions + 6 ISOs + 2 calibration spheres) that belong to the Blossom Point common munitions collection and that were measured by the MPEDEMIS. Subsets of the items were also measured by the MM and 2X2 sensors as indicated by their respective columns – Y for ‘yes’ and ‘N’ for ‘no’.

Name	Mark/Mod	Class*	Fins	Fuse	Spotting Charge	Rotating Band	Condition**	MM	2X2	Comments
20mmAA	MK7	P	N	N	N	Y	F/W	N	N	Dummy Round
20mmAA	MK7	P	N	N	N	Y	F/W	Y	Y	
20mmTP	M55A3B1	P	N	N	N	Y	U/P	Y	Y	
20mmTP	M55A3B1	P	N	N	N	Y	U/P	Y	N	With Cartridge
25mm	M794	P	N	N	N	N	Pristine	Y	N	With Cartridge
37mm	M59	P	N	N	N	N	F/W	Y	N	
37mm	M59	P	N	N	N	Y	F/W	Y	N	NRL37-5
37mm	M59	P	N	N	N	Y	F/W	Y	N	NRL37-124
37mm	Trenchart/Hotchkiss	P	N	N	N	Y	U/P	Y	Y	(pre WWI)
37mm	M74 HETP	P	N	N	N	Y	U/P	Y	N	
37mm	M74 HETP	P	N	N	N	Y	F/W	Y	Y	NRL37-1
37mm	M74 HETP	P	N	N	N	Y	F/W	Y	N	NRL37-3
37mm	M74 AT;TP	P	N	N	N	Y	F/W	Y	N	NRL37-4
37mm	M74 AT;TP	P	N	N	N	Y	F/W	Y	Y	NRL37-6
37mm	M55A1	P	N	N	N	N	F/W	Y	N	
37mm	M80A1	P	N	N	N	Y	F/W	Y	N	
40mm	M385A1	G	N	N	N	Y	U/P	Y	N	
40mm	M385TP	G	N	N	N	Y	F/W	Y	Y	Smoke Grenade
40mm	MK2 MOD12	P	N	Y	N	Y	U/P	Y	N	
40mm	MK2 MOD26	P	N	Y	N	Y	U/P	Y	Y	
40mm	MK2	P	N	N	N	Y	F/W	Y	N	
57mm	M1&6 PR	P	N	N	N	Y	U/P	Y	Y	
57mm	M1&6 PR	P	N	N	N	Y	F/W	Y	N	
60mm	M49A4	M	N	N	N	N	F/W	Y	N	
60mm	M49A4	M	Y	N	N	N	F/W	Y	Y	
60mm	M49A4	M	Y	Y	N	N	F/W	Y	N	NRL60-120
60mm	M49A4	M	Y	Y	N	N	F/W	N	N	URS-110
60mm	M60	M	Y	Y	N	N	U/P	Y	Y	
75mm	M89	P	N	N	N	Y	F/W	N	N	
75mm	M89	P	N	N	N	N	F/W	N	N	
76mm	M496	M	Y	Y	N	N	U/P	N	N	
81mm	M43A1	M	Y	N	N	N	F/W	N	N	
81mm	M82	M	Y	Y	N	N	U/P	Y	N	

81mm	M82	M	Y	N	N	N	U/P	Y	Y	
81mm	M82	M	N	N	N	N	U/P	Y	N	
105mm	M84	P	N	N	N	N	F/W	N	N	Smoke Rusty/Hollow
105mm	M84	P	N	N	N	Y	F/W	N	N	Smoke
105mm	M1	P	N	Y	N	Y	U/P	Y	Y	
105mm	M456A1	M	Y	Y	N	N	U/P	Y	Y	
120mm	M931	M	Y	N	N	N	U/P	Y	N	
155mm	M107	P	N	Y	N	Y	U/P	Y	Y	
155mm	M741	P	N	Y	N	Y	U/W	N	N	Dispensing
Grenade	MK2	G	N	Y	N	N	Practice	Y	N	
Rifle Grenade	M31	G	Y	Y	N	N	F/B	N	N	
Rockeye	M118	S	Y	Y	N	N	U/P	N	N	Practice
BDU33	MK76	Bomb	Y	N	N	N	F/B	N	N	25lb Practice
2.25in	MK3 MOD2	R	Y	Y	N	N	F/W	Y	N	With Motor
2.36in	M6	R	Y	Y	N	N	F/W	N	N	Partial fin No nose cone
2.36in	M6	R	Y	Y	N	N	F/W	N	Y	
2.5in	M11A3	R G	Y	Y	N	N	F/BF	N	N	Practice
2.75in	HE-FFAR	R WH	N	Y	N	N	U/P	N	N	
2.75in	MK1	R WH	N	Y	N	N	F/W	Y	N	
Stokes	3" Stokes	M	N	Y	N	N	F/W	N	N	
4.2in	M335A2	P	N	Y	N	Y	F/W	N	N	
4.2in	M314A3	P	N	Y	N	Y	F/W	N	N	
4.2in	M2A1	P	Y	N	N	Y	F/W	Y	N	
4.2in	M329A2	P	Y	N	N	Y	F/P	Y	N	Smoke
8in	M106	P	N	Y	N	Y	U/P	Y	N	
Large ISO40	Schedule40	ISO	N	N	N	N	Pristine	N	N	
Large ISO80	Schedule80	ISO	N	N	N	N	Pristine	N	Y	
Medium ISO40	Schedule40	ISO	N	N	N	N	Pristine	N	N	Rusty
Medium ISO80	Schedule80	ISO	N	N	N	N	Pristine	Y	Y	
Small ISO40	Schedule40	ISO	N	N	N	N	Pristine	Y	N	
Small ISO80	Schedule80	ISO	N	N	N	N	Pristine	Y	Y	
4in Sphere	aluminum	Cal	N	N	N	N	Pristine	Y	Y	
4in Sphere	steel	Cal	N	N	N	N	Pristine	Y	Y	

*P = Projectile; G = Grenade; M = Mortar; R = Rocket; S = Submunition; WH = Warhead

**F/W = Fired/Weathered; U/W = Unfired/Weathered; F/P = Fired/Pristine; U/P = Unfired/Pristine; F/B = Fired/Bent; F/BF = Fired/Bent Fins

4.3 EQUIPMENT SETUP

The equipment was setup in accordance with the procedures and guidelines outlined in section 3.1 of the SOP (Appendix B). Figure 1 of the SOP shows the setup for data collection with the MM.

The acquisition parameters used for the three sensors are shown in Tables 4-2 – 4-4. Because the TEMTADS has a different receiver channel digitizer with twice the temporal resolution that the other sensors have, our original plan of using the exact acquisition parameter settings could not be realized. The result is a slightly different set of decay times over the three decay lengths for the 2X2.

Table 4-2 – Fixed acquisition parameter settings used for the MPEDEMIS and MM

# of Stacks	# of Repeats	Gate Window Width (%)	Gate Hold-off Time (μs)	Once/Continuous	TX Coils
20	9	5	50	Once	All

Table 4-3 – TBlock acquisition parameter setting used for the MPEDEMIS and MM

Sensor System	Library Decay Length (ms)	TBlock (s)	Duration (min)	Total Duration (min)
MPEDEMIS	2.7	0.1	0.3	2.4
	8.3	0.3	0.9	7.2
	25	0.9	2.7	21.6
MM	2.7	0.1	0.1	0.8
	8.3	0.3	0.3	2.4
	25	0.9	0.9	7.2

Table 4-4 – Acquisition parameter settings used for the TEMTADS 2X2

Library Decay Length (ms)	# of Stacks	# of Repeats	Gate Window Width (%)	Gate Hold-off Time (μs)	TBlock (s)	Once/ Continuous	TX Coils
2.7	60	3	5	50	0.033	Once	All
8.3	180	1	5	50	0.033	Once	All
25	180	1	5	50	0.1	Once	All

4.4 CALIBRATION ACTIVITIES

It is crucial to demonstrate that all systems used in collecting library-quality data are operating as expected. This would normally be performed by comparing the extracted βs for data collected over a medium ISO80 – specified in section 3.3 of the SOP (Appendix B) – to existing library βs for the same item. However, since the 3ms library ISO entries are non-existent at the start of this data collection, βs extracted from data collected using the different systems over the same ISO are compared instead.

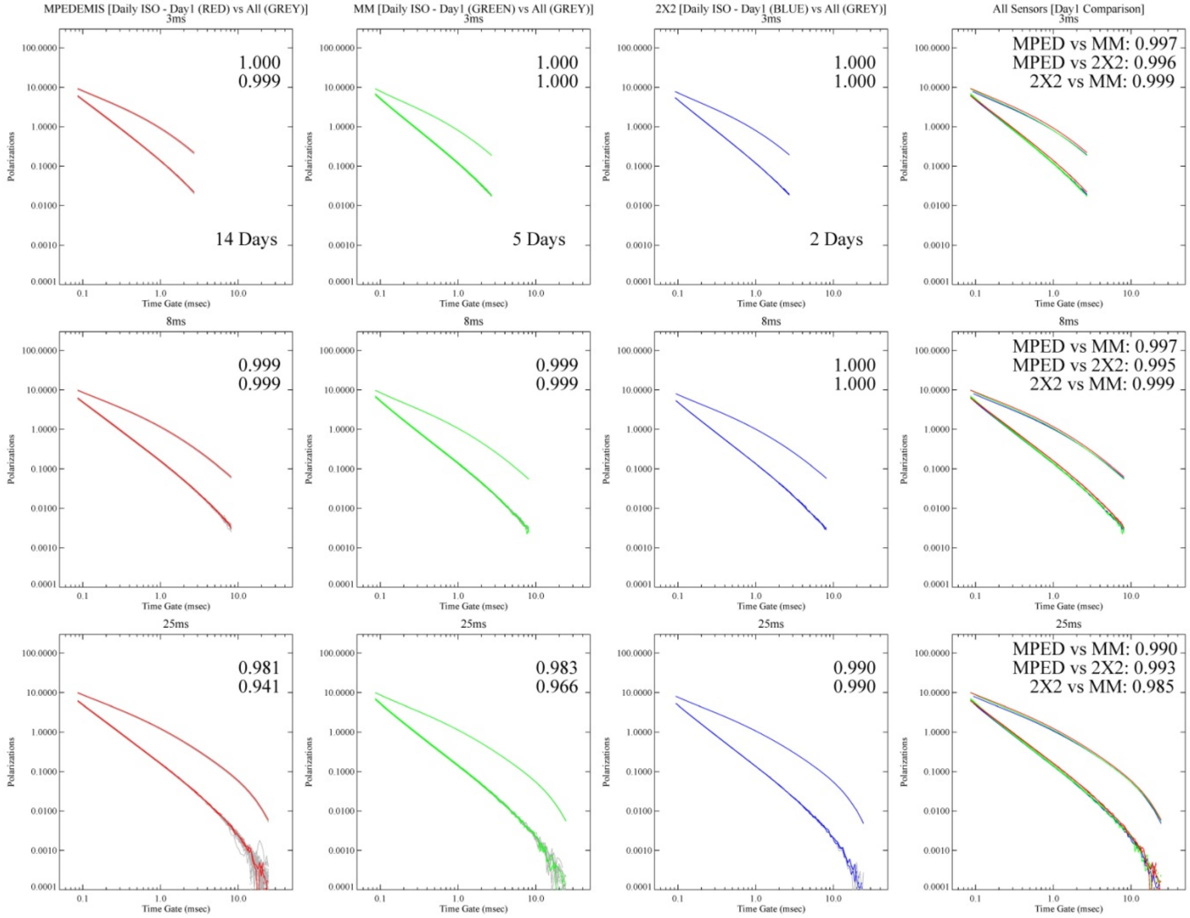


Figure 4-1 – βs extracted from data collected by the three sensors – MPEDEMIS (red), MM (green) & 2X2 (blue) - for a medium ISO80 centered under the arrays. The rows show the 3ms, 8ms & 25ms decays, respectively, and the last column compares each decay length across sensors. The two numbers in the panels within the first three columns represent the average and worst values for the 3-β match metric when comparing βs extracted from the first ISO data to all the remaining ISO data (14 days worth of data for the MPEDEMIS, 5 days for the MM & 2 days for the 2X2). The numbers in the panels within the last column represent the 3-β match metric comparing the first ISO data for the stated sensors.

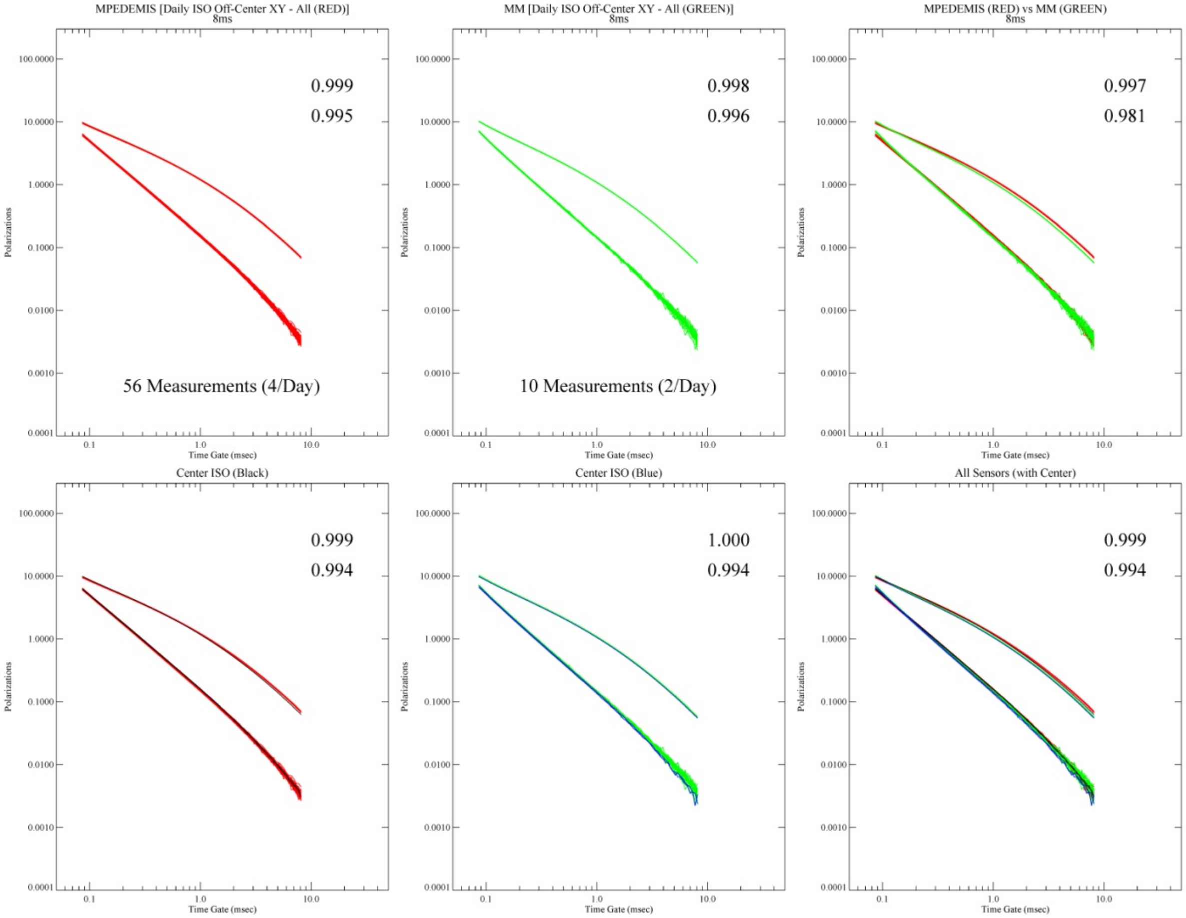


Figure 4-2 – Off-center and center medium ISO80 βs extracted from 8ms data collected with MPEDEMIS (red and black, respectively) and MM (green and blue, respectively). The off-center points for the MPEDEMIS were chosen to be – refer to Figure 2-3 – (1) the center of the Tx1, Tx2, Tx4, Tx5 group; (2) the center of the Tx2, Tx3, Tx5, Tx6 group; (3) the center of the Tx4, Tx5, Tx7, Tx8 group; and (4) the center of the Tx5, Tx6, Tx8, Tx9 group. The off-center points for the MM are described in section 3.3 of the SOP (Appendix B) and number just two locations. The bottom row compares the initial center ISO βs to all the off-center βs for each sensor. Again, the last column compares the βs across sensors.

4.5 DATA COLLECTION PROCEDURES

The data collection procedures and guidelines are fully outlined in the SOP (Appendix B). This starts with an initial system check (section 3.2), followed by the system calibration check (section 3.3) and a few other steps (section 3.4) before getting into the data collection activities (sections 3.5-3.7).

4.6 VALIDATION

All inversions of library quality data collected over each munitions item as stipulated by the steps of section 3.6C of the SOP (Appendix B) were held to performance objective 4 of Table 3-1, with the noted exceptions discussed in 3.4.3. The extracted βs were subsequently displayed in a series of panel plots that summarized the extent of the variability in the βs across orientations, depths and sensors. As examples, Figures 4-3 – 4-8 show these panel plots for the 20mmAA MK7 munitions item (i.e. not the dummy round, to differentiate it from the other 20mmAA MK7 measured) while Figures 4-9 – 4-14 show them for the 155mm M107. From such panel plots for each munitions item, a decision was made as to which βs should be included as entries to the appropriate library (i.e. the 2.7 ms, 8.3 ms or 25 ms library), as well as to any additional measurements that should be conducted.

In all the plots, the numbers represent the UX-Analyze 3-β library match metric. This match metric is used to compare the βs estimated from collected data over an object with any other set of βs (i.e. from a library, or estimated from other data collected over the same or a different object). It is based on using all three βs to compare size and shape aspects of the object. A 3-β match metric of 1 will occur when the object βs match the other βs perfectly. Generally, anything greater than 0.9 is considered a good match. That being said, although created to have some inherent noise handling capability, the metric is best used in combination with a visual comparison since noise will at times deteriorate the metric below the 0.9 threshold even when a good match exists to the eye.

Focusing first on the 20mmAA MK7 munitions item (Figures 4-3 – 4-8), we can note the following:

1. Scanning the βs of Figure 4-3 with the aid of the match metrics, one set of βs can be chosen for each decay length to represent the item at any orientation and depth for the MPEDEMIS.

2. The same can be said for the MM and 2X2 based on Figures 4-4 and 4-5, respectively

3. Scanning the βs of Figure 4-6 with the aid of the match metrics, the βs are consistent whether the PEDEMIS or MM is used

4. The same can be said whether the PEDEMIS or 2X2 is used or whether the 2X2 or MM is used based on Figures 4-7 and 4-8, respectively

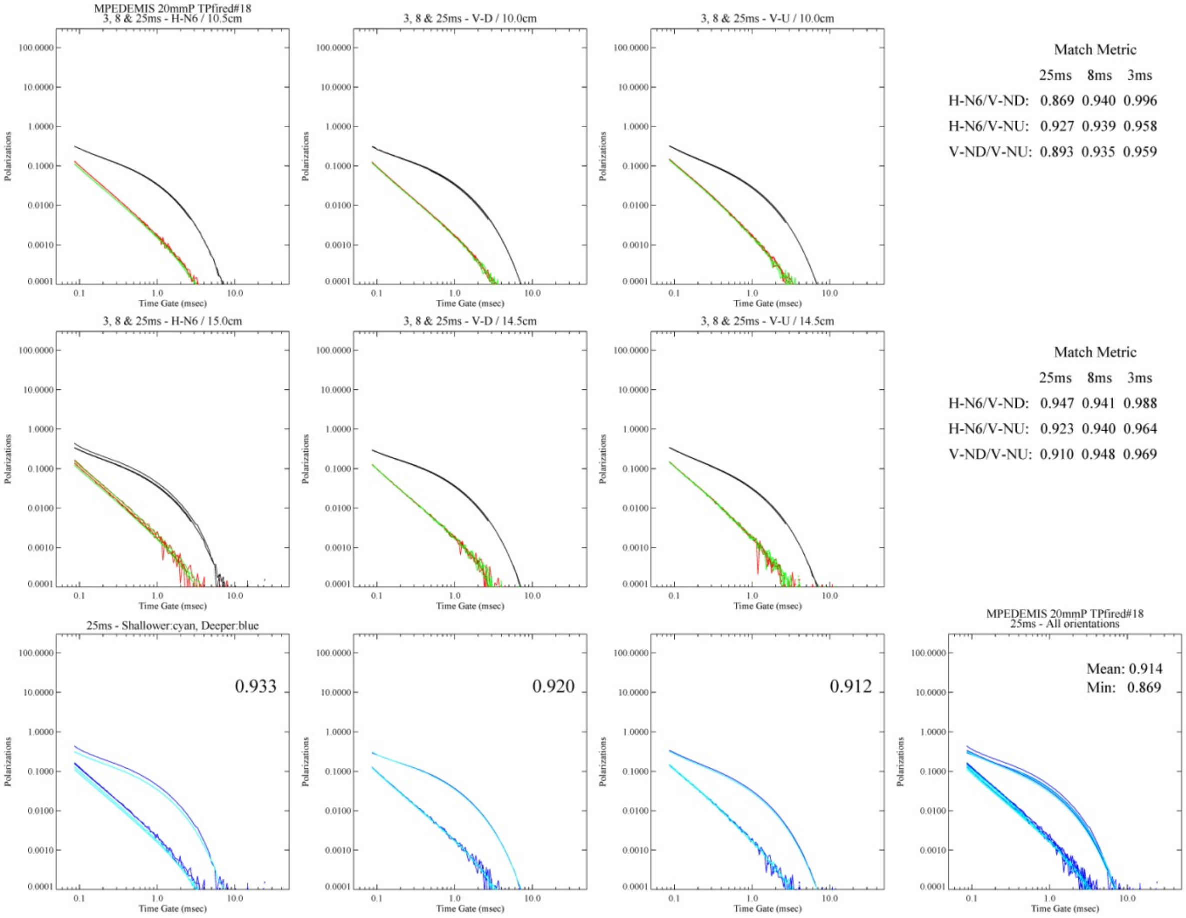
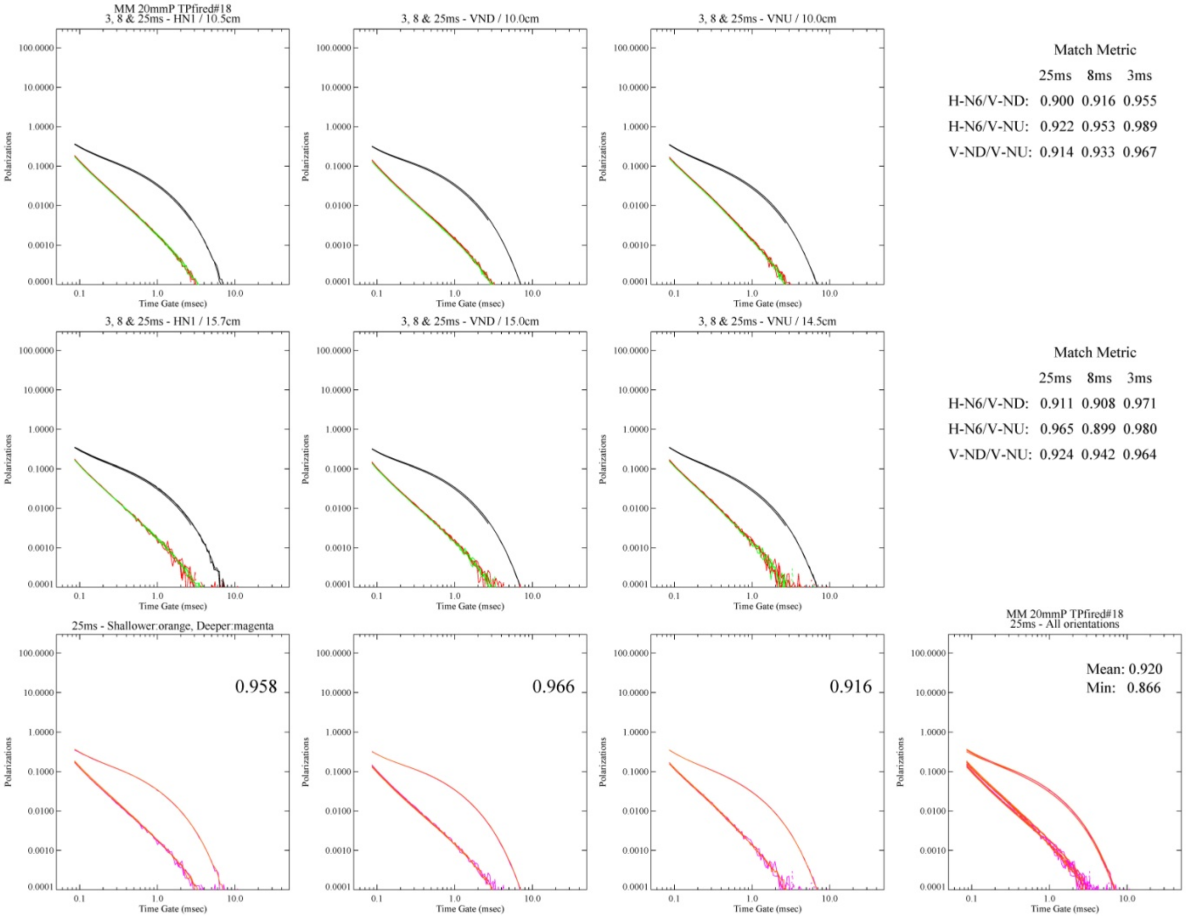


Figure 4-3 – βs extracted from data collected over the 20mmAA MK7 by the MPEDEMIS. The top row shows βs (all three decays over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) at the smaller depth. The second row shows the same information at the second larger depth. The bottom row compares the 25ms βs for the different depths for each orientation and - the very last panel on the right - over all orientations. The match metric matrices on the right show how the βs compare across orientations for each decay length. Any match metric > 0.9 is generally considered a good match.



Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.900	0.916	0.955
H-N6/V-NU:	0.922	0.953	0.989
V-ND/V-NU:	0.914	0.933	0.967

Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.911	0.908	0.971
H-N6/V-NU:	0.965	0.899	0.980
V-ND/V-NU:	0.924	0.942	0.964

Figure 4-4 – βs extracted from data collected over the 20mmAA MK7 by the MM. The top row shows βs (all three decays over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) at the smaller depth. The second row shows the same information at the second larger depth. The bottom row compares the 25ms βs for the different depths for each orientation and - the very last panel on the right - over all orientations. The match metric matrices on the right show how the βs compare across orientations for each decay length. Any match metric > 0.9 is generally considered a good match.

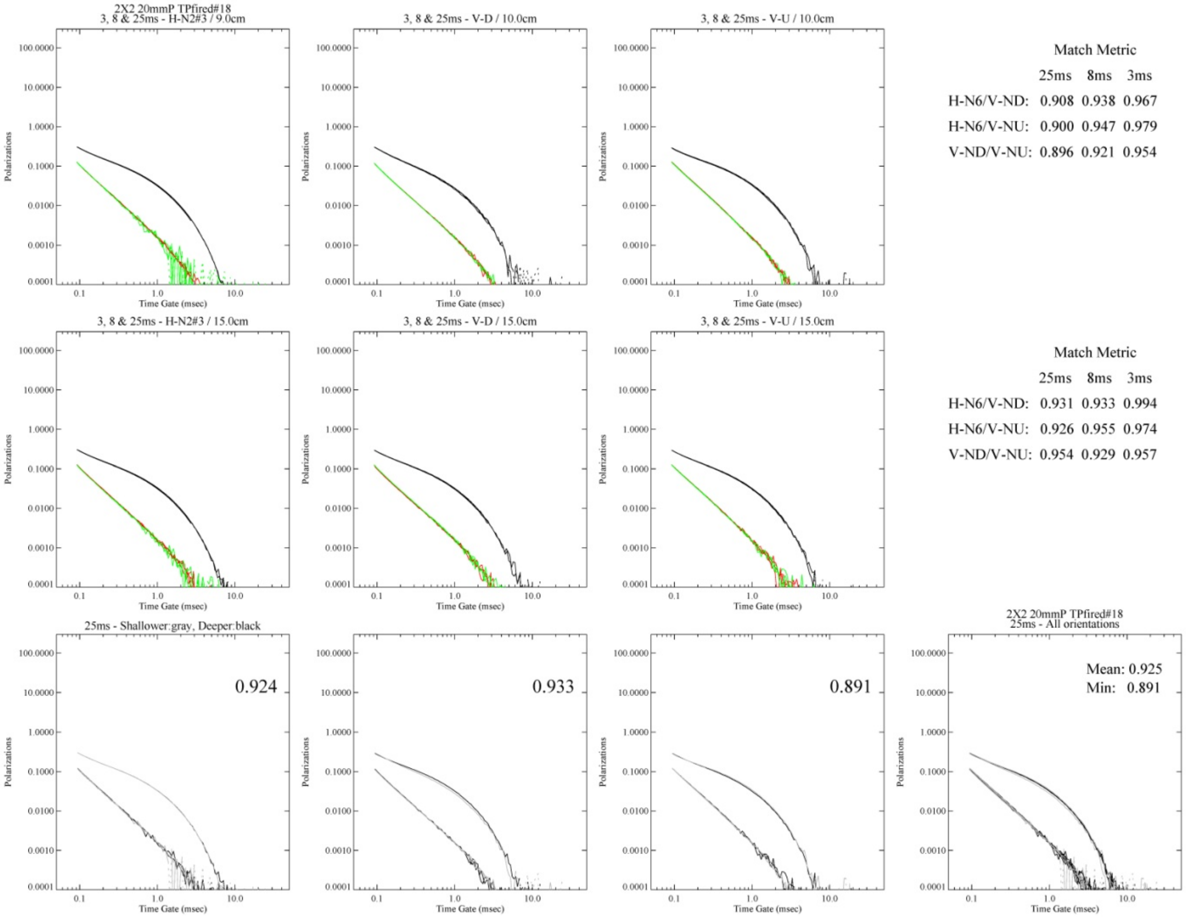


Figure 4-5 – βs extracted from data collected over the 20mmAA MK7 by the 2X2. The top row shows βs (all three decays over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) at the smaller depth. The second row shows the same information at the second larger depth. The bottom row compares the 25ms βs for the different depths for each orientation and - the very last panel on the right - over all orientations. The match metric matrices on the right show how the βs compare across orientations for each decay length. Any match metric > 0.9 is generally considered a good match.

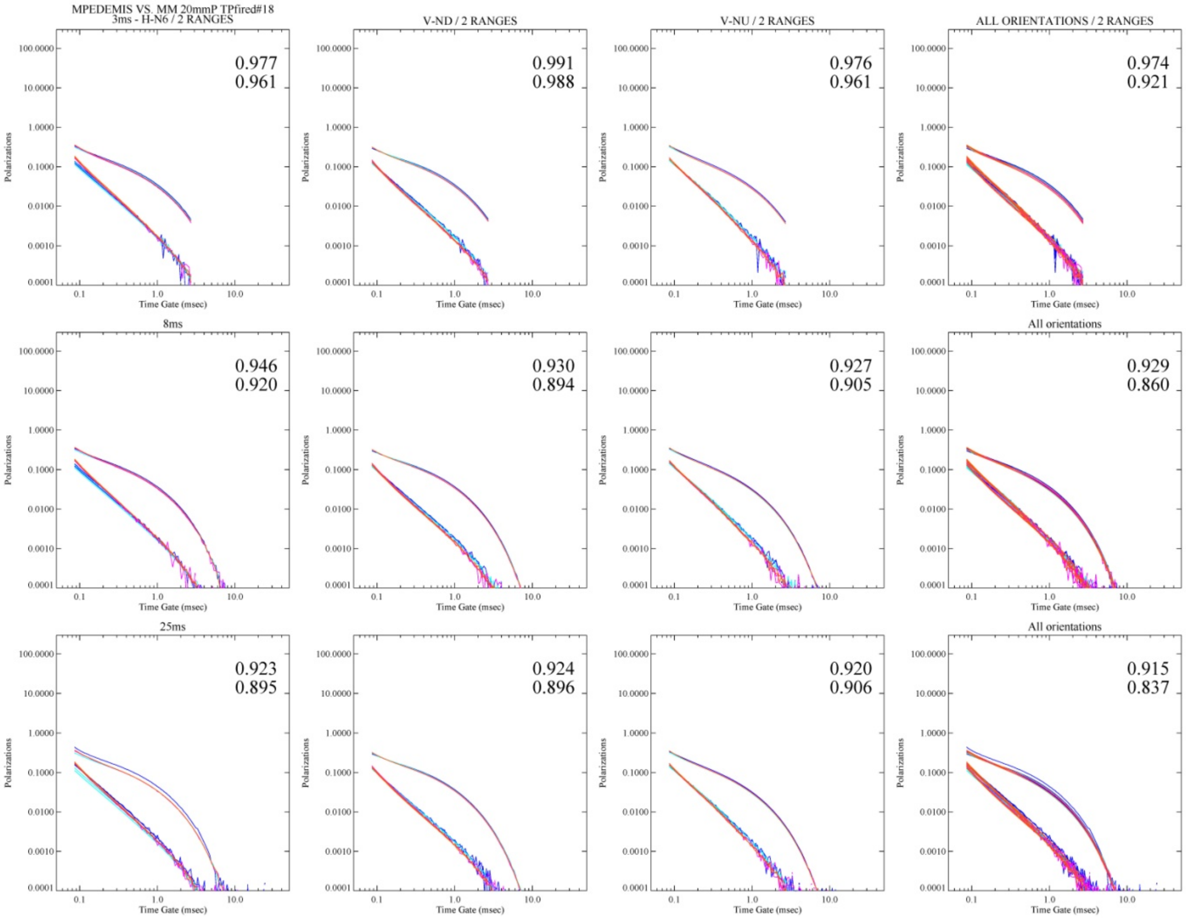


Figure 4-6 – Comparison of βs extracted from data collected over the 20mmAA MK7 by the MPEDEMIS and MM. The top row shows 3ms βs (the two depths for the two sensors all over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) and - the very last panel on the right - over all orientations. The second and third rows show the same information for the 8ms and 25ms βs, respectively. The two numbers in all the panels represent the average and worst values for the 3-β match metric when comparing all βs within each panel pair-wise.

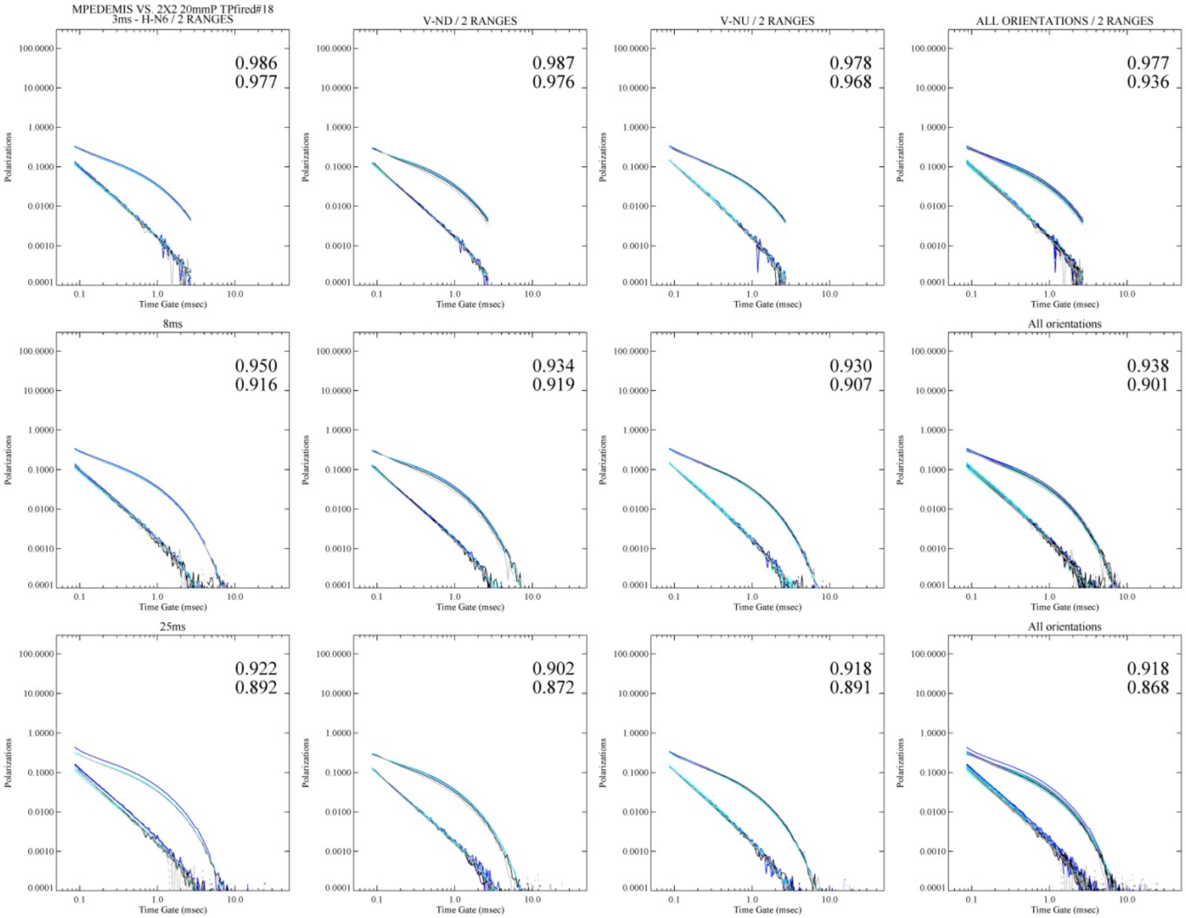


Figure 4-7 – Comparison of βs extracted from data collected over the 20mmAA MK7 by the MPEDEMIS and 2X2. The top row shows 3ms βs (the two depths for the two sensors all over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) and - the very last panel on the right - over all orientations. The second and third rows show the same information for the 8ms and 25ms βs, respectively. The two numbers in all the panels represent the average and worst values for the 3-β match metric when comparing all βs within each panel pair-wise.

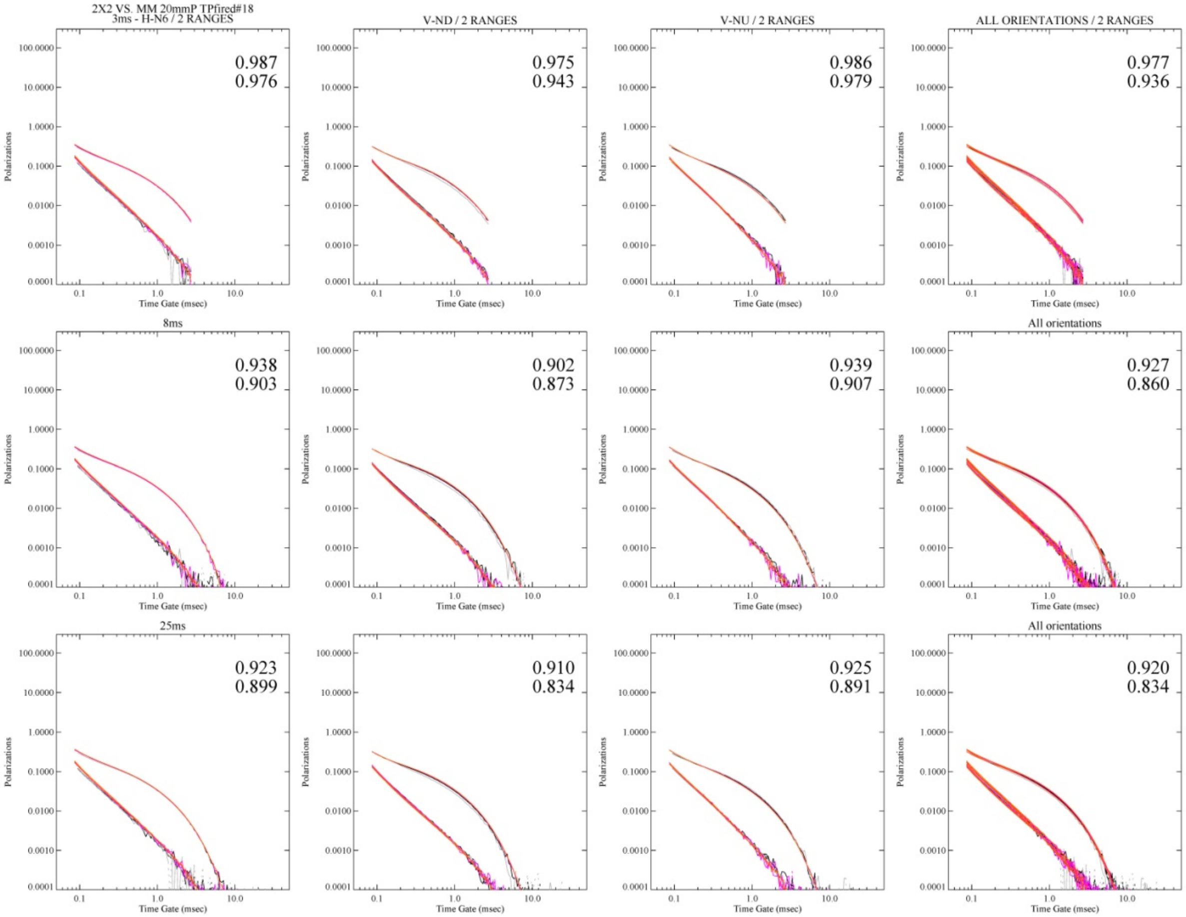


Figure 4-8 – Comparison of βs extracted from data collected over the 20mmAA MK7 by the 2X2 and MM. The top row shows 3ms βs (the two depths for the two sensors all over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) and - the very last panel on the right - over all orientations. The second and third rows show the same information for the 8ms and 25ms βs, respectively. The two numbers in all the panels represent the average and worst values for the 3-β match metric when comparing all βs within each panel pair-wise.

Observations 1 and 2 above were made, for the 25 ms decay length βs at least, based on the plots in the bottom row of Figures 4-3 – 4-5, where a good match existed across depths (first three panels, left to right) as well as across orientations (right-most panel). The fact that some match metrics fell below the good match threshold of 0.9 here is more a reflection of the deficiency of the metric in terms of noise handling than a function of a poor match to shape and amplitude. Evidence in support of the latter observation is given by re-evaluating the match metrics for the bottom row using only amplitudes greater than 0.001 (below which most of the noise exists). The corresponding new numbers for the bottom row of Figure 4-3, left to right, in this case are 0.988, 0.999, 0.997 and {mean: 0.980, min: 0.953}.

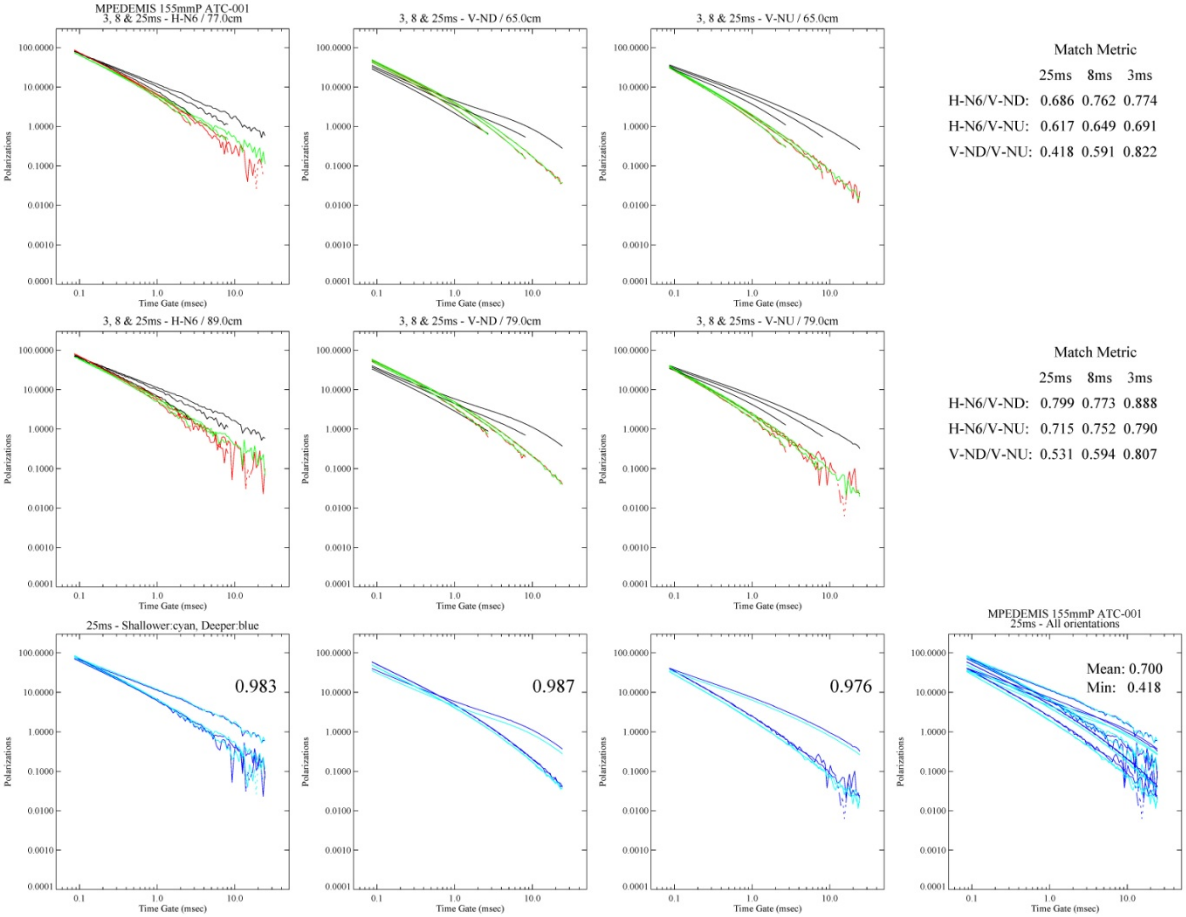
The same observations for the shorter decay length βs were made by making reference to the match metric matrices in the right-most column and noting that all the numbers were 0.9 or greater when comparing βs of one orientation versus another at a given depth. In addition, confirmation of a good match across depths was made by referring to the right-most column of Figures 4-6 – 4-8 (i.e. top two panels of the right-most column).

The conclusion from all four observations is that only one entry for each library is needed for the 20mmAA MK7 and this will be applicable across all advanced TEM sensors. The choice for the entries should be a set of βs (one for each decay length) where the primary βs are smoothest and the secondary βs contain the least amount of noise. Candidates with these properties are the βs extracted from MM data collected at the smaller depth for the vertical, nose down orientation (Figure 4-4; top row; 2nd panel from the left) and are currently selected through a manual visual process.

Next, focusing on the 155mm M107 munitions item, we can note the following:

1. Scanning the βs of Figure 4-9 with the aid of the match metrics, three sets of βs – one for each orientation – are needed to represent the item for the MPEDEMIS
2. The same can be said for the MM and 2X2 based on Figures 4-10 and 4-11, respectively
3. Scanning the βs of Figure 4-12 with the aid of the match metrics, the βs are consistent whether the PEDEMIS or MM is used
4. The same can be said whether the PEDEMIS or 2X2 is used or whether the 2X2 or MM is used based on Figures 4-13 and 4-14, respectively

In similar fashion to the process used with the 20mm AA MK7 panel plots discussed earlier, observations 1 and 2 above were made, for the 25 ms decay length βs at least, based on the plots in the bottom row of Figures 4-9 – 4-11, where a good match also existed across depths (first three panels, left to right), but this time not so across orientations (right-most panel). By using the match metric matrices above this latter plot panel, the relative degree of mismatch between the various orientations can be inferred (here the term “mismatch” is used here to emphasize the fact that the match metrics are all below the generally accepted 0.9 threshold for a good match). Specifically, for the 155mm M107, the greatest mismatch occurs between the vertical βs (nose



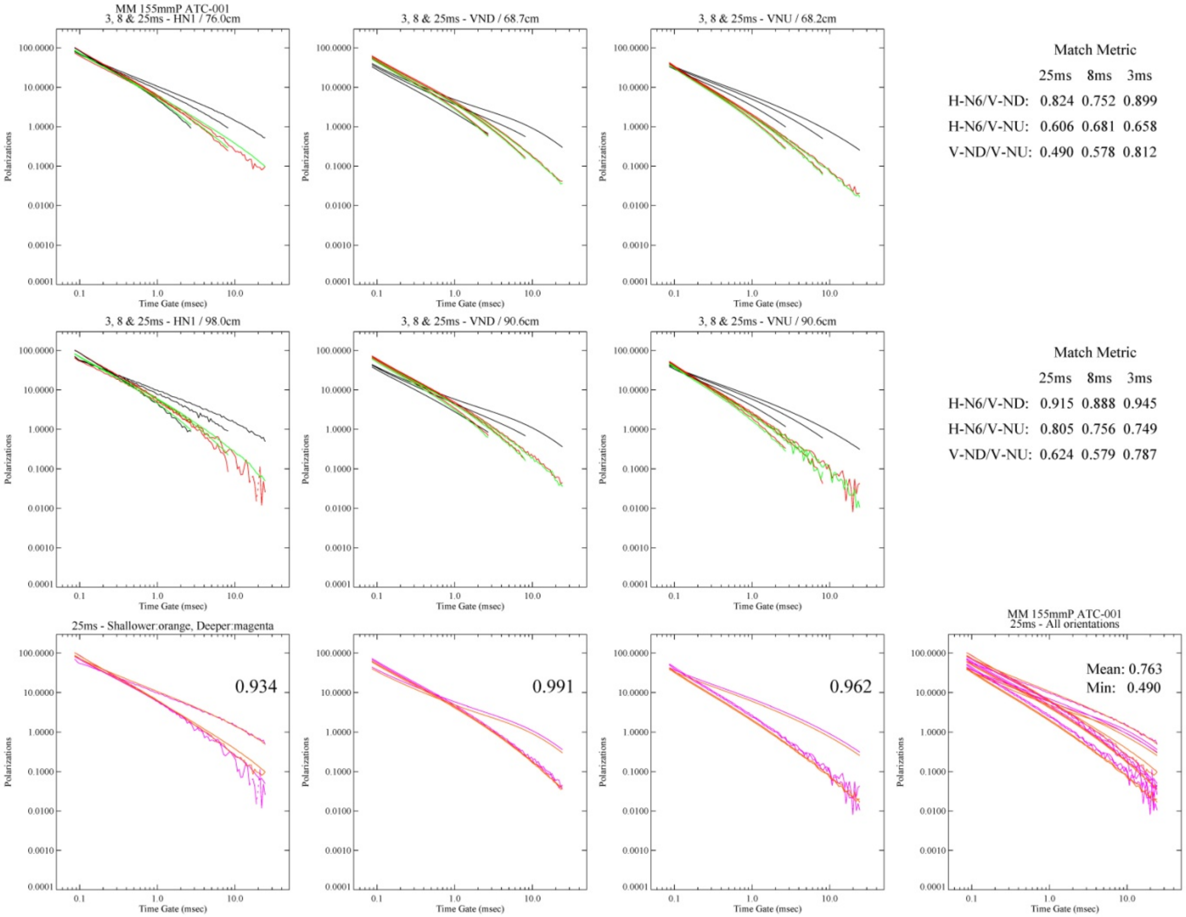
Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.686	0.762	0.774
H-N6/V-NU:	0.617	0.649	0.691
V-ND/V-NU:	0.418	0.591	0.822

Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.799	0.773	0.888
H-N6/V-NU:	0.715	0.752	0.790
V-ND/V-NU:	0.531	0.594	0.807

Figure 4-9 – βs extracted from data collected over the 155mm M107 by the MPEDEMIS. The top row shows βs (all three decays over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) at the smaller depth. The second row shows the same information at the second larger depth. The bottom row compares the 25ms βs for the different depths for each orientation and - the very last panel on the right - over all orientations. The match metric matrices on the right show how the βs compare across orientations for each decay length. Any match metric > 0.9 is generally considered a good match.



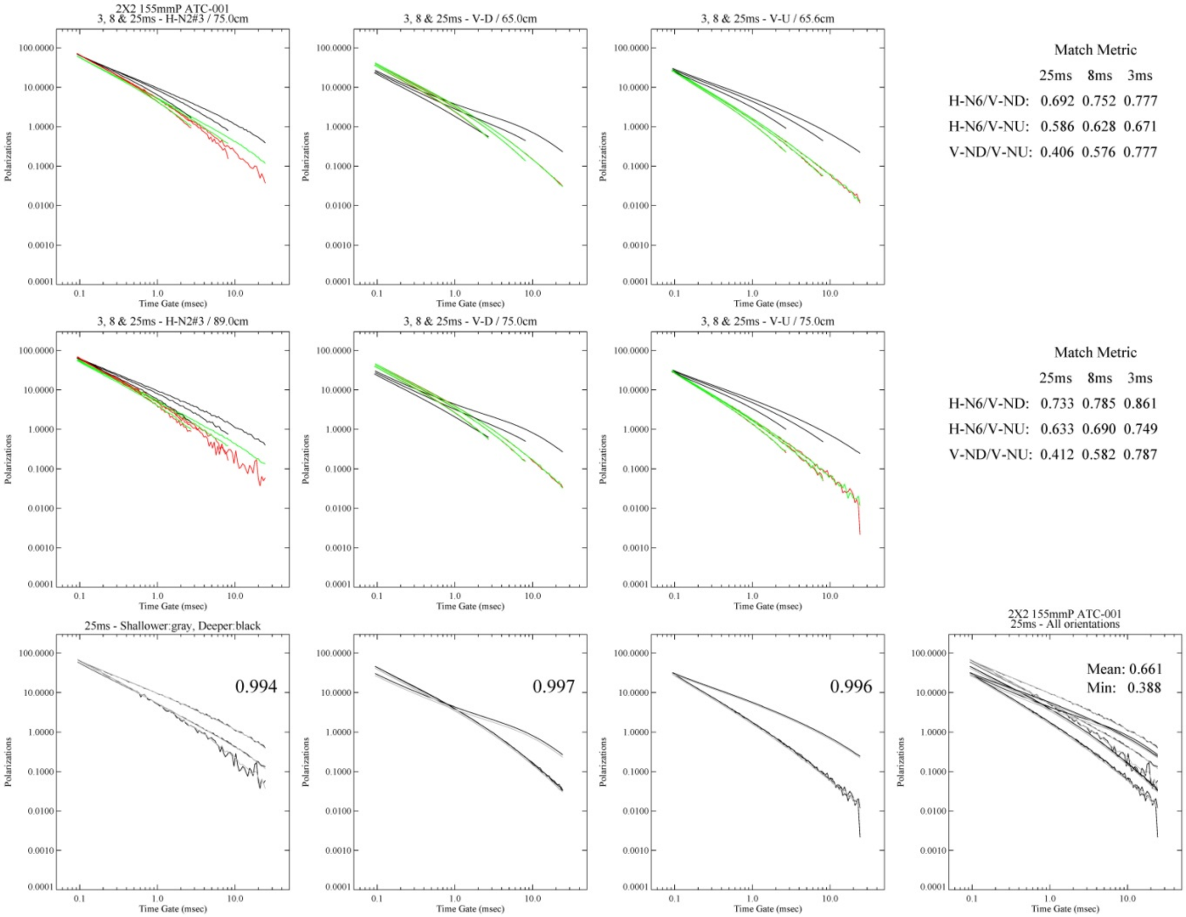
Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.824	0.752	0.899
H-N6/V-NU:	0.606	0.681	0.658
V-ND/V-NU:	0.490	0.578	0.812

Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.915	0.888	0.945
H-N6/V-NU:	0.805	0.756	0.749
V-ND/V-NU:	0.624	0.579	0.787

Figure 4-10 – βs extracted from data collected over 155mm M107 by the MM. The top row shows βs (all three decays over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) at the smaller depth. The second row shows the same information at the second larger depth. The bottom row compares the 25ms βs for the different depths for each orientation and - the very last panel on the right - over all orientations. The match metric matrices on the right show how the βs compare across orientations for each decay length. Any match metric > 0.9 is generally considered a good match.



Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.692	0.752	0.777
H-N6/V-NU:	0.586	0.628	0.671
V-ND/V-NU:	0.406	0.576	0.777

Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.733	0.785	0.861
H-N6/V-NU:	0.633	0.690	0.749
V-ND/V-NU:	0.412	0.582	0.787

Figure 4-11 – βs extracted from data collected over the 155mm M107 by the 2X2. The top row shows βs (all three decays over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) at the smaller depth. The second row shows the same information at the second larger depth. The bottom row compares the 25ms βs for the different depths for each orientation and - the very last panel on the right - over all orientations. The match metric matrices on the right show how the βs compare across orientations for each decay length. Any match metric > 0.9 is generally considered a good match.

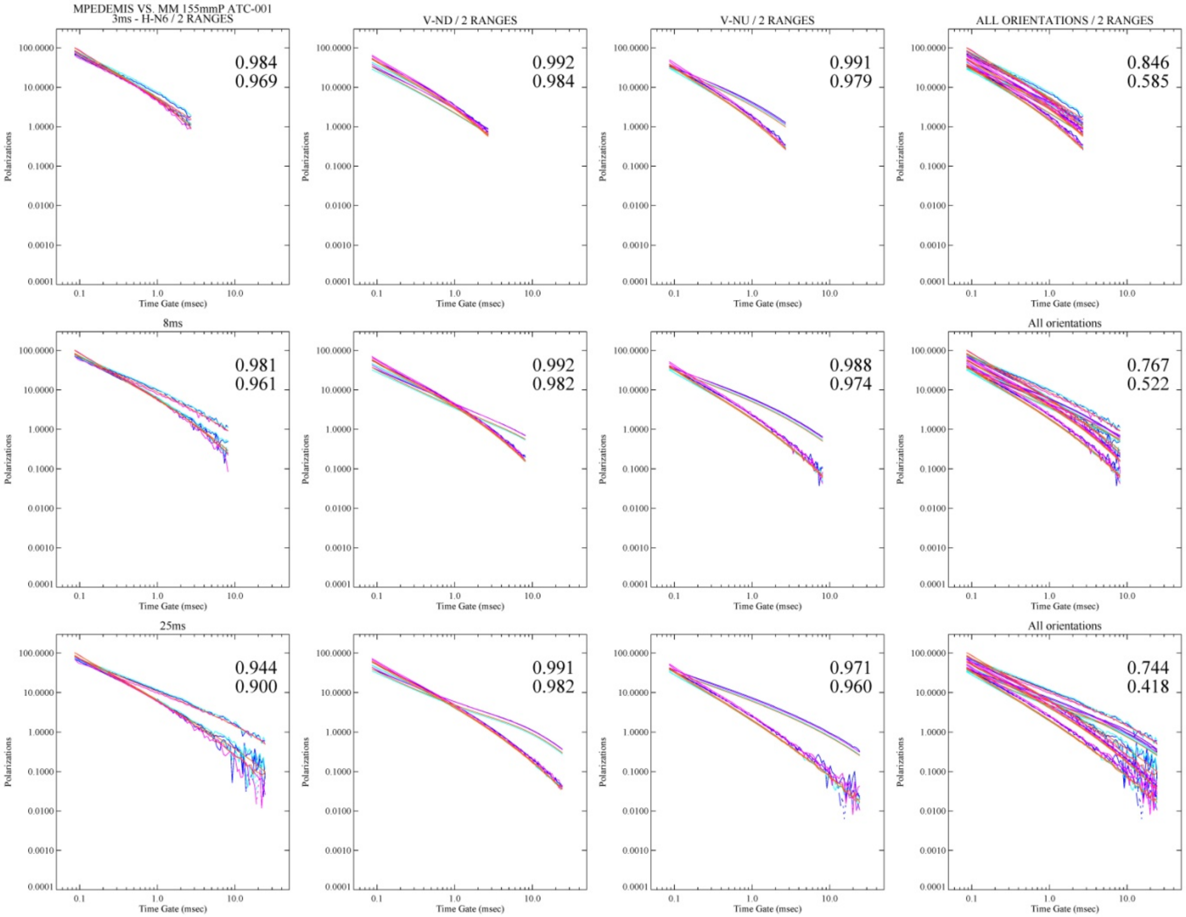


Figure 4-12 – Comparison of βs extracted from data collected over the 155mm M107 by the MPEDEMIS and MM. The top row shows 3ms βs (the two depths for the two sensors all over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) and - the very last panel on the right - over all orientations. The second and third rows show the same information for the 8ms and 25ms βs, respectively. The two numbers in all the panels represent the average and worst values for the 3-β match metric when comparing all βs within each panel pair-wise.

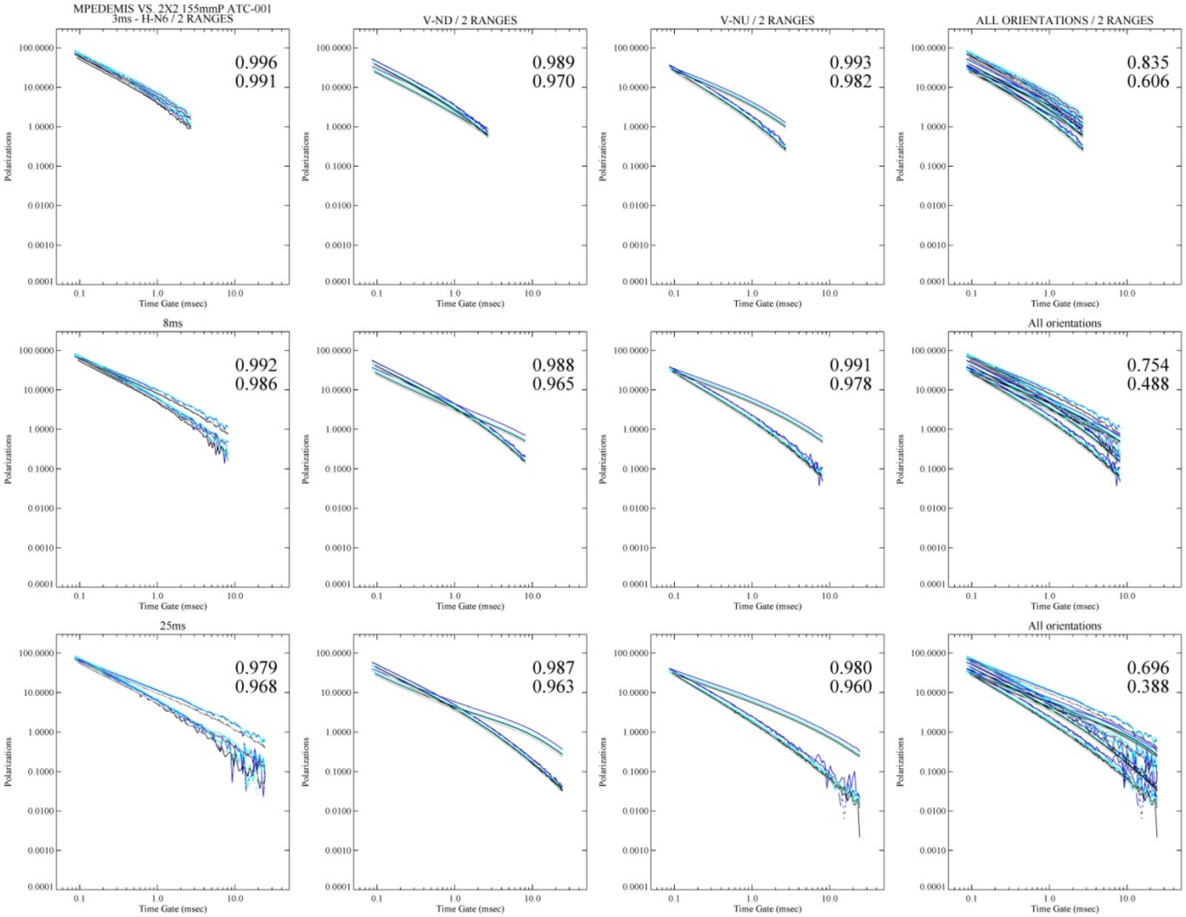


Figure 4-13 – Comparison of βs extracted from data collected over the 155mm M107 by the MPEDEMIS and 2X2. The top row shows 3ms βs (the two depths for the two sensors all over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) and - the very last panel on the right - over all orientations. The second and third rows show the same information for the 8ms and 25ms βs, respectively. The two numbers in all the panels represent the average and worst values for the 3-β match metric when comparing all βs within each panel pair-wise.

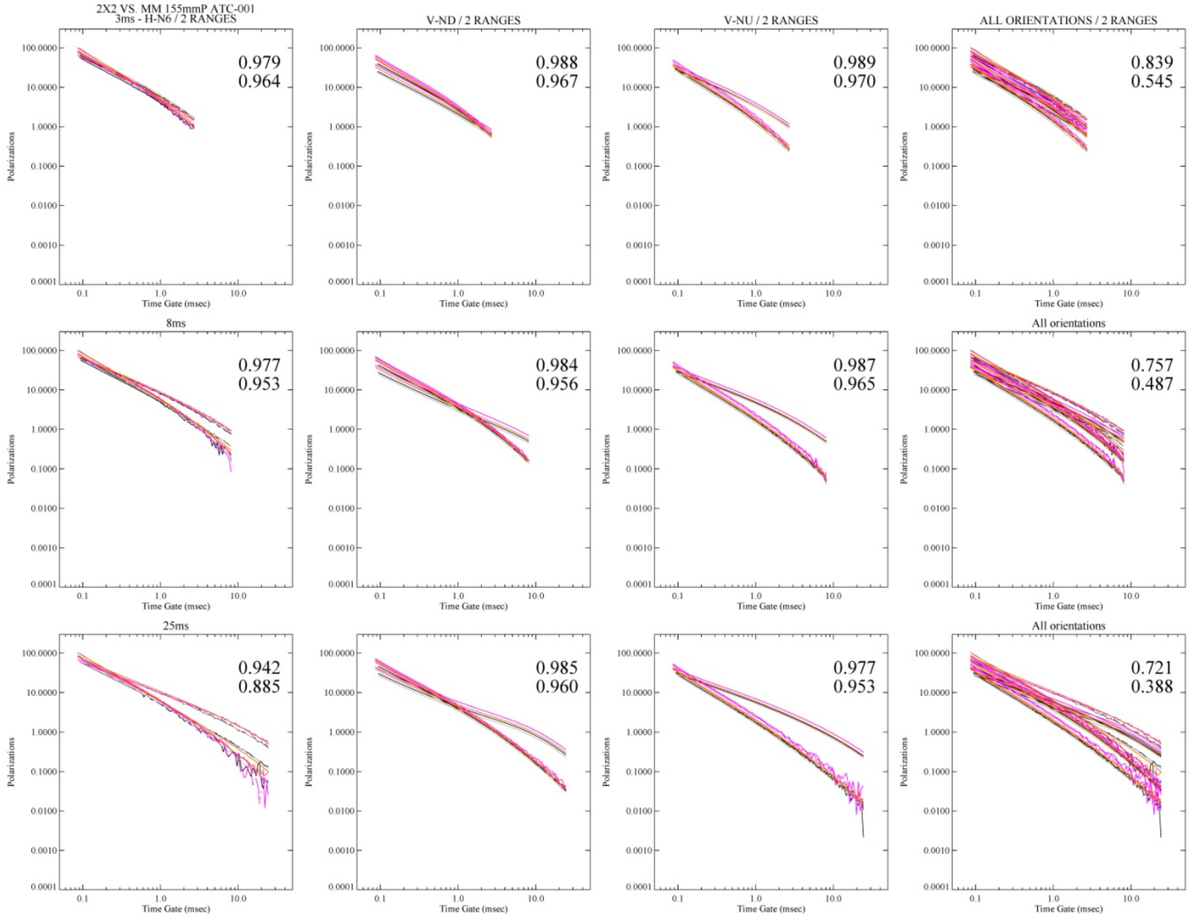


Figure 4-14 – Comparison of βs extracted from data collected over the 155mm M107 by the 2X2 and MM. The top row shows 3ms βs (the two depths for the two sensors all over-plotted) for the three orientations (left to right: horizontal; vertical, nose down; and vertical, nose up) and - the very last panel on the right - over all orientations. The second and third rows show the same information for the 8ms and 25ms βs, respectively. The two numbers in all the panels represent the average and worst values for the 3-β match metric when comparing all βs within each panel pair-wise.

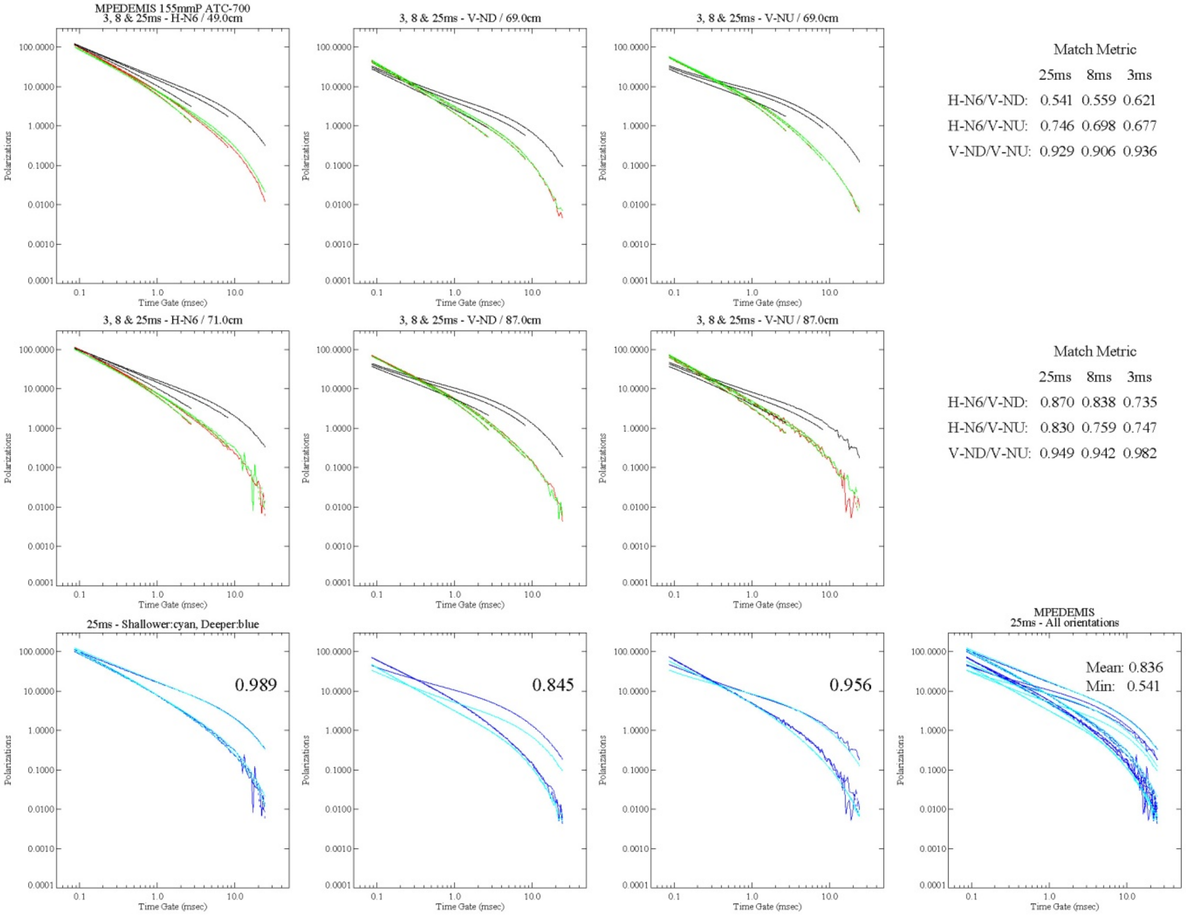
down versus nose up), and the least mismatch occurs between the horizontal and vertical nose down βs.

The conclusion from all four observations is that three entries for each library are needed for the 155mm M107 – one for each orientation – and that these will be applicable across all advanced TEM sensors. The candidates for the entries, in this case, are the βs extracted from 2X2 data collected at the smaller depth for the two vertical orientations and the βs extracted from MM data collected at the smaller depth for the horizontal orientation – again, manually selected via a visual inspection for the smoothest (minimal noise) primary and secondary βs.

The final entries for the three classification libraries for all the munitions items measured are selected via a manual decision process as outlined in the prior two examples, although in most cases βs for all three sensors won't necessarily be available (refer to Table 4-1 to identify the sensors that were used on each item). The objective is to only select library entries per item that are distinct enough from one another. A UX-Analyze match metric exceeding the 0.9 threshold, or a slightly smaller metric (because of the influence of noise on the metric) in combination with a visual confirmation of a match, provides a means to group βs that are similar thus narrowing the pool of distinct groups of βs. Smooth and low noise sets of βs are then selected to represent each distinct group as the final library entries.

As a final note, it should be mentioned that in the rare event that βs are not similar for a particular item orientation across the different depths, additional data should be recommended for collection at an intermediate depth. One such example is shown in Figure 4-15 for the 155mm M741 where the βs for the vertical nose down orientation were clearly distinct when comparing across depths. Upon collecting additional data at an intermediate depth, it was determined that the βs extracted from this intermediate depth data matched the βs at the larger depth very well (Figure 4-16). This latter confirmation suggested the initial data at the smaller depth may have been collected closer than the largest item dimension of L to the sensor, resulting in the observed divergent βs. As it turns out, this was indeed the case with L for the 155mm M741 being 84cm for the item.

Although beyond the scope of this project, this raises the question of what should we be populating our libraries with if a site contains shallow large munitions (i.e. where item depths are generally much smaller than L) among a mess of large items? Perhaps this is an unrealistic situation to ponder. Current practice follows the conservative approach of flagging all large items as targets of interest even when match metrics are poor because generally these amount to a very small percentage of the entire target list.



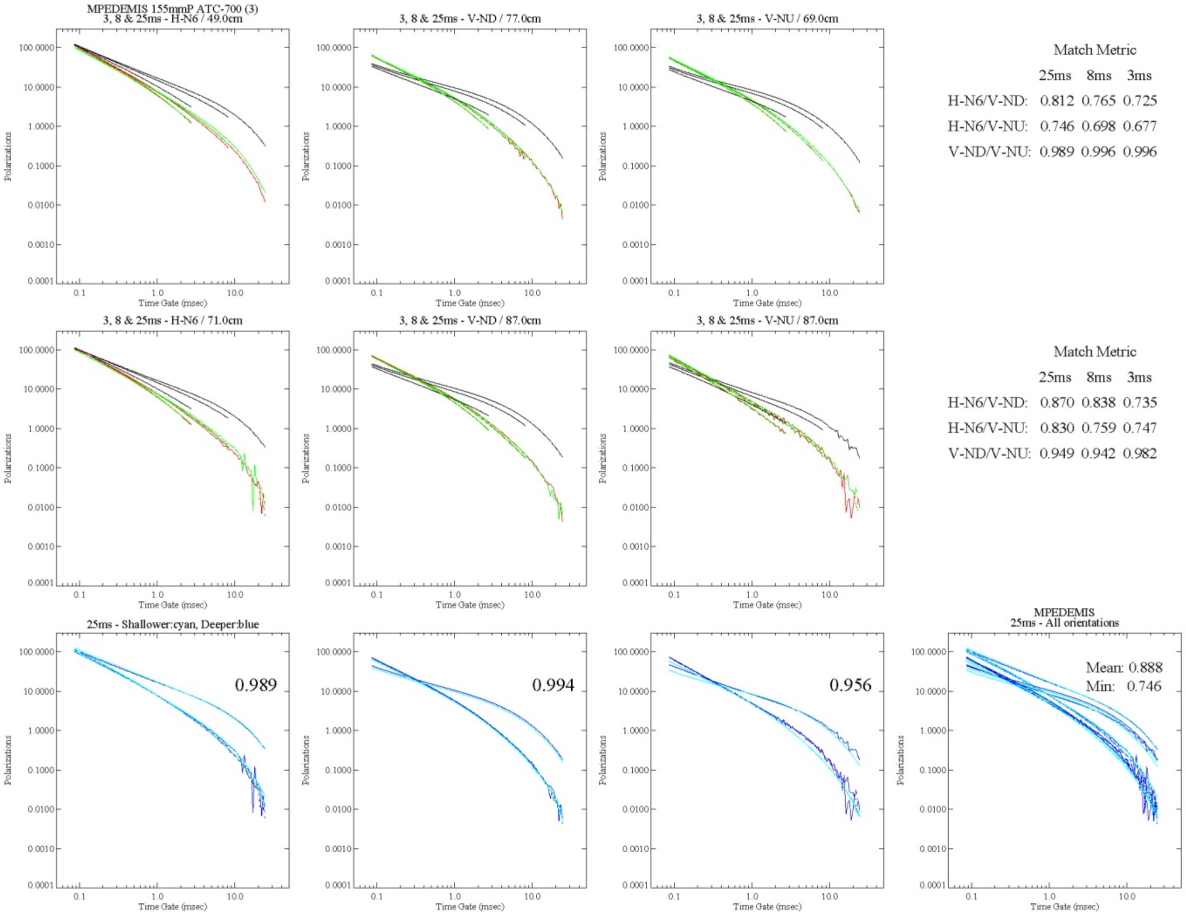
Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.541	0.559	0.621
H-N6/V-NU:	0.746	0.698	0.677
V-ND/V-NU:	0.929	0.906	0.936

Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.870	0.838	0.735
H-N6/V-NU:	0.830	0.759	0.747
V-ND/V-NU:	0.949	0.942	0.982

4-15 – βs extracted from data collected over the 155mm M741 by the MPEDEMIS. In this case, a clear mismatch exists between the 25ms βs at the different depths for the vertical nose down orientation, as seen by the second from the left panel in the bottom row.



Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.812	0.765	0.725
H-N6/V-NU:	0.746	0.698	0.677
V-ND/V-NU:	0.989	0.996	0.996

Match Metric

	25ms	8ms	3ms
H-N6/V-ND:	0.870	0.838	0.735
H-N6/V-NU:	0.830	0.759	0.747
V-ND/V-NU:	0.949	0.942	0.982

4-16 – βs extracted from additional data over the 155mm M741 by the MPEDEMIS. The additional data were collected at an intermediate depth to the initial two depths (i.e. 77cm, where initially depths were at 69cm and 87cm) and the corresponding βs are shown in the top row. The second row shows the βs for the initial larger depth – same as in Figure 4-15. In this case, the 25ms βs at the different depths for the vertical nose down orientation match well, indicating that the initial smaller depth was likely closer to the sensor than the largest dimension L for the item.

5.0 DATA ANALYSIS

5.1 PREPROCESSING

The first step in the preprocessing will be to normalize the recorded signals by the TX currents to account for any TX variations. The next step will be to exclude a number of early time gates that include distortions due to TX ringing and related artifacts, generally all well before 0.1 ms. Consequently, only responses beyond these early distortions will be included in the parameter estimation analysis to follow. The final preprocessing step will be to subtract a background response from each target measurement by using data collected either not too long before or after. This could either be the before or after background shot, or an average of the two.

5.2 PARAMETER ESTIMATION

The preprocessed data reflect details of the sensor/target geometry as well as inherent EMI response characteristics of the target itself. In order to separate out the intrinsic target response properties from sensor/target geometry effects we invert the signature data to estimate principal axis magnetic polarizabilities for the targets. The data are inverted using the standard induced dipole response model wherein the effect of eddy currents set up in the target by the primary field is represented by a set of three orthogonal magnetic dipoles at the target location [8]. The measured signal is a linear function of the induced dipole moment **m**, which can be expressed in terms of a time dependent polarizability tensor **B** as

$$\mathbf{m} = \mathbf{U}\mathbf{B}\mathbf{U}^{T}\cdot\mathbf{H}_0$$

where **U** is the transformation matrix between the physical coordinate directions and the principal axes of the target and $\mathbf{H}_0$ is the primary field strength at the target. The eigenvalues $\beta_i(t)$ of the polarizability tensor are the principal axis polarizabilities.

Given a set of measurements of the target response with varying geometries or "look angles" at the target, the data is inverted non-linearly to solve for the target's (X, Y, Z) dipole location. At each iteration within this inversion, the nine element polarizability tensor (**B**) is solved for linearly. We require that this tensor be symmetric; therefore, only six elements are unique. Initial guesses for X and Y are determined by signal-weighted mean positions. The routine normally loops over a number of initial guesses in Z, keeping the result giving the best fit as measured by the chi-squared value. The non-linear inversion is performed simultaneously over all time gates, such that the dipole (X, Y, Z) location applies to all decay times. The polarizability tensors over all time gates are then jointly diagonalized to extract the eigenvalues and the three angles representing the yaw, pitch, and roll of the target (Euler angles ψ, θ, ϕ).

Figure 5-1 shows an example of the principal axis polarizabilities determined from TEMTADS data for a 75 mm projectile. The blue curve is the polarizability when the primary field is aligned with the long axis of the projectile, while the green and red curves correspond to the cases where the primary field is aligned with the shorter dimensions along the other two principal axes. Due to the symmetry of the projectile about the long axis, the shorter dimensions are identical and so the polarizabilities are equal in this case. The smaller amplitudes later in the decay, relative to the blue curve, reflect this difference in size between the shorter and longer dimensions.

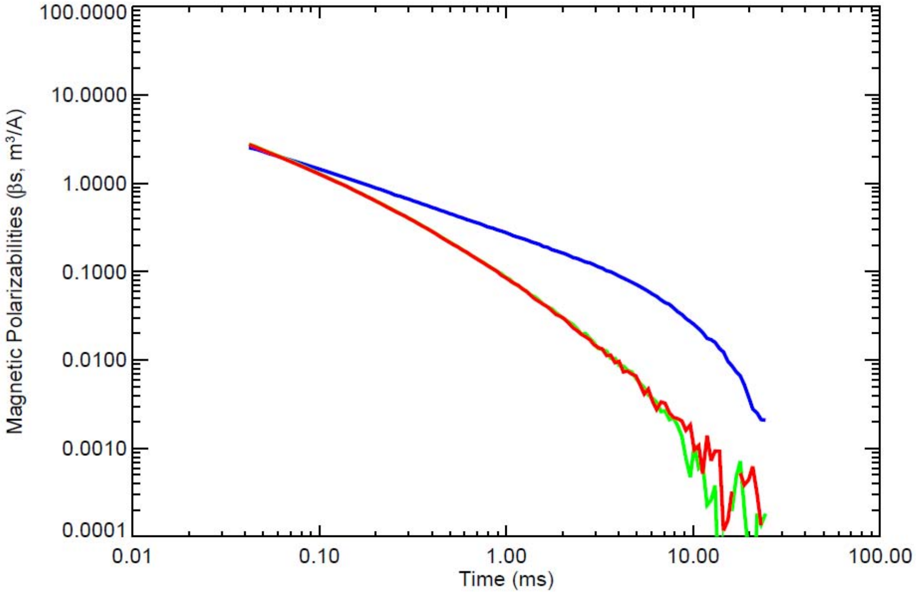


Figure 5-1 – Principal axis polarizabilities for a 75 mm projectile

The accuracy of the estimated polarizability curves will depend on how well the model agrees with the data, and obviously, on how appropriate the dipole model is. The fit coherence presents a measure of how well the model agrees with the data. It is defined as the square of the cross-correlation coefficient that is computed using the data and model vectors. A fit coherence of 1 will occur when the model matches the data perfectly. This special case implies that the model is perfectly appropriate. The dipole model is an approximation that is used because of its analytical simplicity but is only really applicable when the sensor is at least a distance of the largest object dimension, L, away. The more the sensor-to-target range exceeds L, the better the dipole approximation becomes. The model is also strictly valid for compact homogenous objects. If the object gets more complicated and is composed of different metallic components then there is less agreement with the dipole model. The disagreement, however, generally remains small as long as the sensor-to-target range is large enough. For test stand data, where background noise is at a minimum, the fit coherence in most cases is expected to exceed 0.99.

5.3 FINAL DATA PRODUCT

The final data product for each munitions item to be added to one of the three classification libraries consists of the library data along with the munitions item metadata. The library data includes the following:

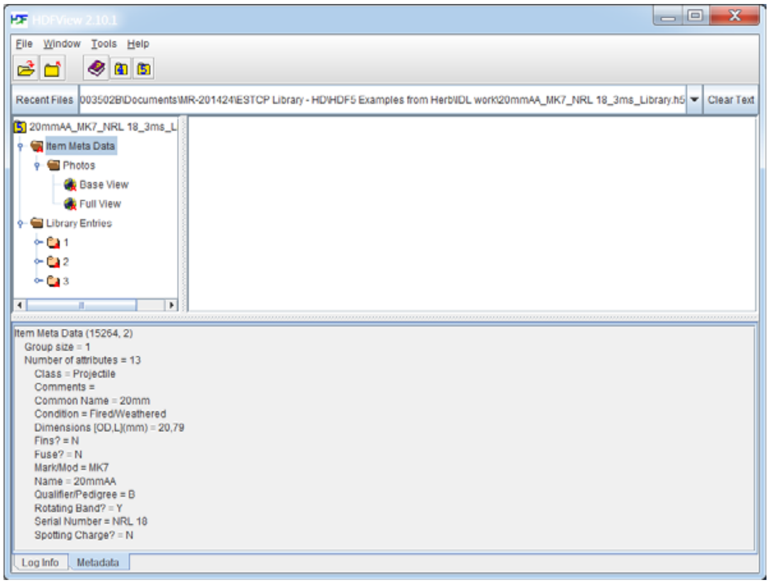
- The estimated β decays along the 3 principal axes of the item and the associated times in the decay

- The additional estimated fit parameters – i.e. X, Y, Z, yaw, pitch, roll, 1-(fit error) and fit coherence
- The background data used
- The data mask used – i.e. a matrix equal in size to the sensor response data and populated with 1s for data used in the inversion and 0s for those not used

The metadata includes all the information given by the row entries of Table 1 in Appendix A of the SOP (Appendix B) and represents all the useful descriptive information that can be obtained for a munitions item.

The plan is to have two different HDF5 file formats: one that embeds the library data and the metadata into the original HDF5 data file (since the HDF5 data files don't currently exist, and will only start appearing with the next-generation Geometrics sensors, these HDF5 files will, for the time being, have to be simulated); and another for every unique munitions item for one of the three classification libraries (these will contain the item metadata and as many library entries of βs as necessary to globally characterize the item, with their associated fit parameters, but no background data or data masks). The latter file would be for unrestricted distribution to end users, while the former will be restricted to researchers or power users.

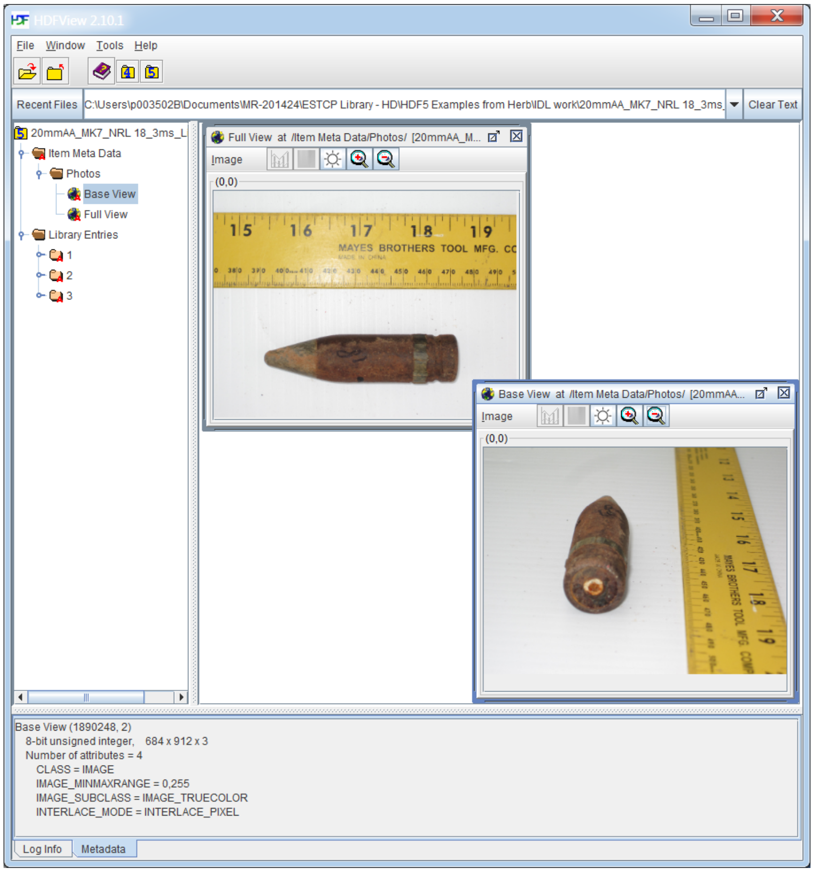
An example of what the HDF5 file format for unrestricted distribution looks like for the 20mmAA MK7 munitions item for the 3ms library is shown in Figures 5-2 – 5-5.



Recent Files: 003502B\Documents\MR-201424\ESTCP Library - HD\HDF5 Examples from Herb\IDL work\20mmAA_MK7_NRL 18_3ms_Library.h5

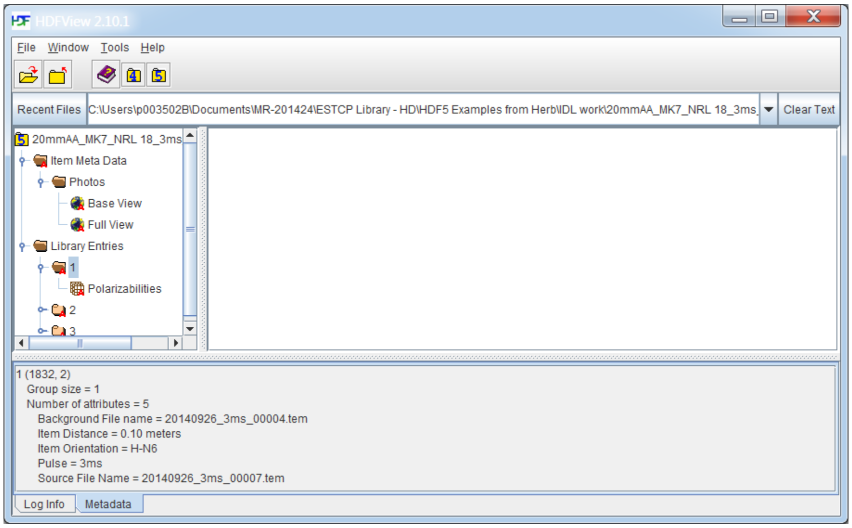
```
Item Meta Data (15264, 2)
  Group size = 1
  Number of attributes = 13
    Class = Projectile
    Comments =
    Common Name = 20mm
    Condition = Fired/Weathered
    Dimensions [OD,L](mm) = 20,79
    Fins? = N
    Fuse? = N
    Mark/Mod = MK7
    Name = 20mmAA
    Qualifier/Pedigree = B
    Rotating Band? = Y
    Serial Number = NRL 18
    Spotting Charge? = N
```

Figure 5-2 – The associated attributes for the Item Meta Data group are shown. Within this group is the Photos sub-group. The Library Entries group contains the βs and associated fit parameters.



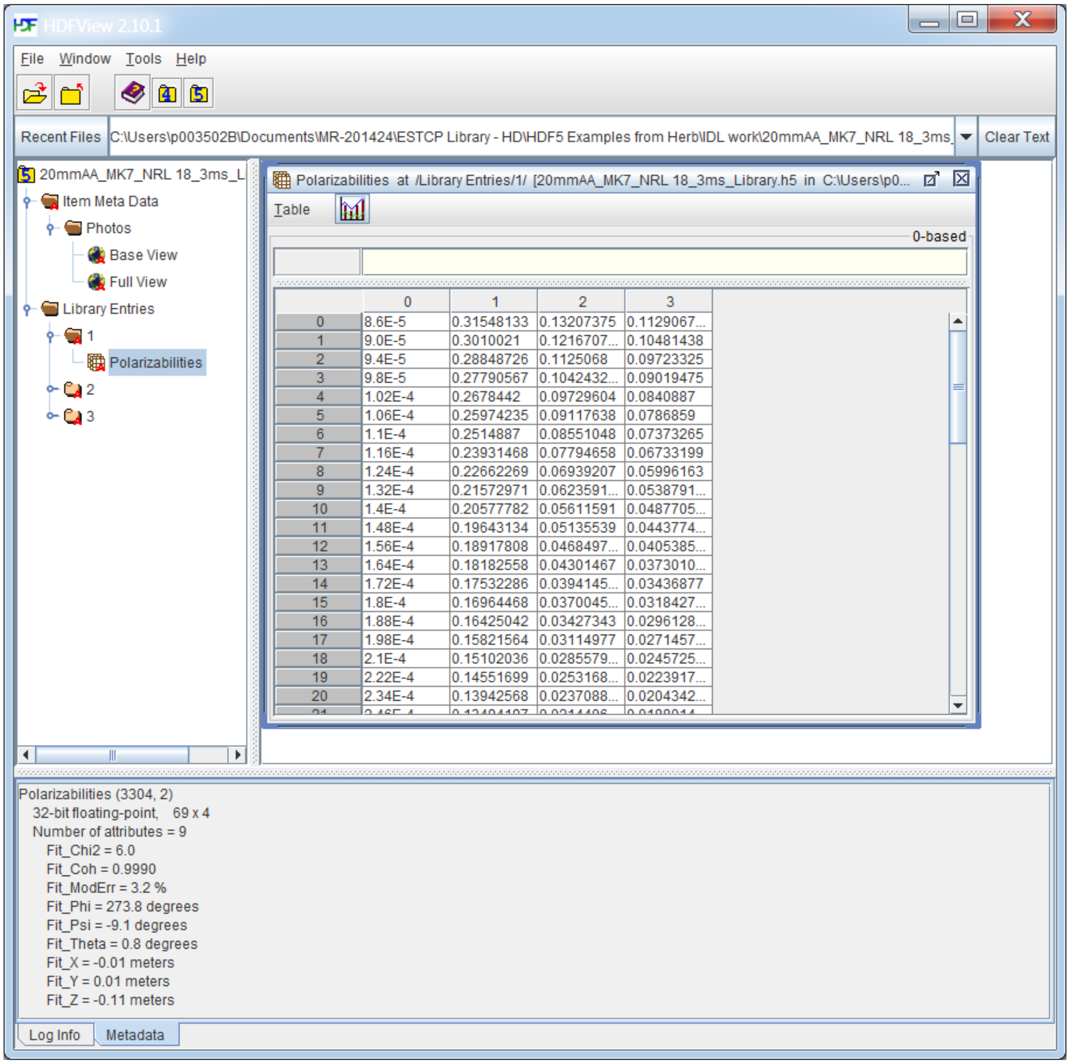
```
Base View (1890248, 2)
   8-bit unsigned integer,    684 x 912 x 3
   Number of attributes = 4
      CLASS = IMAGE
      IMAGE_MINMAXRANGE = 0,255
      IMAGE_SUBCLASS = IMAGE_TRUECOLOR
      INTERLACE_MODE = INTERLACE_PIXEL
```

Figure 5-3 – The two images within the Photos group are shown along with the attributes for the base view image.



```
1 (1832, 2)
   Group size = 1
   Number of attributes = 5
      Background File name = 20140926_3ms_00004.tem
      Item Distance = 0.10 meters
      Item Orientation = H-N6
      Pulse = 3ms
      Source File Name = 20140926_3ms_00007.tem
```

Figure 5-4 – The attributes of the 1 sub-group in the Library Entries group are shown. The three entries included in this example file is for illustrative purposes only since it was observed in section 4.6 that only one entry was really necessary to represent the 20mmAA MK7.



C:\Users\p003502B\Documents\MR-201424\ESTCP Library - HD\HDF5 Examples from Herb\IDL work\20mmAA_MK7_NRL 18_3ms_

Polarizabilities at /Library Entries/1/ [20mmAA_MK7_NRL 18_3ms_Library.h5 in C:\Users\p0...

	0	1	2	3
0	8.6E-5	0.31548133	0.13207375	0.1129067...
1	9.0E-5	0.3010021	0.1216707...	0.10481438
2	9.4E-5	0.28848726	0.1125068	0.09723325
3	9.8E-5	0.27790567	0.1042432...	0.09019475
4	1.02E-4	0.2678442	0.09729604	0.0840887
5	1.06E-4	0.25974235	0.09117638	0.0786859
6	1.1E-4	0.2514887	0.08551048	0.07373265
7	1.16E-4	0.23931468	0.07794658	0.06733199
8	1.24E-4	0.22662269	0.06939207	0.05996163
9	1.32E-4	0.21572971	0.0623591...	0.0538791...
10	1.4E-4	0.20577782	0.05611591	0.0487705...
11	1.48E-4	0.19643134	0.05135539	0.0443774...
12	1.56E-4	0.18917808	0.0468497...	0.0405385...
13	1.64E-4	0.18182558	0.04301467	0.0373010...
14	1.72E-4	0.17532286	0.0394145...	0.03436877
15	1.8E-4	0.16964468	0.0370045...	0.0318427...
16	1.88E-4	0.16425042	0.03427343	0.0296128...
17	1.98E-4	0.15821564	0.03114977	0.0271457...
18	2.1E-4	0.15102036	0.0285579...	0.0245725...
19	2.22E-4	0.14551699	0.0253168...	0.0223917...
20	2.34E-4	0.13942568	0.0237088...	0.0204342...

```
Polarizabilities (3304, 2)
  32-bit floating-point,    69 x 4
  Number of attributes = 9
    Fit_Chi2 = 6.0
    Fit_Coh = 0.9990
    Fit_ModErr = 3.2 %
    Fit_Phi = 273.8 degrees
    Fit_Psi = -9.1 degrees
    Fit_Theta = 0.8 degrees
    Fit_X = -0.01 meters
    Fit_Y = 0.01 meters
    Fit_Z = -0.11 meters
```

Figure 5-5 – The βs data within the 1 group is shown along with the fit attributes for those βs.

6.0 CONCLUSION

The data collection and analysis described in this report accomplished the following:

1. Created three libraries (2.7, 8.0, and 25 ms decay lengths) of the munitions available at Blossom Point that can be used for future advanced classification projects.

2. Demonstrated that data collected with one advanced classification sensor can be used to derive a library for a different sensor.

3. Proposed and tested the practice of including a single set of polarizabilities for a type of MEC if all βs for the different orientations and depths match with at least a 0.9 fit metric. If the fit metric is less than 0.9 for measurements at different depths or orientations additional polarizabilities are included in the library to account for the β variations.

4. Produced HDF5 format files that include measured data, inversion results and metadata about the test item characteristics.

5. Refined the SOP for library data collection to include appropriate and achievable performance objectives.

The next phase of this project will be data collection events at munitions museums or repositories. These data will be collected for less common MEC to expand the libraries described in this report.

7.0 REFERENCES

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2. Advanced EMI Data Collection Systems' Demonstrations, ESTCP Project 201165 Cost and Performance Report, October 2013, http://serdp-estcp.org/content/download/28445/280201/file/MR-201165-CP.pdf

3. New Man-Portable Vector Time Domain Electromagnetic Induction Sensor and Physically Complete Processing Approaches for UXO Discrimination Under Realistic Field Conditions, SERDP Project MR-1443 Final Report, April 2012, http://www.serdp-estcp.org/content/download/15302/175070/file/MR-1443-FR.pdf

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5. http://www.geosoft.com/solutions/industry/government/government-sponsored-uxo-software

6. Portable Electromagnetic Induction Sensor with Integrated Positioning, SERDP Project MR-1712 Final Report, August 2013, http://www.serdp-estcp.org/content/download/20933/220064/file/MR-1712-FR.pdf

7. G&G Sciences, “Advanced Ordnance Locator for Standoff Detection & Classification of Surface and Buried UXO,” G&G Sciences, Inc, Grand Junction, Final Report, December 2008.

8. Bell, T. H., Barrow, B. J., and Miller, J. T., "Subsurface Discrimination Using Electromagnetic Induction Sensors," IEEE Transactions on Geoscience and Remote Sensing, Vol. 39, No. 6, June 2001.

APPENDIX A. POINTS OF CONTACT

POINT OF CONTACT	ORGANIZATION	Phone e-mail	Role in Project
Dr. Herb Nelson	ESTCP Program Office 4800 Mark Center Dr. Suite 17D08 Alexandria, VA 22350	571-372-6400 (O) 202-215-4844 (C) herb.nelson@nrl.navy.mil	Program Manager, MR
Ms. Natalia Ainsfield	HydroGeoLogic, Inc. 11107 Sunset Hills Rd. Suite 400 Reston, VA 20190	703-736-4531 (O) nainsfield@hgl.com	Program Assistant, MR
Mr. Craig Murray	Parsons PGS 1776 Lincoln St. Suite 600 Denver, CO 80203	303-764-8868 (O) 720-219-3749 (C) craig.murray@parsons.com	PI
Dr. Nagi Khadr	Parsons PGS 1776 Lincoln St. Suite 600 Denver, CO 80203	303-837-4081 (O) 303-501-2393 (C) nagi.khadr@parsons.com	QA Officer/ Data Analyst
Dr. Dan Steinhurst	Nova Research, Inc. 1900 Elkin St. Suite 230 Alexandria, VA 22308	202-767-3556 (O) 703-850-5217 (C) daniel.steinhurst.ctr@nrl.navy.mil	Data Collection Manager
Mr. Glenn Harbaugh	Nova Research, Inc. 1900 Elkin St. Suite 230 Alexandria, VA 22308	301-392-1702 (O) 804-761-5904 (C) glenn.harbaugh.ctr@nrl.navy.mil	UXO Technician/ Data Collector
Dr. Tom Bell	Leidos 4001 North Fairfax Dr. Arlington, VA 22203	703-312-6288 (O) thomas.h.bell@leidos.com	Data Analyst
Dr. Bruce Barrow	Leidos 4001 North Fairfax Dr. Arlington, VA 22203	703-276-4804 (O) bruce.j.barrow@leidos.com	Data Analyst

APPENDIX B. SOP

STANDARD OPERATING PROCEDURE

Data Collection for Classification Library Updates

1 Purpose and Scope

The purpose of this Standard Operating Procedure (SOP) is to identify the means and methods to be employed when acquiring data using an advanced electromagnetic induction (EMI) sensor over one or more munitions items where the intent is to extract polarizabilities (βs) for addition to the Classification Libraries. The advanced EMI sensors refer to sensors such as the TEMTADS 2x2 (TEMTADS) or the MetalMapper (MM); while the Classification Libraries refer to the separate libraries needed for the different standard acquisition settings used during dynamic and cued operation of these sensors - i.e. the 2.78 ms, 8.33 ms and 25 ms decay settings. The Classification Libraries are essential tools in support of the classification analyses efforts that are afforded by use of advanced EMI sensors.

2 Personnel, Equipment and Materials

2.1 Personnel and Qualifications

The following individuals will be involved in the data collection:

- Field Geophysicist

  Qualifications: Experience with operating the advanced EMI sensor to be used

  Responsibilities: Collecting data over the munitions item(s) and keeping a detailed activity log

- Quality Control (QC) Geophysicist

  Qualifications: Experience with processing and analyzing advanced EMI sensor data

  Responsibilities: Oversight of the data collection process with the aim of maintaining data integrity

- UXO Technician

  Qualifications: Certified/knowledgeable in identifying munitions items

  Responsibilities: Collecting the necessary metadata for the munitions item(s) in question and providing safety escort for the team

- Data Analyst

  Qualifications: Experience with processing and analyzing the advanced EMI sensor data

  Responsibilities: Detailed examination of the data with the ultimate goal of extracting high quality βs for the munitions item(s) to be included in one or more of the Classification Libraries

The roles of the QC Geophysicist and Data Analyst may be combined if the workload permits.

2.2 Equipment

The following is a list of required equipment:

- Advanced EMI sensor system – e.g. TEMTADS or MM
- Non-metallic test stand (to support the sensor)
- DAQ computer stand/table
- Calibration object (medium ISO schedule 80)
- 25’ metric tape measure
- Digital camera
- Optional: Computer accessories – e.g. external display, keyboard, mouse, etc.

2.3 Materials

The following is a list of recommended materials:

- Wooden boards of various size and length
- Styrofoam sheets and/or blocks of various size and thickness
- Permanent markers
- Zip ties
- Electrical tape

3 Procedures and Guidelines

3.1 Equipment Setup

The goal here is for a cost-effective and straightforward setup that allows for efficient collection of high quality data over the munitions item(s) in question. Refer to **Figure 1** for pictures portraying a successful setup configuration when using the MM over a wide range of munitions item sizes.

A. **Assemble the test stand**

Important Considerations:

I. The test stand must be such that the height can be easily adjusted – this is especially important in indoor settings where attaining an optimal sensor height in relation to the floor, ceiling, and the presence of the largest target to be measured is necessary to avoid saturating the sensor response channels (refer to step **3.2**.D.ii. on how to determine if saturation is taking place and on how to fix the problem)

II. Whether the test stand is being assembled indoors or outdoors, care must be taken to account for all potential sources of interference

   i. If another EMI sensor is operated simultaneously, maintain an offset distance between sensors of at least 100m (300ft)

   ii. If indoors, keep lights and other AC electrical equipment (battery chargers, etc.) off while operating – i.e. at least those within a 10m (30ft) radial exclusion zone about the test stand

   iii. All metallic objects within a 3m (10ft) exclusion zone must not be moved during measurement sequences starting and ending with background shots. Any tools and metallic objects that are expected to be used during data collection should be stored well outside this exclusion zone

   Note: If any of the potential sources of interference listed above does take place during data collection, you will need to stop and recollect all measurements taken from the last background measurement onwards before proceeding

III. The test stand must be stable enough so that no movement can take place during sensor operation. Keep in mind that wind can be a source of movement

Note: If movement of the test stand does take place during data collection, you will need to stop, secure the stand, and recollect all measurements taken from the last background measurement onwards before proceeding

B. **Secure the sensor array on the test stand**

Note: If movement of the sensor array does take place during data collection, you will need to stop, secure the array more rigidly to the stand, and recollect all measurements taken from the last background measurement onwards before proceeding

C. **Assemble the DAQ computer stand**

Important Considerations:

I. Place computer stand as far away as cabling will safely and comfortably allow
II. If within the 3m (10ft) exclusion zone:
   - DAQ computer location must remain securely fixed
   - Chair used, if any, must be non-metallic

Note: If II. is violated in any way, you will need to stop and recollect all measurements taken from the last background measurement onwards before proceeding.

Figure 1 – Photographs showing varying aspects of a successful sensor test stand configuration. The plastic shelving is affordable, adjustable and widely available; the wooden boards serve well in providing a stable platform for the MM sensor; and the Styrofoam blocks are both light and strong enough to support a range of item sizes to be measured at various distances, thus ensuring efficiency while preserving versatility. In addition, the cabling and DAQ computer stand are secured and positioned in such a way as to minimize interference during the data collection process.

D. **Connect all cabling per manufacturers' documentation**

TEMTADS: *TEMTADS MP 2X2 Cart User's Guide, v2.00*, MTADS Program, US Naval Research laboratory, Chemistry Division, Washington, DC, May 2014
MM: *MetalMapper Manual, Preliminary Version*, Geometrics Inc., San Jose, CA, July 2011

E. **Secure cables and strain-relief**

This step is generally considered good practice since unsecured cables can:

- Be damaged, through straining
- Get disconnected, by getting unplugged
- Cause noise in the data, by moving during data collection activities.

3.2 Initial System Check

The goal here is to verify that the sensor operates correctly and is free of undesired interferences.

A. **Turn on the system**

B. **Set up the different acquisition parameter settings**

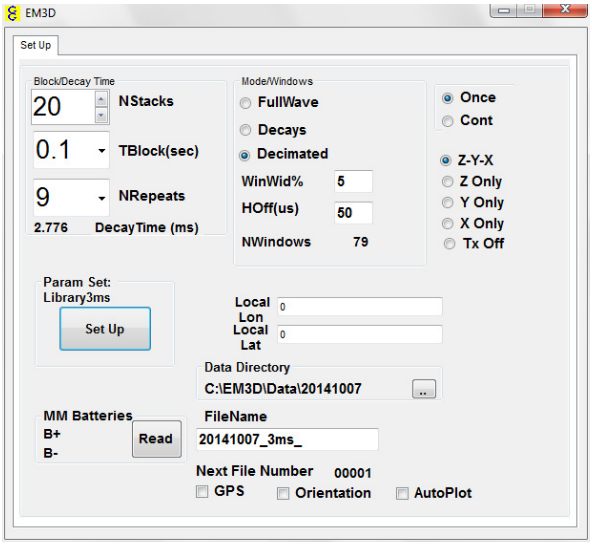
The procedures to save different sensor acquisition settings are straightforward and can be found in the manufacturers' documentation. This step is particularly important if the intent is to collect data over more than a couple of items at all three decay settings since the operation of going from one set of sensor settings to a different one will be reduced to a single mouse click on a drop down list. **Figure 2** shows the MM EM3DAcquire v6 screens that are relevant to the set up process.

C. **Display all essential plots for QC purposes**

The ability to view the data upon collection allows for a much better chance of catching sensor malfunctions or other interferences in the data as they occur. **Figure 3** shows the MM EM3DPlot screen that allows one to define the data plot windows along with the recommended layout for efficient viewing. The plots are: (left window) the Tx currents for each Tx coil with all curves over-plotted; (top right window) the Z,Y,X channel responses from left to right, respectively, for each Rx cube – with all Rx curves over-plotted – when the TxZ coil fires; (middle right window) same plot configuration as those just described but for when the TxY coil fires; and (bottom right window) ditto for when the TxX coil fires. The decay data shown in the rightmost windows are collectively referred to as the TxRx pair data.

D. **Verify that the sensor operates correctly and is free of undesired interferences**

I. Acquire a static measurement using the acquisition parameter settings resulting in the 3 ms decay with the recommended effective stacking (NStacks*NRepeats) of at least 180 and examine the following (the 3ms decay is chosen here to expedite matters, but any of the three decays maybe used):



NStacks 20

TBlock(sec) 0.1

NRepeats 9

DecayTime (ms) 2.776

○ FullWave
○ Decays
● Decimated

WinWid% 5

HOff(us) 50

NWindows 79

● Once
○ Cont

● Z-Y-X
○ Z Only
○ Y Only
○ X Only
○ Tx Off

Param Set: Library3ms

Local Lon 0

Local Lat 0

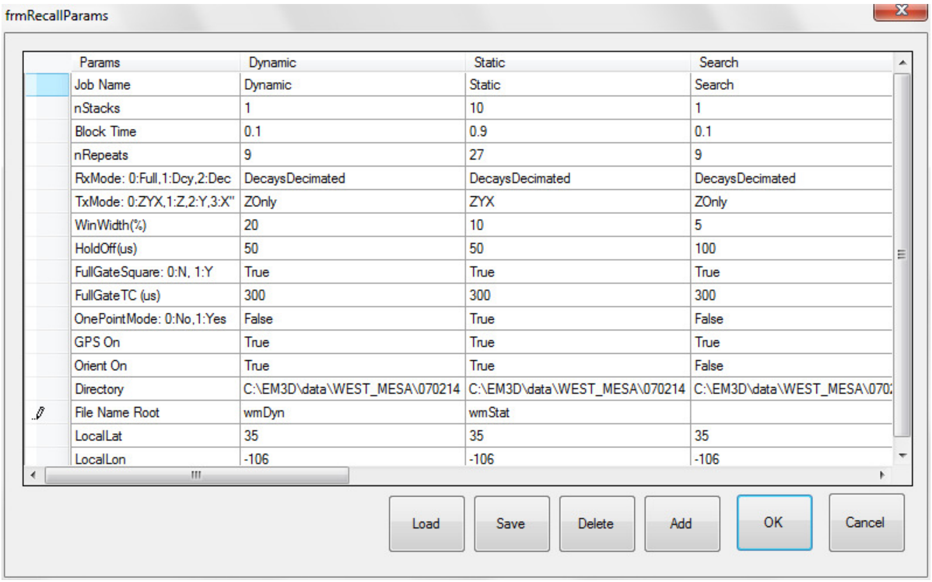
Data Directory C:\EM3D\Data\20141007

MM Batteries
B+
B-

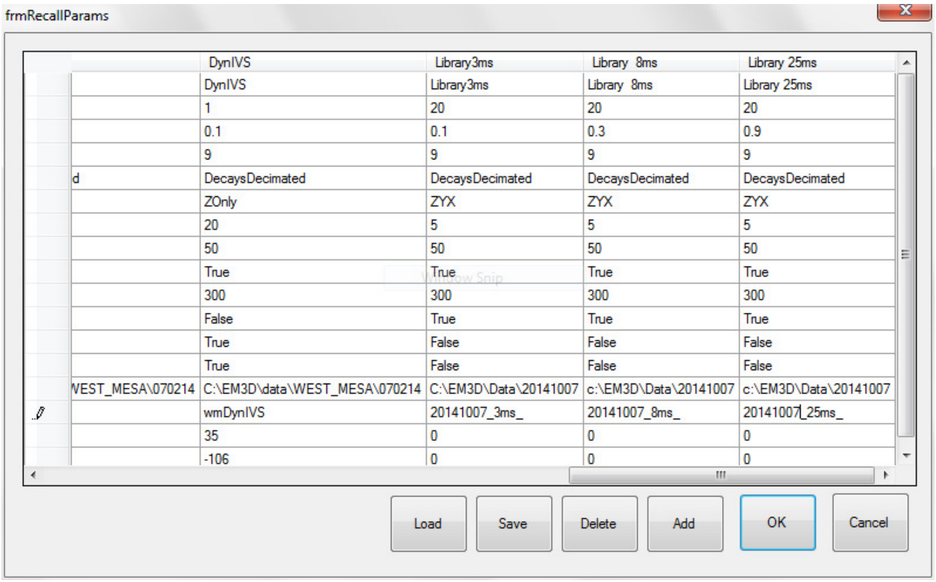
FileName 20141007_3ms_

Next File Number 00001

☐ GPS ☐ Orientation ☐ AutoPlot

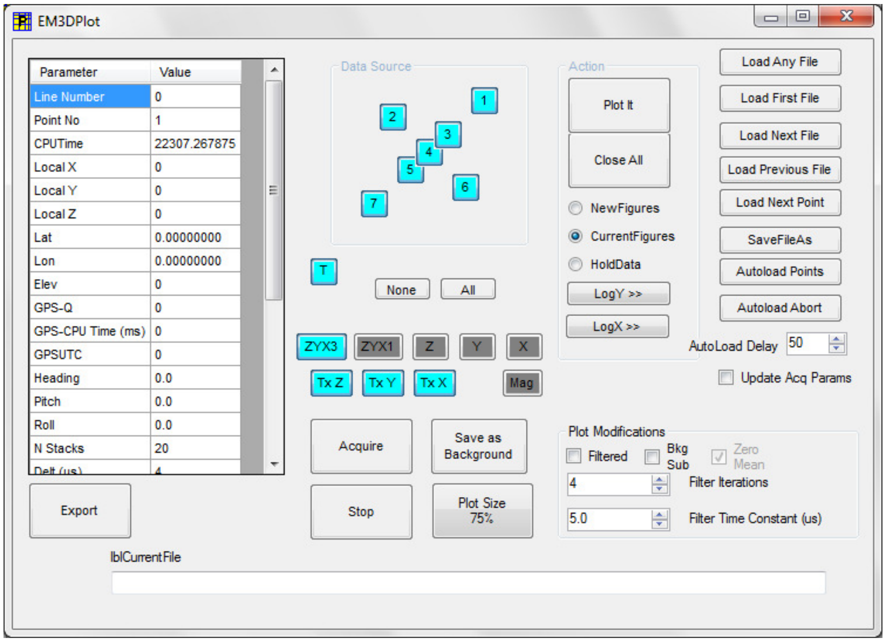


Params	Dynamic	Static	Search
Job Name	Dynamic	Static	Search
nStacks	1	10	1
Block Time	0.1	0.9	0.1
nRepeats	9	27	9
RxMode: 0:Full,1:Dcy,2:Dec	DecaysDecimated	DecaysDecimated	DecaysDecimated
TxMode: 0:ZYX,1:Z,2:Y,3:X"	ZOnly	ZYX	ZOnly
WinWidth(%)	20	10	5
HoldOff(us)	50	50	100
FullGateSquare: 0:N, 1:Y	True	True	True
FullGateTC (us)	300	300	300
OnePointMode: 0:No,1:Yes	False	True	False
GPS On	True	True	True
Orient On	True	True	False
Directory	C:\EM3D\data\WEST_MESA\070214	C:\EM3D\data\WEST_MESA\070214	C:\EM3D\data\WEST_MESA\070:
File Name Root	wmDyn	wmStat	
LocalLat	35	35	35
LocalLon	-106	-106	-106



	DynIVS	Library3ms	Library 8ms	Library 25ms
	DynIVS	Library3ms	Library 8ms	Library 25ms
	1	20	20	20
	0.1	0.1	0.3	0.9
	9	9	9	9
d	DecaysDecimated	DecaysDecimated	DecaysDecimated	DecaysDecimated
	ZOnly	ZYX	ZYX	ZYX
	20	5	5	5
	50	50	50	50
	True	True	True	True
	300	300	300	300
	False	True	True	True
	True	False	False	False
	True	False	False	False
VEST_MESA\070214	C:\EM3D\data\WEST_MESA\070214	C:\EM3D\Data\20141007	c:\EM3D\Data\20141007	c:\EM3D\Data\20141007
	wmDynIVS	20141007_3ms_	20141007_8ms_	20141007_25ms_
	35	0	0	0
	-106	0	0	0

Figure 2 - The EM3DAcquire screens that are relevant to the acquisition parameters set up process for the MM are shown here. The top GUI allows one to set all the parameter values and upon clicking on the 'Set Up' button launches another GUI represented by the middle screen. The lower screen is the same GUI, but now the hidden rightmost columns are revealed by use of the slider. In this case, the last three columns reveal the three different parameter settings saved under the names of Libray_3ms, Library_8ms and Library_25ms.



Parameter	Value
Line Number	0
Point No	1
CPUTime	22307.267875
Local X	0
Local Y	0
Local Z	0
Lat	0.00000000
Lon	0.00000000
Elev	0
GPS-Q	0
GPS-CPU Time (ms)	0
GPSUTC	0
Heading	0.0
Pitch	0.0
Roll	0.0
N Stacks	20
Delt (us)	4

○ NewFigures
● CurrentFigures
○ HoldData

AutoLoad Delay 50

☐ Update Acq Params

Plot Size 75%

☐ Filtered ☐ Bkg Sub ☑ Zero Mean

4 Filter Iterations

5.0 Filter Time Constant (us)

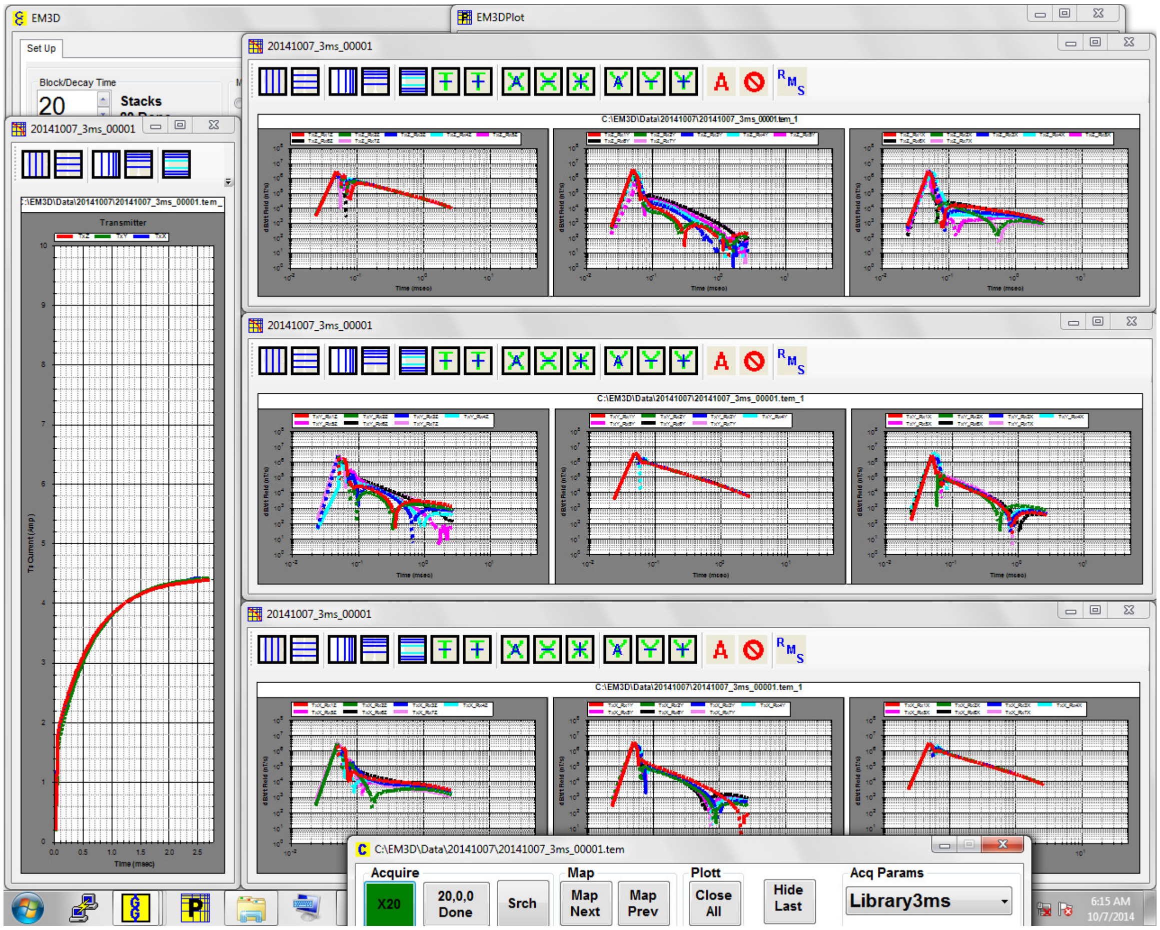


Figure 3 – The EM3DPlot screen that is relevant to setting up the data plot windows for the MM is shown at the top. This GUI allows one to specify the data plot windows to launch by clicking on the buttons (blue) before hitting the ‘Plot it’ button. Data must be loaded before the plot windows can launch and be arranged for easy viewing as shown above. Once open, the plot windows will continually replenish themselves with the most recently acquired data. The EM3DAcquire window at the very bottom allows for the efficient selection of acquisition parameters via a dropdown list before the ‘Acquire’ button (green) is hit.

i. **Tx Currents**

All Tx currents should be in the range of within ~80% of being fully charged, i.e. for

TEMTADS:	5.5 – 6.8 Amps
MM:	3.6 – 4.5 Amps

ii. **TxRx Pair Data**

Scan all TxRx pair data decay plots for any abnormal signs, such as flattened decays, step discontinuities, extended growing trends towards the later time gates, and missing (i.e. 0 or NaN) data

Note: If there are signs of flattening at rail (i.e. maximum/positive and minimum/negative) values at the early time gates, this is an indication of saturation taking place and suggests that the sensor location may need to be changed. Increasing the sensor distance from obvious metallic structures – such as raising the sensor on the test stand away from a steel reinforced floor – will likely help as long as there is space to move without being influenced by other surrounding metallic structures – such as a metal roof, in this case. If there are no attainable “sweet spots” at a particular location (i.e. where all TxRx pair channels do not show signs of saturation), then the location must be changed entirely – e.g. from indoors to outdoors. If there is a “sweet spot” for the sensor, remember that this must also accommodate the item(s) to be measured without going into saturation and without having to place the item(s) too close to the steel reinforced floor. A good test is to insert the largest item in the vertical orientation under the center of the sensor. In this case, the center RxZ channel for the MM will likely be the first to saturate (see **Figure 4** for an example of saturation in the Rx4Z channel taking place). For the TEMTADS, all 4 RxZ channels should saturate simultaneously. By focusing on these channels, the sensor location can further be tweaked to allow for an acceptable range of measurement positions for the item where no saturation will take place and enough of a stand off from the floor exists (~L/2) to rule out possible mutual interaction effects. If an acceptable range of measurement positions is not attainable, then the setup location must be changed entirely, at least when measuring the larger items in question.

Note: If the Tx current values and the TxRx pair data appear normal, then proceed; otherwise diagnose or seek support from the manufacturer to resolve any outstanding issues before proceeding.

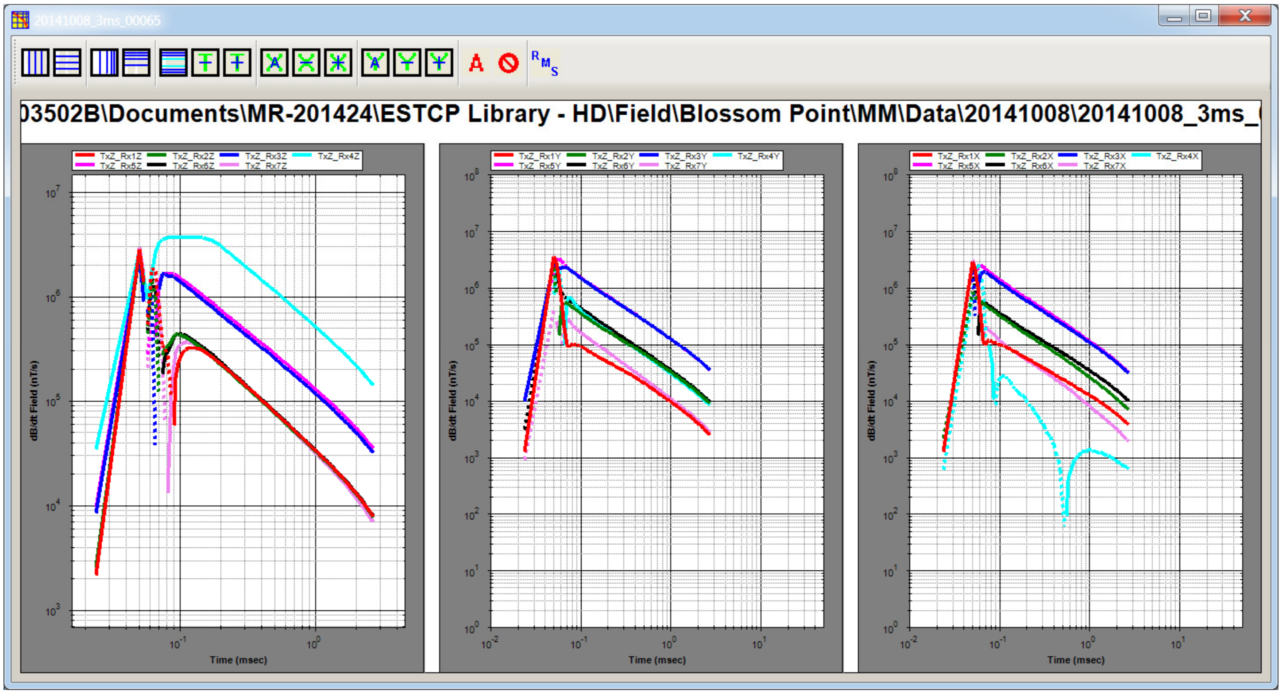


Figure 4 – The MM TxZ_Rx4Z decay (leftmost cyan curve) showing tell-tale signs of saturation where it flattens out in early time at a maximum of just under 4x10^6 nT/s. Since Rx4 is the center Rx cube in the MM, this is suggestive of a metal source being too close to the center of the array. A remedy would be to increase the distance between the MM and the metal source until the flattening disappears and the decay beyond 8x10^{-2} msec only shows signs of decreasing.

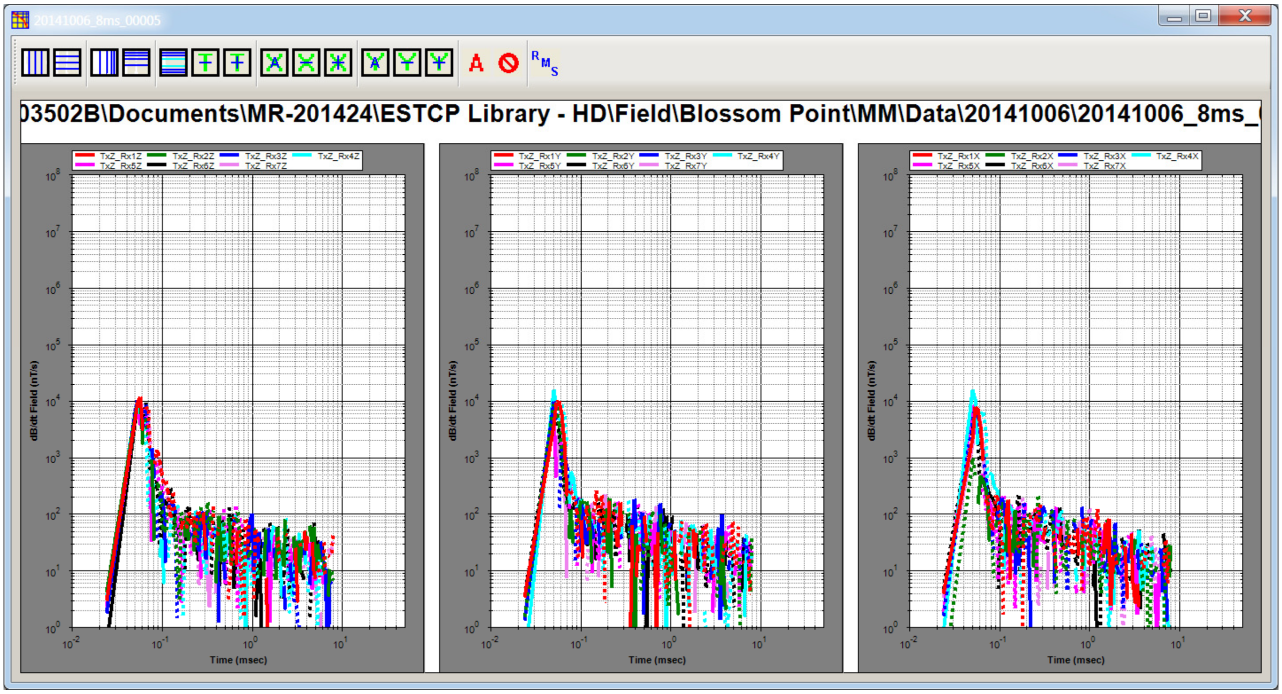
II. Differenced Background Data

Acquire a couple of sequential static measurements using the 8 ms decay time parameter settings and designate one of them as the background (using the ‘Save as Background’ button as seen in **Figure 3**). For the other, examine the following for all the background-subtracted TxRx channel data (obtained by activating the ‘Bkg Sub’ checkbox in **Figure 3**):

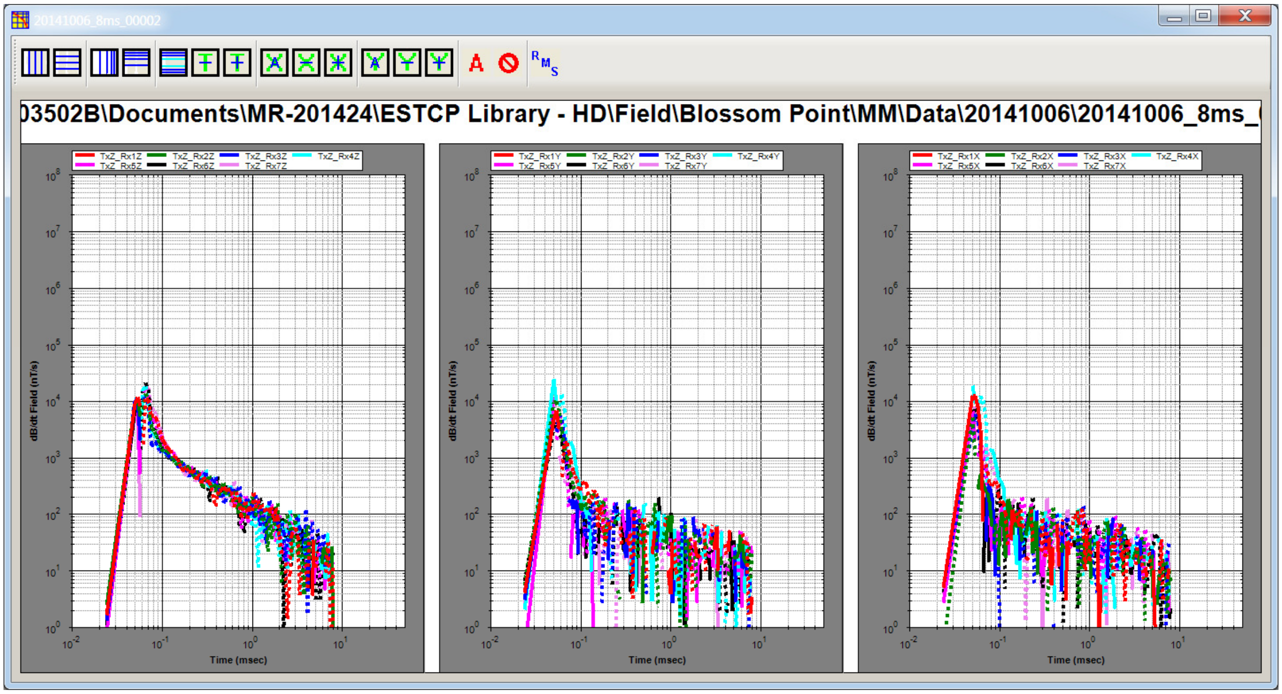
i. Slope of decay

The general decay of the differenced background data for all channels should follow a $1/\sqrt{t}$ trend – a straight line on a log-log plot with a negative rise to run value of 1:2. This means that the trend line drops one large division for every two large divisions in time. This is clearest when looking at the decay portion beyond 10^{-1} msec in the top three plots of **Figure 5**.

It should be noted that if enough time elapses between the two backgrounds that are differenced, then the actual changes in background will start to creep into the data starting with the monostatic channels. This is especially relevant when collecting data in high gradient environments such as an indoor setting. In **Figure 5**, the bottom three plots



3502B\Documents\MR-201424\ESTCP Library - HD\Field\Blossom Point\MM\Data\20141006\20141006_8ms_



3502B\Documents\MR-201424\ESTCP Library - HD\Field\Blossom Point\MM\Data\20141006\20141006_8ms_

Figure 5 – Differenced data for sequential background shots separated by about 2 minutes (top three plots) versus about 14 minutes (bottom three plots). The general decay of the differenced background data for all channels should follow the expected sensor noise trend of $1/\sqrt{t}$. This is a straight line on a log-log plot with a negative rise to run value of 1:2, or a drop in one large division for every two large divisions in time. The top three plots show this behavior very clearly for the decay portion beyond 10^{-1} msec. When too much time elapses between backgrounds that are differenced, actual background changes will start to creep in changing the slope. This starts with the monostatic channels, as seen here by the leftmost lower plot.

are differenced data for sequential background shots taken 14 minutes apart, instead of just 2 minutes apart for the top set of plots. As is clear in this example, the slope for the differenced monostatic decays changes due to the influence of the interim varying background. It is therefore important to allow the smallest amount of time to lapse between backgrounds collected for this exercise.

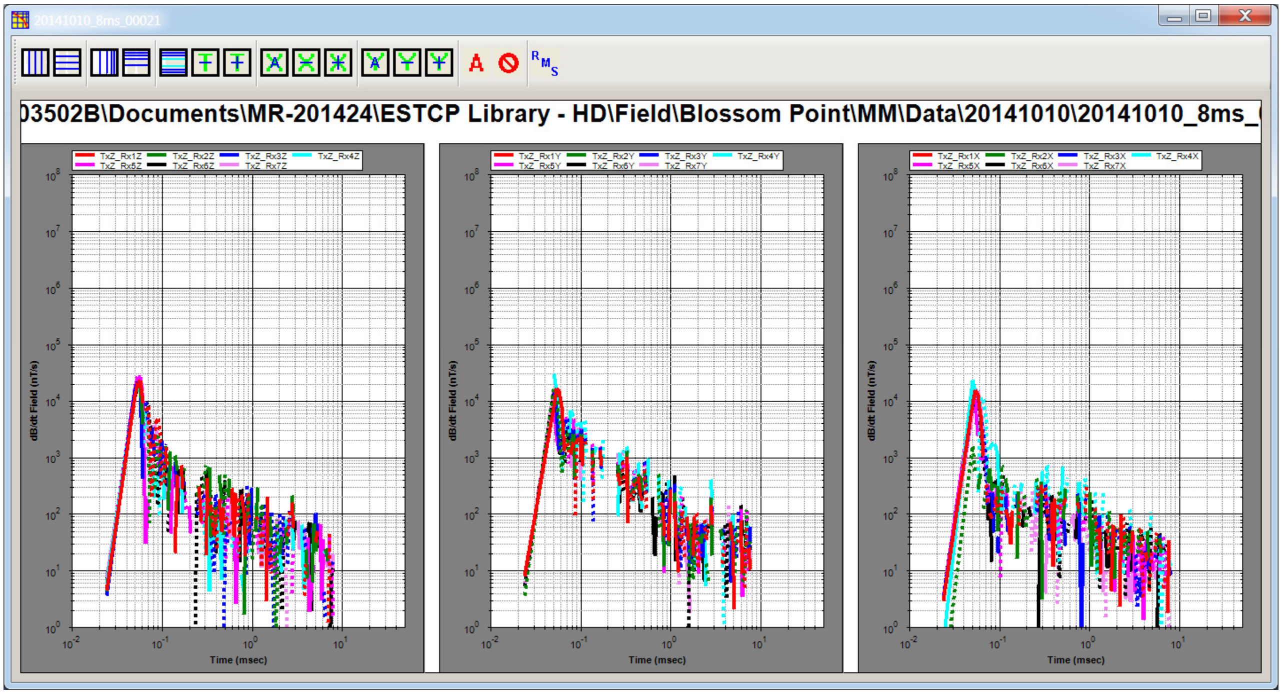
ii. **Maximum acceptable amplitude**

All TxRx trace amplitudes at 2×10^{-1} msec should read:

- TEMTADS: $<10^{-1}$ mV/A
- MM: $<3 \times 10^{2}$ nT/s

While the interfaces for both the TEMTADS and MM systems are expected to be standardized in the future, they currently display the TxRx pair data in different units. To go from mV/A to nT/s, the conversion factor is $1000 * I_{Tx}$/(effective area of the Rx coil)

Note: If both i. and ii. are violated, this is suggestive of a likely source of electromagnetic interference. The background differenced data must be recollected with all possible local sources of interference – i.e. any lights, especially fluorescent lights, and other AC electrical systems – powered down. **Figure 6**, for example, shows the effect of fluorescent lights. If the issue persists, diagnose further or seek support from the manufacturer to resolve any outstanding issues before proceeding.



03502B\Documents\MR-201424\ESTCP Library - HD\Field\Blossom Point\MM\Data\20141010\20141010_8ms_

Figure 6 - Differenced background data showing the effects of overhead fluorescent lights. In this case, both the slope and amplitude tests fail.

3.3 System Calibration and Repeatability

The goal here is to verify that the sensor:

1. Responds predictably to a standard object (calibration); and
2. Continues to do so throughout the data collection (repeatability).

The standard object of choice is the medium schedule 80 ISO (specifically, a black, welded steel, Schedule 80, straight pipe nipple, threaded on both ends, obtained at http://www.mcmaster.com/ as part number is 4550K292). The reasons are that these are widely available; are manageable to handle; provide for healthy responses; and demonstrate reproducible βs at all three decays over a number of different samples.

In order to have meaningful measures of success for both the calibration and repeatability stages that are based directly on the TxRx pair data, accurate and consistent positioning of the ISO is a critical requirement. This demands either specialized apparatuses or great time and pains to attain the necessary positioning to achieve success. Thus, for generality as well as expediency purposes, measures of success will instead be based on the βs extracted from the collected data. In the case of the TEMTADS, data will be collected by placing the ISO under the center of the array, while for the MM, an additional two off-center locations are recommended to ensure that problems with the outermost Rx cubes are more readily detected (refer to **Figure 7** for definitions of the recommended off-center locations).

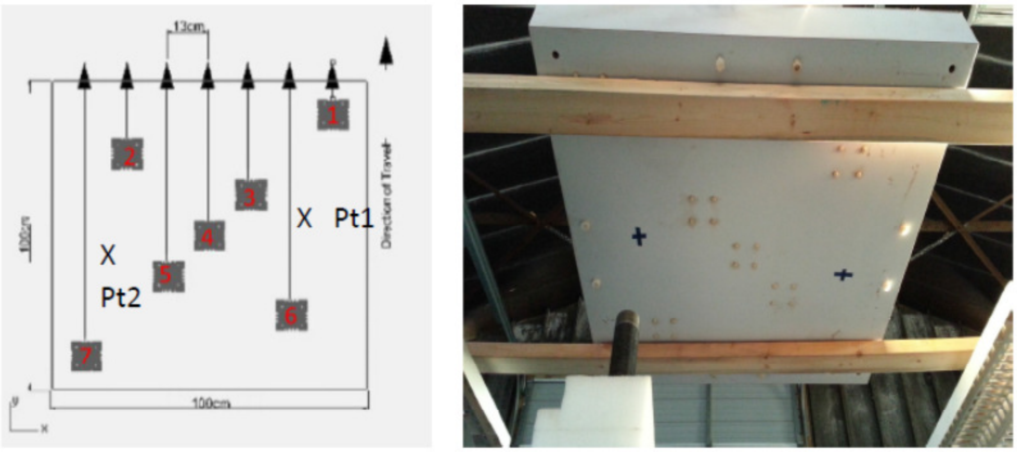


Figure 7 - The off-center locations for the MM defined as: Pt1 – approximately equidistant to Rx1, 4 & 6; Pt2 – approximately equidistant to Rx2, 4 & 7. The top of both panels above represent the front of the MM, but the schematic panel is a view from the top. This means that the ISO in the photo is under Pt1.

For the calibration phase, the expectation is that the βs for the different decay data will be extracted with a fit coherence > 0.99 and match to a high degree with the existing medium schedule 80 ISO entries in the respective libraries. There are many measures for a good match, but the following should be true: βs must match 'to the eye' in both shape and amplitude; and the UX-Analyze 3-β match metric must be well above 0.9.

Repeatability of the system over the duration of the data collection period will be verified by collecting data over the ISO each time the sensor is restarted for data collection activities. These episodes will be referred to as the daily QC data collection (see step **3.5**B.). For the repeatability measure of success, the βs must be extracted from each daily QC data collection with a fit coherence > 0.99 and must match extremely well with the initial set of βs extracted during the calibration phase. In this case, the UX-Analyze 3-β match metric must be well above 0.95.

A. **Collect the standard object data**
   I. For decay settings of interest, collect:
      i. Background
      ii. **TEMTADS:** Vertically-oriented ISO centered under the array at a depth of 32cm
      MM: Vertically-oriented ISO centered under the array at a depth of 32cm and also under each of the off-center points (Pt1 and Pt2 defined in **Figure 7**) at the same depth
      Note: The depth is defined as the distance from the bottom of the sensor housing to the center of the item

B. **Transfer and store the data**
   I. Place all data in .zip files or other such archives prior to transfer for efficiency and to preserve date/time metadata of files
   II. Copy to long term secure storage system

C. **Consult with the data analyst**
   I. Obtain verification of the integrity of the system (i.e. that Tx current values and all TxRx channel signal and noise levels are normal).
   II. Obtain verification that the system is calibrated by ensuring that the βs for the ISO are extracted with a fit coherence > 0.99 and are consistent with existing library entries (i.e. that a UX-Analyze 3-β match metric well above 0.9 is attained, for example). In addition, any off-center βs should be consistent with βs extracted from the data collected under the center of the array (with a UX-Analyze 3-β match metric well above 0.95, in this case).
   III. Make any necessary changes based on the findings

3.4 Before Data Collection

A. **Check batteries**

If batteries are below 90% fully charged, replace batteries with fully charged ones and place low ones on charge

B. **Create a 3m (10ft) radial area exclusion zone around the test stand**

Clear all metallic objects that may be moved during the data collection period from the exclusion zone. Also, refrain from entering the exclusion zone while the sensor is acquiring data.

C. **Ensure that all items to be measured have identifiers**

For each item to be characterized, ensure that each item has a unique, non-removable identification marking (e.g. stamped serial number). If no such marking exists, apply a temporary identifier number and collect a photograph of the item, displaying the marking

3.5 Daily Startup Activities

A. **Connect batteries to the system and turn the system on**

B. **Collect the daily QC data**

This follows the same steps outlined in step **3.3**A. In addition:

I. Verify that the system is operating as expected
    i. Tx currents are in the expected range (step **3.2**D.I.i)
    ii. No anomalous TxRx traces exist (i.e. flattened lines, step discontinuities, etc)
II. Send data to analyst
    i. All βs must be extracted with a fit coherence > 0.99
    ii. All βs must match previously extracted βs (with a UX-Analyze 3-β match metric well above 0.95, for example)

3.6 Data Collection Activities

For each item:

A. **Photograph (to be included as metadata accompanying the βs)**[*]

I. Place the item on a solid white color background with the long axis parallel to a clearly visible ruler; lighting should be such that shadows are minimized

II. Photograph

III. Repeat for any additional orientations necessary to capture the complete state of the item Examples:
   - i. Base view – to document if the base plate is present, or if the item is filled or empty
   - ii. Nose view – to show if the fuze is missing, or if non-symmetry exists
   - iii. Other views – to record dents or other damage
   - iv. Item markings, if still visible

Figure 8 - Example photographs for a BDU33 25lb practice bomb showing (from left to right) a full view; a base view; and a nose view.

B. **Identify (based on markings and other identifiers)**[*]

I. Fill in all cells of **Table 1** in Appendix A (The UXO tech must approve all entries before going on to the next step)

II. Forward the completed item metadata to the data analyst for inclusion with the extracted βs in the classification libraries

C. **Collect sensor data**

I. Place the item at one of the ***required three orientations (i.e. Horizontal; Vertical, nose down; or Vertical, nose up)*** at a depth equivalent to the largest dimension of the item (L) and check if saturation of any TxRx pair channel data occurs (refer to step **3.2**D.ii. on how to determine if saturation is taking place)

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[*] Activity may be conducted asynchronously for efficiency, as long as each item has a clear identifier as discussed in step **3.4**C.

If saturation occurs, increase the depth by the suggested increments until saturation in all channels has been eliminated:

i. ***Small*** (i.e. caliber < 50mm)**: *1cm increments***
ii. ***Medium*** (i.e. 50mm < caliber < 100mm)**: *2.5cm increments***
iii. ***Large*** (i.e. caliber > 100mm)**: *5cm increments***

Note: The above rules of thumb are recommendations only and should not replace common sense. The goal of this exercise is to move the item far enough away from the sensor to prevent saturation, without sacrificing signal strength by moving it further than necessary. If the signal is weak and it appears that more signal strength could be gained by moving it closer (without saturation reoccurring), than do so provided depth > L.
Note: Large aspect ratio items (i.e. where L/OD > 6) will at times, for particular orientations, present weak signal strengths at L. In those cases, the starting depth should be moved closer between L/4 and L/2 to obtain a healthy signal.

II. For ***all decay settings*** of interest, collect:
   i. Background
   ii. Item, as oriented and at the depth determined in step I.

III. Repeat steps I. and II. for remaining orientations

Note: The Backgrounds in step II. may not need to be collected each time. This will depend on how much time has elapsed since the last backgrounds were collected. It is recommended that backgrounds (for all decay settings of interest) be taken at 20 minute intervals, never to exceed 30 minutes

Note: The horizontal item orientation relative to the array should also be recorded. For example, H-NPt1 for the MM might signify that the item is horizontal and oriented across track with the nose pointing towards the Pt1 side.

IV. Repeat step II. for a second depth for all three orientations.

Rough guidelines for selecting the second depths are:
   i. ***Small**:* add L/2 to the first depth
   ii. ***Medium:*** add between L/3 and L/2 to the first depth
   iii. ***Large:*** add between L/4 and L/2 to the first depth

Note: The goal here is to move the item as close to a distance of L/2 further from the sensor while still maintaining sufficient signal strength to be able to extract secondary βs that can be reliably compared to the ones extracted at the shallower depth. For those items with large aspect ratios, this may be a problem and so a shallower second depth is needed.

Note: If an extended interruption in the data collection occurs before background data can be collected, always resume by recollecting all measurements taken from the last background measurement onwards before proceeding. The goal is to always have the data sandwiched by two backgrounds collected less than 30 minutes apart.

3.7 Daily Shutdown Activities

A. **Transfer and store the data**
   I. Include field notes and photographs with the sensor data files
   II. Place all data in .zip files or other such archives prior to transfer for efficiency and to preserve date/time metadata of files
   III. Copy to long term secure storage system

B. **Power down and secure the system**

C. **Place all batteries on charge**

4 Quality Control

Practical considerations limit the real-time QC of the data acquisition activities to mostly qualitative assessments. A complete quantitative assessment will be performed post-collection by the data analyst. The full set of measurement quality objectives (MQOs) are as follows:

	MQO	Metric	Success Criteria
	For each munitions item		
1	Were the complete metadata collected?	Table 1, Appendix A; photograph(s)	Table 1 completed; photograph(s) taken
2	Were data collected at all decays of interest?	Intention coming into the data collection	All targeted libraries addressed
3	Were all required data collected?	Step **3.6**C of this SOP	*At a minimum,* 3 required orientations at two depths
	For each data set collected for extraction of βs		
4	Was inversion successful?	Fit coherence (with sanity check of position & orientation parameters)	Fit coherence > 0.98[*] (with X,Y,Z to within +/- 15 cm[**] and Tilt & Azimuth to within +/- 30°[***])
	Validation of ISO βs extracted		
5	Do extracted βs agree with existing Classification Libraries entries?	3-β match to βs in existing Classification Libraries	> 0.9
	Daily QC data		
6	Are extracted βs for the ISO as expected?	3-β match to initial βs extracted	> 0.95

[*] Fit coherence > 0.90 may be more appropriate for large aspect ratio items

[**] For larger items in the vertical orientation Z to within +/- 30 cm

[***] Tilt & Azimuth bounds may sometimes be meaningless for large and/or composite items, especially for the 2.78ms decay

The data will not be used to update the Classification Libraries until these MQOs are met or until the project team agrees on modifications to these MQOs.

Appendix A

Table 1 - Required munitions descriptive information to accompany photographs and βs, with an example entry for the BDU33 represented in **Figure 8**. Note that the Qualifier/Pedigree field is based on Andy Schwartz's definition as stated below the table.

Name		BDU33	
Mark/Mod		MK76	
Dimensions (mm)	**OD**	102	
	Length	635	
Common Name		BDU33	
Class Category		Bomb 25lb	
Fins?		Y	
Fuzed?		N	
Spotting Charge?		N	
Rotating Band?		N	
Appearance/Condition		Fired/Bent	
Qualifier/Pedigree*		B	
Photo(s)		2068,2069,2070	
Serial Number		NRL PB-1	
Comments			

***The following gradations are used:**

A. **Fully described**
B. **Known Mark/Mod, not fully described**
C. **Only outer diameter(OD) or common nomenclature is known**
D. **TOI shape confirmed but no other nomenclature available or is not trusted**

Attachment 1

SOP Startup QC Checklist

This checklist is to be completed by the QC Geophysicist before moving on to the item data collection activities.

QC Step	QC Process	Yes/No	Initials of QC Geophysicist
1. Equipment Setup	Have all steps been followed?		
2.Initial System Check	Were all steps successfully completed?		
3.System Calibration	Have all steps been followed and has the data analyst confirmed the expected operation of the system based on MQOs 4 & 5?		
4. Before Data Collection	Have all steps been followed?		

SOP Data Collection QC Checklist

This checklist is to be completed by the QC Geophysicist for each daily data collection.

QC Step	QC Process	Yes/No	Initials of QC Geophysicist
5.Daily Startup Activities	Were all steps successfully completed and has the data analyst confirmed the expected operation of the system based on MQOs 4 & 6?		
6.Data Collection Activities	Have all steps been followed?		
7.Daily Shutdown Activities	Have all steps been followed?		

SOP Successful Completion QC Checklist for each Item

This checklist is to be completed by the QC Geophysicist (with input from the Data Analyst) before ending the data collection activities.

QC Step	QC Process	Yes/No	Initials of QC Geophysicist
1. MQOs 1-3	Have all checklist items been addressed?		
2.Additional Configurations?	Has the data analyst recommended more measurements based on great variations observed in the extracted βs?		
3. MQO 4	Were the inversions successful based on the fit coherences and position/orientation parameters?		