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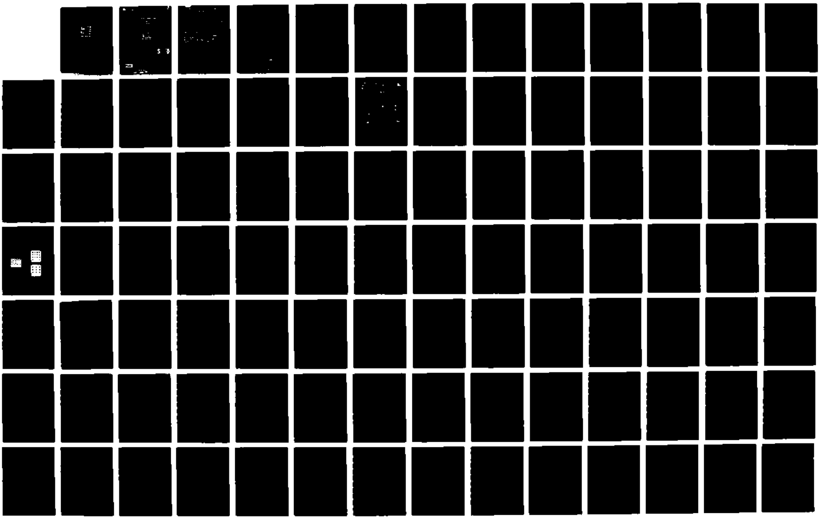

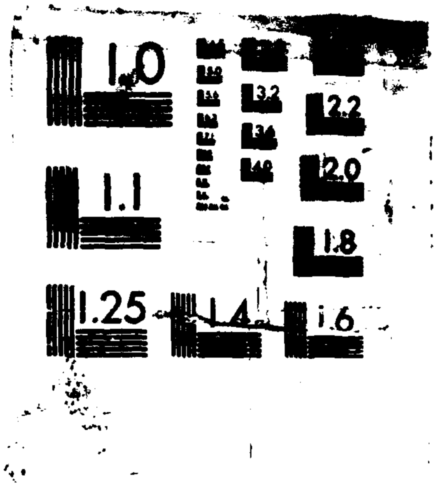

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BATTLEFIELD MANAGEMENT
and
FIRE CONTROL SYSTEM
for M1A1

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study of fire control and battlefield management requirements and relationships for the M1 Abrams Main Battle Tank is presented. Three possible approaches for integrating advanced fire control and battlefield management capabilities into the M1 are described. Each is evaluated for near term M1 design and schedule impacts and compatibility with projected growth requirements. The application of VHSIC processing is examined, and an approach for insertion of that technology is discussed.

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1. INTRODUCTION

The U.S. Army's ground combat vehicle forces are entering an era that will be marked by the need for substantial change in vehicle electronics, as new tactics and an increasingly sophisticated threat are translated into specific vehicle design requirements.

Significant design impacts will occur in fielded vehicles as a result of three basic effects:

1. New functions are being required of the vehicles and their crews, and these must be accomplished more efficiently;
2. More combat performance is being required of and designed into key subsystems (e.g., enhanced armament and lethality);
3. Changes in these subsystems will require modification to others in order to maintain acceptable performance (e.g., stabilization of enhanced armament and higher protection level turrets).

Many of the changes that will occur during the next several years will be focused on increasing the efficiency and speed with which a battle can be conducted. They will be accomplished, in large part, by automating many of individual vehicle communications and fire control functions that are currently accomplished manually.

The brute force computational power needed to achieve the desired levels of automation on individual vehicles will be available in the form of VLSI and VHSIC circuit technologies, which can provide compact high-throughput electronics packages. However, the cost of this technology, the accompanying large increase in vehicle-based data flow, and very limited availability of additional space inside vehicles, will combine to create potentially significant problems with the practical implementation of these objectives.

The fire control system (FCS) on modern combat vehicles has been the primary driver of weapon station architectures, with the key requirements being stabilization and control of electro-optical sensors and weapons, sensing of significant environmental parameters, and the computation of weapon pointing commands. It will continue to dominate as automated target sensing and classification, and modern control techniques are applied.

In March 1984, General F. J. Brown (ref. 2) described a user's perspective on battlefield management, defining a critical need to integrate combat systems and information gathering sources into a Data-Linked Maneuver Force. This concept stressed the primary importance and the functionality of the individual combat vehicle, with the tank commander, who is currently over-stressed in intense combat conditions, being the critical element.

General Brown's recommendation was to substitute technology for a wide variety of repetitive, time consuming and manual functions. This must be accomplished while minimizing stress on individual unit commanders and not overburdening them with additional duties. A Battlefield Management/Integrated Command and Control System (BMS/ICCS) will create a "Force Multiplier" effect, by providing the small unit commander with the capability to process tactical information in real time using vehicle-based information management systems.

It is clear that the individual combat vehicle is a key element in this concept of a Data-Linked Manuever Force. Current combat vehicle data handling and processing is either manual, or integral to the Fire Control processing function. Growth capability is essential and is recognized as a major factor for BMS and advanced fire control. Additionally, the vehicle-based BMS node must be capable of communication with higher level systems (i.e. CCCI, MCS), both within the army and across other service branches.

Many of the detailed operational characteristics of a BMS have not been defined, and it is not the intent of this study to attempt further definition of these. Our purpose is to examine the probable directions that will be taken and to evaluate the resulting impact on the architecture of the combat vehicle. Our objective is to lay the groundwork for a systematic approach to growth that takes into account all of the probable areas of major changes and their interrelationships.

If the design and integration of individual, time-phased growth objectives in FCS and BMS are not coordinated and approached in an integrated manner, there could be a proliferation of electronics boxes, software modules, and interconnects that would quickly become unmanageable and prohibitively costly to acquire and maintain. The level of sophistication in new and product-improved weapon stations requires that the system architecture be carefully planned and designed to accomodate the growth that will most certainly occur over the next decade.

This study examines the near term requirements for FCS and BMS on the M1A1 tank system, their probable areas of growth, and the hardware/software implications of those requirements. The applicability and development status of key component and interconnect technologies are examined, and a specific approach is recommended for the development of BMS and advanced FCS capabilities on the M1A1 tank.

The key information in this report will be found in sections 3, 5, and 6. Section 3 of the report discusses the current and projected relationships between the fire control and battlefield management systems, and forms the foundation for the approaches discussed later. Section 4 addresses component technologies that are significant to the FCS/BMS requirement. While it supports the direction taken for system architectures, reading this section is not required for an understanding of the systems issues discussed later.

Section 5 summarizes key architectural considerations and describes the M1 fire control system, which is the baseline for the BMS and advanced FCS architectures described in section 6.

2. SUMMARY AND CONCLUSIONS

A need has been identified to provide an automated data and communications management capability for future land combat forces. The exact nature of the communications networks and interfaces that will comprise future Battlefield Management Systems have not all been defined. However, it is clear that a primary element of that structure will be a communications and data processing node that is mounted in front line combat vehicles, such as the M1A1.

The army's approach to fighting future wars has identified preliminary functional requirements for that vehicle mounted BMS node. The major uncertainty is the exact timeframe during which major steps in functional growth will occur. A similar statement can be made for the fire control system, which will also require substantial growth, although not necessarily at the same times as the BMS.

Although the M1A1 tank is a large vehicle, there are significant limitations in the availability of internal turret space for stowage of additional equipment and cabling. A considerable amount of engineering will be required to even integrate a minimum configuration BMS. The problem is further compounded by the likelihood of near term requirements for changes in other turret subsystems, due to factors totally unrelated to BMS. Finally, it is clear that there will be a continued need for growth in system capability even after a baseline configuration is defined and integrated.

With these factors in mind, it is important that design changes being planned for the M1A1 FCS and BMS consider the totality of the requirements over the next several years. The traditional growth path in combat vehicle electronics systems has emphasized "self-sufficiency" in new functions in order to simplify integration and minimize impact on the existing equipment designs. Over a period of time and a number of changes, however, this ultimately leads to an unacceptable proliferation of electronics boxes and complex interconnects.

The M1A1 turret is at, or very near, the saturation point for integration of major new electronics subsystems. Thus, more emphasis must be placed on the efficient use of on-board sensors and electronics. This may require redefinition of some traditional subcontractor roles and the replacement of some equipment that meets current needs but has no inherent flexibility or growth capability.

This study examined the relationship of BMS and FCS and the probable design impacts of functional and performance growth in these areas. It concluded:

(1) the on-vehicle BMS and FCS functions are closely interrelated, requiring similar computational capability and

data flow;

(2) the potential exists for data sharing between the BMS and FCS functions, which could lead to elimination of some of the current fire control equipment without loss of performance;

(3) both the BMS and FCS will experience substantial growth that is primarily centered on increased "intelligence" (computational capability) rather than the addition of more sensing hardware.

Because of this, it is important that vehicle related BMS and FCS issues be addressed as a single problem. This report recommends that a development be undertaken for an integrated FCS/BMS processing and control system, and that it address the FCS impacts of armament and armor enhancement as well as the near term BMS functions. It also recommends that the new processor system be based on standard electronic modules and nonproprietary architectures that can be procured in open competition and are compatible with VHSIC insertion.

The recommended approach may not be compatible with the current M1A1 Block II production schedule objectives. However, this should be further evaluated in terms of the long term benefits of a more orderly transition to an integrated FCS/BMS. That analysis was beyond the scope of this study.

3. BMS/FCS REQUIREMENTS AND RELATIONSHIPS

This section of the report summarizes the specific requirements for FCS and BMS operation in the near term and projects the probable areas for major performance and interface growth. It also discusses the equipment required to accomplish these functions and its suitablility for growth.

It is becoming increasingly difficult to categorize and assign responsibility for specific functions of combat vehicle operation to an individual subsystem. The sharing of data across traditional subsystem boundaries and the need to optimize the use of on-vehicle computing power will make this division of responsibility even more difficult as currently planned product improvements become reality.

Thus, as discussed below, the assignment of specific functions to either the FCS or BMS category is somewhat arbitrary. However, it will become apparent that this assignment has no affect on the conclusions of the analysis and is merely a convenience for the purposes of communication.

As combat vehicle systems become more sophisticated, it is clear that the traditional design approach of subsystem self-sufficiency and physical separation of subsystem designs by functional objective is no longer economically feasible or required from a technology point of view. Thus, it is important to view the control and communications requirements for future vehicles from a higher level systems perspective, and to re-examine traditional partitioning of the system functions.

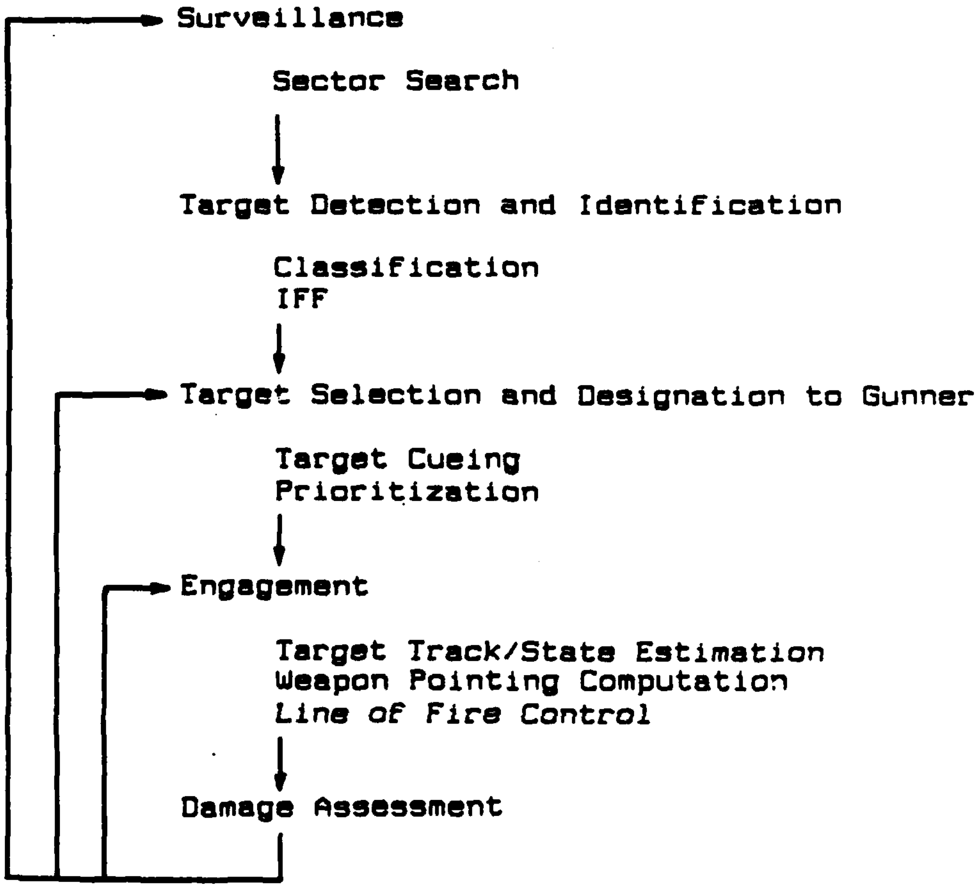
For the purposes of this discussion, however, we will attempt to associate high level functions primarily with either the Fire Control System or the vehicle "node" for the Battlefield Management System. In doing this, we make the following (somewhat arbitrary) distinction:

> Fire Control (FCS) functions will be considered to be those associated with the detection, identification, and engagement of individual targets on the battlefield and the measurement of vehicle and environmental parameters that affect performance of these functions.
>
> Battlefield Management (BMS) functions will be those required for consolidation and communication of tactical data and command and control information between vehicles, and for the timely presentation of key planning and status information to vehicle commanders.

It should be noted that each of these systems is both a source and a destination for data that is indigent to the other.

3.1 FIRE CONTROL SYSTEM

The fire control operational requirements can be grouped into the following basic functional elements and flow:



Each of these areas has unique requirements and distinct relationships to growth issues for the M1 and its role in the BMS system.

Although there are currently no formally established fire control system growth requirements beyond the Commander's Independent Thermal Viewer (CITV) and the CO2 laser rangefinder, it is likely that additional requirements will be established before 1990.

A major objective in fire control evolution must be to extract the greatest benefit from BMS and the equipment inherently available on the vehicle. To accomplish this, fire control will continue to demand increasingly significant computational capability at the vehicle level. This is driven both by needs for enhanced performance and improved supportability with minimum cost impact.

While some growth will occur in the form of new sensors and specific hardware, much of it will be centered on extracting more useful information through additional data processing and consolidation of data already available. Table 3-1 and the following paragraphs summarize the current and near term FCS requirements for M1A1 along with the probable growth paths it will take in the long term.

For the purposes of this discussion, "Current/Near Term" will refer to capabilities and/or technologies that, from a cost/schedule/requirements point of view, should initially be in systems fielded under the M1A1 Block II program. "Long Term/Growth" refers to items requiring longer development that are desirable, but not essential, to an operational system. It is assumed that development of these will occur at some point in time, and that consideration for their ultimate integration should be made in the initial system architecture.

3.1.1 SURVEILLANCE

The surveillance function consists of scanning pre-selected terrain areas for potential targets. It is primarily accomplished with the use of magnified direct view optics and/or thermal imaging sensors.

3.1.1.1 Current/Near Term

Surveillance on the M1 and M1A1 is conducted through the use of open hatch observation and/or the gunner's primary sight (GPS), which has both direct view and thermal imaging capability. Sector search with the GPS is accomplished by rotating the turret in azimuth (to which the GPS is mechanically linked) and the sight head mirror (to which the main gun is slaved) in elevation.

In recognition of the need for high performance closed hatch surveillance independent of the gun system, the Block II M1A1 will also integrate a second viewing device - the Commander's Independent Thermal Viewer (CITV). This thermal imaging sensor can be controlled independently of the turret and provides the capability for simultaneous independent surveillance by the commander and gunner and the ability for continued surveillance by the commander while the gunner is engaging a target.

Both the GPS and the CITV lines of sight are controlled by stabilization and control electronics which normally follow tracking rate commands from the operator's control handles. The CITV also has the capability to automatically scan a pre-defined sector at a constant rate to relieve the operator of the need to continually command the line of sight on a repetitive surveillance action.

The thermal imagers on both sights currently generate non-standard video signals for displaying the scene imagery.

<u>Interface with BMS</u>

The primary near term interface of the FCS surveillance function with the BMS will be to provide the BMS node with the vehicle's

Table 3-1. Fire Control System Functional Requirements

FUNCTION	CURRENT/NEAR TERM	LONG TERM/GROWTH
SURVEILLANCE	Manual LOS Control Manual Search Block II Supplemented by CITV with Simple Auto-scan	Automatic Sector Assignment High Speed Scan Adaptive to Intelligence Data from BMS network
TARGET DETECTION & IDENTIFICATION	Manual Operation Using Low/High Optical Magnifications Block II Supplemented by CITV	Automatic Video Target Detection Automatic Target Detection by Non-Imaging Sensors Automatic Target Classification Automatic IFFN Focal Plane IR Imagers
TARGET SELECTION & DESIGNATION	Manual Selection by Commander Automatic Slew of GPS to CITV LOS on Command (Block II)	Computer-Maintained Multi-Target Queue Automatic Adaptive Prioritization and Designation Capability to Insert BMS-Designated Targets Into The Vehicle Target Queue
TARGET ENGAGEMENT	Manual Tracking - Aided by Stabilization Automatic Lead Computation - Manual Alignment, Nominal Ballistics, Linear Target Motion Automatic Line of Fire Control - Offsets + Stabilization + Firing Limiters	Automatic Target Tracking Improved Lead Computation - Automatic Alignment/Zero, Second Order Kinematic Lead Improved Line of Fire Control - Adaptive Stabilization & Firing Limiters, Barrel Dynamics
DAMAGE ASSESSMENT	Manual - Using High Resolution Optics	Assisted By Image Processing & Automatic Target State Evaluation

surveillance sector information. This would be used primarily at the platoon command level to control and monitor surveillance of the assigned sectors of responsibility.

The data required by the BMS node would be azimuth orientation and ranges at the extremes of the surveillance sectors.

3.1.1.2 Long Term/Growth

In the long term, the selection of surveillance sectors and the allocation of sensor resources will become more automated. In particular, sector scanning will be computer controlled to take advantage of automated sensor data processing, externally derived intelligence data, and knowledge about battlefield lines of sight and potential areas of approach. Additionally, surveillance assignment will probably be coordinated across elements of one or more platoons to maximize the composite surveillance capability of the unit.

From a line of sight control perspective, the impact of this surveillance capability on the fire control system hardware will be minimal. The current analog control and stabilization electronics will be adequate, with the required rate commands being generated in a digital processor.

Interface with BMS

The surveillance function will use terrain data, vehicle position/heading data, and sector responsibilities/target intelligence transmitted by the platoon leader through a BMS platoon net to derive the required control commands to the sight(s). A direct command link from the BMS to the line of sight (LOS) control function in the FCS will exist.

3.1.2 TARGET DETECTION AND IDENTIFICATION

Target detection occurs when an object of potential military significance is seen in the surveillance sector. Depending upon the probable nature of the target and the current mission requirements, additional discrimination is usually undertaken to recognize the class of the target (e.g., truck, tank, APC, etc.) and/or its specific type (e.g., T-72, BMP) before further action is taken.

3.1.2.1 Current/Near Term

Currently, target detection and the various levels of identification are accomplished manually, with the commander or gunner viewing through on-board direct view optics or the thermal imager. Detection of possible targets usually occurs during the surveillance function with the optics in a wide field of view mode. Target identification is accomplished by switching the optics to a higher resolution narrow field of view mode. Both the GPS and the CITV provide the required sensing capability.

Implicit in the identification process being discussed here is the classification of a detected target on the battlefield as friend, foe, or neutral (BIFF-N).

The primary source for target detection is the thermal scene image. The thermal imagers in the GPS and CITV develop a real-time electrical signal (non-standard video) that contains all of the scene data currently in their fields of view. This is then displayed on CRT's for observation by the commander and/or gunner.

There is currently no provision for accepting target information from off-vehicle sources other than by verbal location description (using landmarks, etc.) over a radio net, followed by a manual search and detection in what is believed to be the described area.

Interface with BMS

The only near term interface of the detection/identification function with BMS would be indirect. The ability to display map and target information via the BMS will improve a commander's apriori knowledge of potential targets, but he will still have to actually detect and confirm their identity manually. This information, combined with location data on friendly elements, could also provide some assistance in the BIFF function.

3.1.2.2 Long Term/Growth

The mid-to-long growth in this area will be to automated image processing of the thermal data. The ability to process entire fields of view in a fraction of a second and automatically classify and cue detected objects offers the potential for major improvements in the rate of target acquisition and the surveillance sectors that can be effectively covered by individual vehicles.

The major technical obstacle to incorporating this capability into the M1A1 is the associated computational requirements. Recent studies by fire control developers have concluded that an autocuing capability will require 3 to 4 Mops of scalar and 45 to 50 Mops of array processing throughput. This level of throughput capability will first become technically feasible for combat vehicles with the availability of VHSIC processors in the 1987-89 timeframe.

Lessor technical impacts would also occur relative to the formatting, distribution, and display of the video data. The current video signal format is not compatible digital processing or displaying on conventional scanning displays. Thus, the signal would have to be scan converted and distributed in real time to the VHSIC processor. Formatting the processed signal and generating symbolic display overlays is straightforward.

Interface to BMS

In the long term, this is an area with major interface to the BMS function. The ability to electronically locate and classify targets means that this data is inherently in a form suitable for automatic computer to computer communication. Thus, specific target information from individual vehicles could be automatically consolidated and coordinated at higher command levels.

Similarly, target information from off-vehicle sources could be communicated via the BMS to the vehicle and then downloaded into an FCS target queue for processing.

The interface to the BMS will be straightforward with relatively low data rate interchanges. Basically, target position, velocity and classification data would be available for interrogation or updating by the BMS as new data is developed.

3.1.3 TARGET SELECTION AND DESIGNATION

In the modern battlefield environment a vehicle commander may have to choose a specific target for engagement from among several possibilities. The prioritization and selection process may depend on several factors, including mission objectives, the relative threats posed, whether a target is already being engaged, etc. Once a target has been selected, it must be designated (handed off) to the gunner and acquired by him for engagement.

3.1.3.1 Current/Near Term

Currently, the target prioritization and selection process is manual, relying on the observations and judgment of the vehicle commander. With the M1 and earlier tanks, target handoff is accomplished by manually slewing the turret until the target is in the gunner's sight field of view and can be observed by the gunner. The gunner then assumes control of the gun sight (GPS) and initiates the tracking and engagement process.

With the addition of the CITV to the M1A1, the designation process is automated to the extent that the GPS can be automatically slewed and aligned with the CITV line of sight upon command. Thus, if the CITV is looking at the target of interest, the target can be quickly handed off.

Interface with BMS

In the near term, individual tank commanders may receive target selection guidance from their platoon leader based on his assessment of the consolidated platoon and target status information. However, this will likely initially be communicated through the BMS display, with no automatic interface to the FCS

It is possible that a control interface could be established that would slew the CITV to the target bearing upon request from the vehicle commander. This would require a moding and control interface with the BMS.

3.1.3.2 Long Term/Growth

In the long term, the prioritization and designation function will be assisted by the automated image processing described above and (possibly) by decision support software (artificial intelligence) integral to the BMS. Upon completion of an engagement or otherwise becoming available, the gunner's sight will be automatically slewed to the bearing of the next highest priority target in the queue for that vehicle.

In this mode of operation, the CITV does not have to be aligned to the target prior to handoff and therefore it, and the commander, can continue with other functions without interruption.

The design impact of this capability is relatively minor. It requires computer control of the commanded sight rates and/or control of the reference angles for the designation loop closure. Digital processing will be required to compute the reference angles for the servo loop closure.

Interface with BMS

The interface for this function to the BMS will be through the target queue. The BMS must have the ability to interrogate and modify the contents of the target queue. Modifications might include the insertion of new targets based on external data and/or changing the priority of targets based on additional information or the platoon battle plan.

3.1.4 TARGET ENGAGEMENT

The target engagement function consists of the following major elements.

Target Tracking and State Estimation

Weapon Pointing Computation

Line of Fire Control

Target Tracking and State Estimation is required to establish the position of the target at the time of firing and to predict where the target will be one projectile time-of-flight in the future. Weapon Pointing Computation requires prediction of the ballistic displacements of the projectile, parallax effects, and the target displacement during projectile flight (kinematic lead). These effects are summed to produce a commanded gun angle with respect to the current target position.

Line of Fire Control is the function that physically controls the pointing of the gun at the time of projectile firing. It generally consists of two major elements - a gun/turret stabilization and control system that attempts to position the gun mount along the commanded angles, and a firing limiter that improves upon the basic accuracy of the stabilization system by only allowing the projectile to be fired only when the servo error is small.

3.1.4.1 Current/Near Term

The current architecture for the engagement function in the M1 FCS is illustrated in figure 3-1. Although this does not reflect the latest technology in this area, it must be noted that the current performance capabilities of the M1 and M1A1 are adequate, and there are no major deficiencies officially designated as requiring correction.

However, requirements and design studies related to survivability improvement for main battle tanks have identified probable design changes in other vehicle subsystems (particularly armament and armor) that will adversely affect the ability of the current FCS to meet its performance objectives - particularly under mobile conditions. Also, mission requirements for the battle tank are evolving, with a trend towards higher performance expectations in this function.

The probable impact of these on the current FCS configuration is discussed below.

Target Tracking and State Estimation

Target tracking is currently a manual process, with the gunner's handle displacements being sent to the GPS and gun/turret control electronics and interpreted as tracking rate commands. These rates are also sent to the ballistic computer, which combines them to estimate the target velocity. Currently, target velocity effects (kinematic lead) are only computed and compensated in the azimuth channel.

Any upgrading of the tracking capability of the system, such as linear motion compensation, adaptive handle sensitivity shaping, or automatic target tracking will require that a digital processor use control handle and other data to generate the tracking commands. This is a straightforward design modification that should be part of any FCS design change, and it need not affect the analog sighthead control electronics in either the GPS or the CITV.

The referenced near term survivability improvements will not have a first order impact on this FCS function.

Weapon Pointing Computation

The weapon pointing computations currently provide full continuous update compensation for ballistic lead and parallax effects. In addition, azimuth target velocity is estimated from

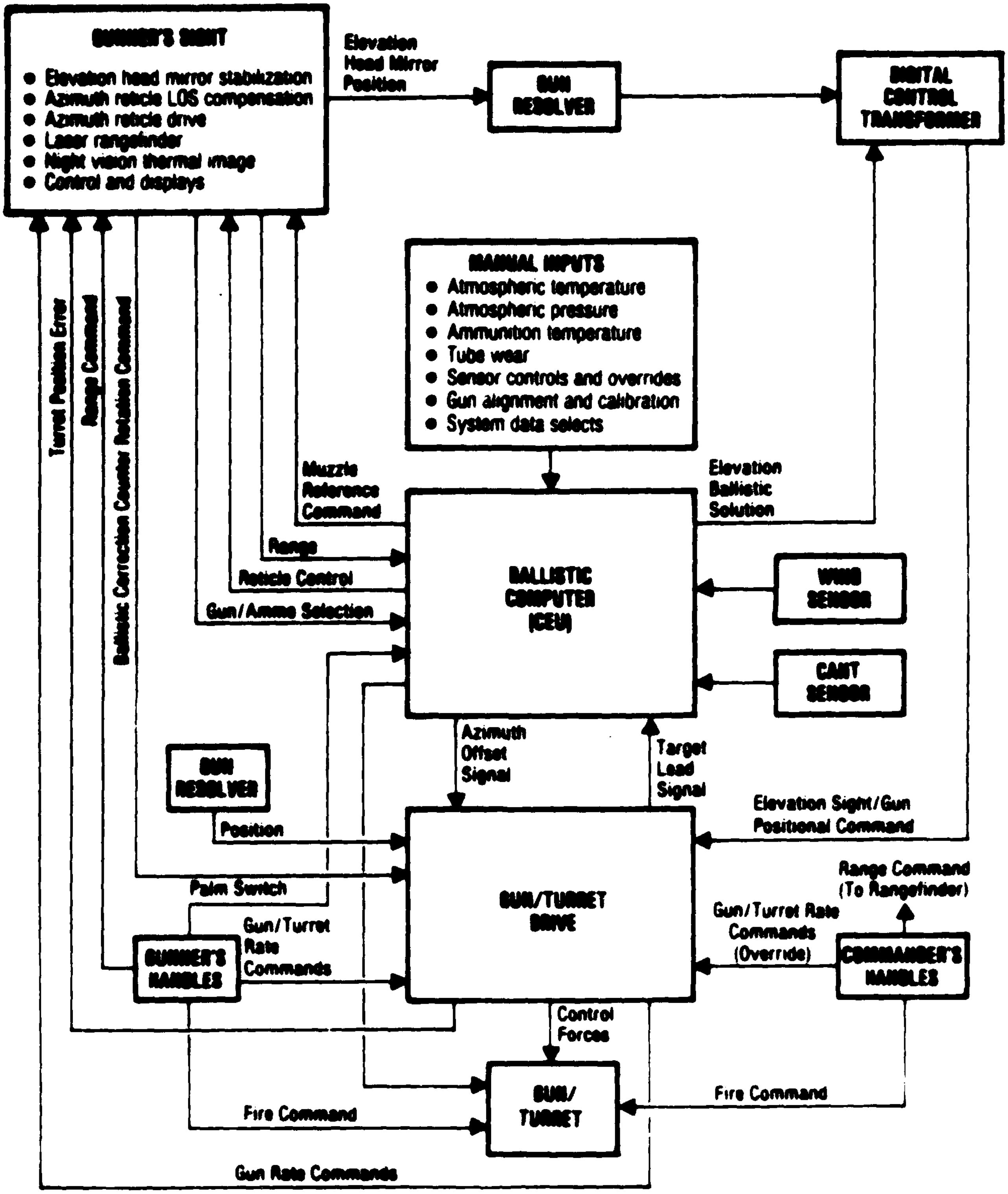


Figure 3-1. Current M1 FCS Engagement Function

tracking commands and a kinematic lead component is computed in that channel to compensate for target motion during projectile flight.

The following environmental and vehicle parameters are measured or estimated and compensated for in the equations: Gun/Sight Alignment, Ammo Zeroing Adjustments, Target Range at Firing, Vehicle Cant (Static), Apparent Crosswind, Air Temperature, Air Pressure, Propellant Temperature, Static Gun Tube Bend, and Gun Tube Wear.

The following parameters have been judged to produce relatively minor pointing errors under most conditions and are therefore not currently compensated: Target Altitude Differential, Target Speed in Elevation, Target Acceleration, Target Range Rate, LOS Elevation Angle, Dynamic Cant, Dynamic Barrel Bend, Latitude, and Heading.

Studies are currently underway to define an enhanced armament system for the M1A1. This will result in new ballistic characteristics, but the direction will likely be toward reduced ballistic sensitivity and therefore place no new performance demands on this computational process, and the changes can be handled by changing coefficients in the ballistic computer software.

The barrel characteristics of an enhanced gun will probably lead to more dynamic motion and, consequently, the need for better compensation in this area to avoid performance degradation. Part of this compensation could be accomplished by automating the barrel bend function and part may be accomplished in the line of fire control function.

Line of Fire - Control

Primary control and positioning of the line of fire on the current M1 systems is accomplished by different means in azimuth and elevation.

Elevation Channel - The elevation control function is illustrated figure 5-2. In this channel, the LOS reference to the target is maintained by the GPS elevation stabilization system. The GPS LOS angle is measured by a resolver which is electrically chained to the gun trunnion resolver and then to a digital control tranformer (DCT). The DCT compares the gun mount-to-LOS angle with the commanded angle from the ballistic computer and sends the difference to the GTD as a position error signal. The GTD continuously commands the gun elevation drive to minimize this error.

The basic position loop for slaving the gun to the CITV is similar to that for the GPS. A resolver chain is established at a different frequency from that of the GPS chain, and it links the same gun trunnion resolver with the CITV elevation resolver and a CITV-linked DCT.

The GTD uses pressure feedback from the drive, turret pitch rate, and gun rate information to improve its dynamic positioning accuracy in the presence of terrain induced disturbances.

To further improve the pointing accuracy at the time of firing, the FCS also employs a "coincident firing window". When a request to fire (trigger pull) occurs, the FCS begins monitoring the GTD position error level and does not allow the actual firing to occur until it falls below a preset level. This has the effect of producing statistically smaller stabilization errors at the instant of firing than can be achieved on a continuous basis.

This function is likely to be seriously impacted by armament enhancements. The higher performance gun will result in poorer stabilization performance due to a number of characteristics, including larger inertias, lower mechanical resonances, higher static and dynamic unbalance, and higher dynamic barrel flexing.

Some aspects of this problem are also discussed in reference 5. The preliminary analyses indicate that an armament upgrade will probably not require replacement of the current elevation drives. However, it is likely that major changes will be required in the control laws - including compensation for non-linear hydraulic gain and acceleration sensing and compensation. Additionally, barrel dynamics may have to be measured and integrated into the stabilization and/or precision firing control logic.

Azimuth Channel - The azimuth channel for line of fire control is substantially different than that in elevation, and is illustrated in figure 5-1. In this channel, the GPS head mirror is fixed to the turret. As a result, motion of the sight scene in this axis is controlled directly by the turret motion.

The required gun offset (lead) angles are achieved by driving the reticle within the field of view and steering the laser rangefinder to follow the reticle. The servos to accomplish this are located in the GPS and are driven by commands from the ballistic computer. In order to minimize apparent reticle motion due to changing lead angles, the dynamics of the turret and reticle motion are matched, and the turret is counter-driven with respect to the reticle.

The position loop for the CITV in azimuth more closely resembles the GPS elevation loop. Since the CITV sighthead assembly has azimuth freedom with respect to the turret, its line of sight angle can be measured directly with a resolver and used in conjunction with a DCT to slave the turret in azimuth.

As in elevation, additional sensors are used to improve the dynamic response of the control system. In this case, pressure feedback from the azimuth drive, hull turning rate, and turret azimuth rate measurements are used.

Because the gun represents a relatively small part of the total turret inertia in azimuth, the use of enhanced guns will not have a major affect on this axis. However, the application of major new armor structure could have a significant effect - principally due to larger inertias and much larger unbalances. This may result in a need for control system modifications similar to those discussed above for elevation.

Interface with BMS

Interface between the FCS engagement function and BMS will be minimal from a control perspective. With the exception of situations where BMS-supplied information causes the engagement to be terminated prior to target destruction, there does not appear to be any interface. It is assumed that such interruptions would be accomplished manually by the vehicle commander after being so advised.

There does, however, appear to be the potential for data sharing between the two systems. In particular, the same vehicle motion data (angular rates, acceleration, and velocity) that is used for navigation (position location) purposes by the BMS can also be used for control and stabilization of the line of fire. Similarly, heading and attitude data can be used for weapon pointing computations, thereby eliminating some unnecessary sensor redundancy.

3.1.4.2 Long Term/Growth

Recent analyses of the high stress armor battle of the 1990's have identified a need to decrease the time required to engage and kill a non-cooperative target. Within the FCS engagement function, the following are the most likely means for achieving this.

Target Tracking and State Estimation

Accuracy of the current system is limited by the absence of a direct position error measurement, the low bandwidth of the gunner as a tracking controller, the limited dynamics of the M1 azimuth reticle control system, and the effects of gunner jostling under mobile conditions.

Automatic video target tracking can potentially provide substantial improvements over the current levels of target laying and rate estimation accuracy. In addition, estimates of target acceleration can be derived thereby providing a basis for second order kinematic lead prediction.

Because the tracking function operates on only a small part of the scene image, the data processing requirements for auto-tracking are substantially less than those for automatic detection and classification, and can be easily handled with currently fielded computer technology.

Weapon Pointing Computation

The implementation of two-axis kinematic lead, including target acceleration effects, will be straightforward given an auto-tracking capability.

A second potential growth area is autozeroing. In this process, the actual trajectory of projectiles fired by the system are measured in flight and compared to the predicted trajectory. The differences are compiled over all rounds fired to maintain an up-to-date zeroing correction.

The autozeroing function requires a separate, although somewhat simpler, video tracker to follow the projectile in flight. This may become an important function in the near future because of uncertainty in how well the current "fleet zeroing" concept will apply to both the M256 and enhanced weapons.

Line of Fire - Control

The resolver chain position referencing system is well suited to the current line-of-sight referenced M1 FCS and its mostly analog electronics control system functions. However, with more vehicle functions being digitized and the potential for "off-vehicle" targeting references, this is becoming a less desirable approach.

Additionally, future interfaces with BMS will cause some of the FCS control functions to be referenced to off-vehicle coordinate systems (e.g., earth or UTM). Thus, in the long term, the current resolver chains will be replaced with loop closures internal to the digital control functions.

Interface with BMS

The growth elements discussed above will not change the basic interface to the BMS.

3.1.5 DAMAGE ASSESSMENT

After firing at a target, it is necessary to determine if sufficient damage has been inflicted to allow that specific engagement to be terminated.

3.1.5.1 Current/Near Term

Damage assessment is currently a judgment process based on manually observing the target after firing. When available, observations of such things as projectile impact, fire and/or smoke from the target, sudden changes in target motion, or apparent lack of target activity provide clues for judging the effectiveness of the shot and the current threat status of that target.

It is not likely that this function will change in the near term.

Interface with BMS

There is no direct interface between this FCS function and the BMS. It is assumed that in the near term the vehicle commander will manually update target status for transmission on the BMS net when time permits.

3.1.5.2 Long Term/Growth

Once image processing and automatic target tracking capabilities are implemented, they can also be used to assist in the damage assessment function. The video processor can analyze explosions at the target (e.g., projectile impact) and changes in target motion and/or shape in a manner similar to what is currently done manually.

In many cases there may be sufficient information in the video scene to give a high degree of confidence that the target has been disabled. In these cases the FCS may automatically disengage and proceed to the next target in the queue.

The video processing required for this function will be similar to that for the target classification function and will require the availability of VHSIC technology.

Interface with BMS

Upon termination of an engagement the FCS will automatically update the status of the target to reflect the probable damage inflicted and remove it from the active queue. This data will be sent to the BMS which will transmit it to higher command levels as appropriate.

3.2 BATTLEFIELD MANAGEMENT SYSTEM

This section discusses key characteristics of a vehicle-based Battlefield Management System node and its interface to the FCS. The BMS can be viewed as a communications adjunct to the current "self-contained" target acquisition and engagement functions, which are mostly grouped under the general heading of fire control. Growth in BMS will focus on extending the consolidation of intelligence and the interpretation of data. The vehicle-resident BMS will be the primary "control" source for vehicle status evaluation, external communications, and (where applicable) platoon/company and higher level data consolidation.

In its initial form, the BMS will focus primarily on communications, reporting, and display functions, while posessing some capability for data consolidation at key command levels. However, future application of AI techniques to aid in the interpretation of data and response planning could substantially increase future BMS on-vehicle computation requirements.

Current M1A1 Block II requirements call for a basic vehicle-integrated Battle Management System (BMS) node to be established as soon as practical. BMS will eventually be the communications link between individual vehicles, and Platoon, Company and Battalion Commanders in the data-linked Maneuver Force (ref. Appendix C). The efficient integration of all of these levels is a difficult task, that will be accomplished, at best, over a period of several years.

Studies have been conducted by the user community to determine what functional capabilities are most important in a BMS. These studies included surveys of experienced people at key command levels, including company commanders, platoon leaders, platoon sergeants, and wingmen. On a consolidated basis, the following types of information were identified as being most important. The elements in this group are ranked in approximate descending order of ranked importance.

Critical Situation Alert
Concept of Operation
Identification Friend-Foe-Neutral (IFF-N)
Target Distribution & Prioritization
Heading Reference / Navigation
Call For Fire
Battlefield Geometry
Command Mission
Reports
Vehicle Status
Enemy Weapons Systems

A representative interface of BMS at the platoon leader level is shown in Figure 3-2. The anticipated distribution of BMS nodes and interfaces at other command levels and communications networks are shown in Appendix C. These were derived from reference 1 and are reproduced here to provide a useful perspective.

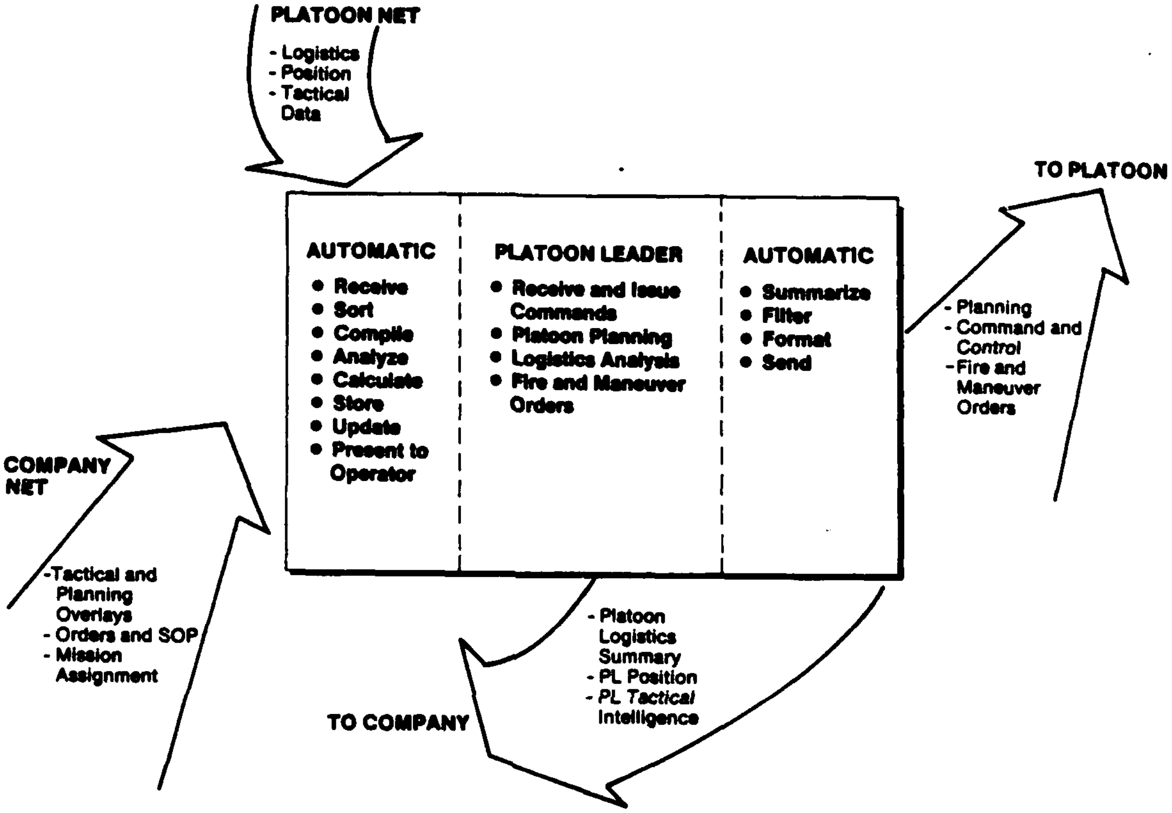


Figure 3-2. BMS Interface to Platoon Leader

In order to view the BMS more from the perspective of vehicle equipment and architecture, it is convenient to group the operational functions into the following general areas:

Radio Communication Networks Interface:

Incoming Messages:
Receiving, Validation and Routing

Outgoing Messages:
Generation, Routing, and Transmission

Soldier - Machine Interface:

Display
Operator Inputs

Report Generation

Terrain, Vehicle & Target Reference

Embedded Training

Decision Support Aids

The anticipated requirements in each of these functional areas are summarized in Table 3-2 and discussed in more detail in the remainder of this section, along with the associated fire control interfaces.

3.2.1 RADIO COMMUNICATION NETWORKS INTERFACE

The communications interface function consists of receiving radio communications from other BMS nodes and formatting and transmitting messages to other nodes.

3.2.1.1 Current/Near Term

In the near term, communications with other BMS nodes will be conducted through SINCGARS radio channels. Automatic encoding, decoding, and authentication of messages is required, together with automatic frequency changing at predesignated time. The function must also provide capability to preset & select radio and auxiliary monitor frequencies through the operator display.

Interface with FCS

It is anticipated that there is no immediate requirement for direct interface between the FCS and the BMS radio communications interface function. Other BMS functions will perform the routing of data to and from the FCS, and these functions will provide the required interface to the communications function.

3.2.1.2 Long Term/Growth

Long term communications interfaces will involve more sophisticated encoding/decoding, larger numbers of networks and interfacing nodes, and possibly other radio equipment interfaces. The BMS node may assume the identity and functions of other communication systems terminals (e.g., JTIDS), and provide the vehicle with direct external communication with the Maneuver, Fire Support, Intelligence/Electronic Warfare, Air Defense and Combat Service Support elements.

Interface with FCS

The long term direct interface of this function to the FCS will remain as described above.

Table 3-2. Vehicle BMS Node Functional Requirements

FUNCTION	CURRENT/NEAR TERM	LONG TERM/GROWTH
COMMUNICATION NETWORKS INTERFACE	Radio Communication by Voice Computer Data Link to SINCGARS Automatic Message Alert to Commander	Automatic Decode and Message Authentication Automatic Frequency Changing and Network Coordination Automatic Message Encoding Prior To Transmission Automatic Transmission Routing
SOLDIER/MACHINE INTERFACE	Video Display of Maps and Standard Overlays Incoming Message Display Menu-Driven Command Structure Message & Report Composition Capability Audio Alerts	High Resolution Color Voice Command Input Helmet-Mounted Display Capability
REPORT GENERATION	Manual Data Entry Report Formatting Assist Radio Transmission of Reports Upon Command	Automatic Data Consolidation, Formatting and Reporting Interpretation of FCS and Other Sensor Data for Special Reports Real-Time Contact and Target Status Update Reports
TERRAIN, VEHICLE, & TARGET REFERENCE	Digital Map Storage (Limited Area) Generation and Display of Tactical Map Overlays Manual Map and Terrain Feature Analysis On-Board Heading Reference Interface to External Position Location Aids	Extended Map Areas and Level of Detail Natural Terrain and 3-D Representations Self-Contained Navigation Automatic Position Update and Reporting Automatic Selection of Routes of Travel Real-Time Situation Display
EMBEDDED TRAINING	Operator's Guides for BMS Use and Maintenance Interactive Training Capability Interface With Peripheral Training Devices	Extended Operation, Training, and Maintenance Support
DECISION SUPPORT AIDS	None	Integration and Automatic Filtering of Intelligence, Fire Support, and Air Defense Networks Embedded Data on Enemy Weapon System Capabilities, Doctrine, and Tactics. AI-based Situation Analysis and Tactical Recommendations.

3.2.2 SOLDIER/MACHINE INTERFACE

The soldier/machine interface function includes the communication and display of BMS-related information to the vehicle operator (normally the commander), and the acceptance and interpretation of commands and data from the operator.

3.2.2.1 Current/Near Term

This function is recognized as being critical to the operational utility of the BMS, from both the operator interface/simplicity of use and vehicle integration viewpoints. Studies to date have focused on the need for a multi-function interactive control and display capability that is integrated into a single graphics-oriented device.

From a user point of view, the following features and characteristics have been identified as important in a BMS soldier/machine interface:

Use of standard military graphic symbols
Minimized alphanumeric text; maximum use of graphics and symbology
Capability for symbology overlays to maps and FCS sights
Digital message alert and display
Full color map display
Free text (word processing) capability
Draw function
Screen Data Input (touch screen entry)
Viewable unbuttoned (hatch open)

The simultaneous display of alphanumerics, symbology, and terrain maps is essential to effective man-machine communications. Color display is also desirable because of its inherent efficiency for information presentation, but the required functions could be performed with a multiple gray scale monochrome display (8 shades are desired as a minimum).

The bulk of the critical information display is envisioned as being map and symbology oriented, and should include the flexibility and capabilities of traditional "paper map" approaches, such as:

Display of essential standard map features (contour lines, roads, vegetation, towns, water)

Display rotation and orientation (similar to rotating a paper map) to help individual tank commanders maintain orientation while navigating their vehicle.

Standard military graphic overlays (operations, fire support, enemy, and engineer/obstacle), and selectable map scaling.

Selective display or highlight capability to allow operators to manually dim or brighten specific overlays (e.g. grid lines, numbers, etc).

The operator input must be simple and highly flexible, with the capability for accepting both text and graphical information. It must support the rapid entry of data required to recall, create, and/or communicate to other vehicles any of the displays described above. A touch sensitive display screen approach appears most suitable for direct actuation of software-selectable control choices and rapid placement of symbology on overlays.

Other requested hardware features include:

8" diagonal screen minimum ("The Bigger, the Better")

512 x 512 pixel resolution minimum

Simultaneous display of alphanumerics, symbology and terrain maps

Repositionable display to allow viewing and interaction from inside the turret, popped hatch mode, and chest out operation.

Capablity of accepting a peripheral printer to copy text and graphic overlays.

As will be shown in the technology discussion, the totality of this desired functional capability is difficult to achieve with currently available equipment.

Interface with FCS

It is envisioned that the BMS soldier/machine interface will be multi-purpose, providing a direct interface with the fire control system as well. The FCS interface will include control panel type functions (including FCS moding and target designation) and the display of alerts and important status information. However, if the display interface to the external system uses standard video formats, this display function might also serve as a back-up for real time display of sight imagery.

3.2.2.2 Long Term/Growth

Continuing technology improvements in video display will provide smaller packages with higher resolution and color display of BMS information to aid operator discrimination. Voice activated data input and helmet-mounted displays are other future growth areas.

3.2.3 REPORT GENERATION

One of the major objectives of the BMS is to relieve the over-stressed tank commander of repetitive and time consuming tasks while improving overall communications. Time-sensitive and critical situations are when status, tactical, and logistical reports are needed the most by higher command levels, but this reporting seldom occurs in a timely fashion now because the situation at hand requires so much attention from the individual vehicle commander.

3.2.3.1 Current/Near Term

Reporting is currently manually performed by voice, radio or wire, and written communications. Table 3-3 summarizes the standard reports and orders planned for handling by the BMS. The operator must be able to compose, recall previous reports, edit for updated information, retransmit and save. Reports will probably be generated by the use of menus rather than keyboard, and will be closely tied to the terrain map. BMS reports will incorporate graphic overlays, symbology, terrain maps, locations, ranges, directions, free drawings and text as appropriate.

<u>Interface to FCS</u>

The primary FCS interface will be for reporting and FCS status information of targets. The BMS will allow manual operator entry of locations of targets (acquired through FCS sighting devices) via touch screen overlay to a digital map. An alternative approach can be to pass LOS direction and target range data directly from the FCS to the BMS. From either of these interfaces, the BMS can automatically calculate grid coordinates, straight line distance, and direction from the vehicle to the target. This data will then be automatically inputted into a spot report.

Logistic data (e.g., ammunition remaining) and equipment status (from BIT) will also be extracted from the FCS for reporting purposes.

3.2.3.2 Long Term/Growth

New techniques of abbreviated reports will be developed where much of the information is automatically acquired by the integration of internal/external systems. Automatic report consolidation will occur at different levels - Platoon leader combining reports from individual tanks; company commanding officer from platoon leaders, etc. Additional sensor data from various subsystems will be integrated for composite situation reporting. For example, by integrating data from the wind sensor, NBC alarms, navigation system and future analysis programs, downwind NBC reports can be automatically generated and transmitted.

Table 3-3. Battlefield Management Reports

- Operation reports
  - Spot report
  - Situation report
  - Contact report
  - Bridge report
  - Cross report
  - Route recon report
  - Obstacle report
  - Bypass report
  - Stand-to report

- Intelligence reports
  - Sensitive items report
  - Prisoner of war (PW)/Captured materiel report
  - Military intelligence jamming interference report (MIJI report)

- Logistics reports
  - Equipment status report
  - Battle loss spot report
  - Ammo status report
  - Ammo request
  - POL status report
  - POL request

- Personnel reports
  - Personnel battle loss report
  - Medical evacuation request

- NBC reports
  - Observers inital report
  - Immediate warning of expected contamination
  - Radiation dose-rate report
  - Areas of contamination report

- Warning Order

- Operations Order

- Fragmentary Order

Interface to FCS

FCS will be integrated with BMS to provide automated passing of derived target data for screen and report update. Contact reports will be automatically transmitted when a tank lases and fires. Image processed "snapshot" pictures of CITV views could also be incorporated into reports for intelligence purposes and further analysis.

3.2.4 TERRAIN, VEHICLE & TARGET REFERENCE

This function provides the relationship of the combat vehicle to the surrounding environment by maps, friendly and enemy unit positioning and status, and target classification (including IFF) and prioritization data.

3.2.4.1 Current/Near Term

The BMS must carry an on-board data base (50 x 50 sq. km desired) of digital map data. This will include key features, such as: Contour lines, Roads, Vegetation, Towns, and Water. The data equivalency of detail found on the standard map scales of 1:250,000 (30km x 30km); 1:50,000 (6km x 6 km); and 1:25,000 (3km x 3km) will be available. Table 3-4 summarizes the information content of these map levels.

Selectable overlays of Friendly units, Enemy units, Obstacles, contour lines, grid lines, LOS and Assigned sectors will be available to allow the tank commander to individually tailor his terrain display.

This function must also generate the required vehicle position and heading information from a combination of on-board equipment and external (radio-linked devices).

Interface to FCS

By providing overlays of LOS and assigned sectors, important relationships can be visually interfaced between BMS and FCS functions for the tank commander. Battlefield Identification - Friend or Foe (BIFF) will provide data to reduce the chance of firing on a target that is friendly, and prevent firing on a target that has already been observed by another source as out of action.

By displaying the distribution of targets sighted by other elements as an overlay to a digital map, BMS can calculate straight line distance and headings for hand-off to the FCS upon command.

Terrain analysis prior to formulating an operational plans will be manual, but will utilize digital mapping and communication features for access of other data bases.

3.2.4.2 Long Term/Growth

On-board digital terrain map storage will be increased (to 100 x 100 sq. km), with continuous zoom and scroll features.

The situation display will be expanded to include natural terrain and 3-D representations (i.e, select a location on the terrain map and then view that area in - dimensional perpective for weapon for weapon placement,etc.). It will also provide real time display of position and location of one's own vehicle, unit, higher units, enemy, and adjacent units by integration of internal navigation and heading reference information with target information from external sensors.

There may be application of Artificial Intelligence software to perform terrain analysis and route selection & display. With additional detail, the BMS may also provide capability for a Mounted Operation in Urban Terrain (M.O.U.T.), showing specific built up areas and consecutive overlays of each building story and subterrain level.

3.2.5 EMBEDDED TRAINING

As the complexity of the combat vehicle increases, continued training and simulation of battle conditions is critical to force readiness.

3.2.5.1 Current/Near Term

An embedded training function must include access to vehicle mass storage of such documents as the System Operators Guide, How to Fight Manual for BMS operations, and Maintenance Manuals. This BMS function should be able to conduct interactive tactical training scenarios (display lifelike targets in FCS and BMS displays), for individual, collective and unit training exercises.

Interface to FCS

Interface to the FCS in the near term is expected to be primarily manual. Interface to the FCS displays will be desirable for situation simulation.

3.2.5.2 Long Term/Growth

Extended and enhanced operational, training and maintenance support, including decision support aids.

Table 3-4. Terrain Map Features (Page 1 of 2)

1:250,000 TERRAIN MAP

- Covers 30 Km x 30 Km area
- Contour lines with elevation numbers
- Town/cities (solid black shape outlining the built up area)
- Vegetation
- Water (rivers, lakes, large ponds, large streams)
- Airfields
- Railroads
- Roads
  - All primary, hard surface, all weather roads (Redballs)
  - All secondary, hard surface, all weather roads (Candystripes)
- Road numbers
- Town names
- Water names
- Bridges

1:50,000 TERRAIN MAP

- Covers 6 Km x 6 Km area
- Contour lines with elevation numbers
- Town/cities (individual buildings)
- Vegetation
- Water (rivers, lakes, ponds, streams, swamps, marshy areas)
- Airfields and airstrips
- Railroads
- Roads
  - All Redballs
  - All Candystripes
  - All light duty all wether, hard or improved surface roads and fair/dry weather, unimproved surface roads (Whiteballs)
- Road numbers
- Town names
- Water names
- Depressions, cuts, fills
- Quarries
- Power lines
- Regional features
  - Stream & river ford sites (Korea)
  - Rice Paddies (Korea)
  - Vineyards (FRG)
  - Underpass heights (FRG)
- Bridges with weight classifications

Table 3-4. Terrain Map Features (Page 2 of 2)

1:25,000 TERRAIN MAP

- Covers 3 Km x 3 Km area
- Contour lines with elevation numbers
- Buildings, Towns, cities (extreme detail)
- Vegetation
- Water (rivers, lakes, ponds, streams, swamps, marshy areas)
- Airfields and airstrips
- Railroads
- Roads
    - All Redballs
    - All Candystripes
    - All Whiteballs
    - All trails
- Road numbers
- Town names
- Water names
- Depressions, cuts, fills
- Quarries
- Power lines
- Regional features
    - Stream & river ford sites (Korea)
    - Rice Paddles (Korea)
    - Vineyards (FRG)
    - Underpass heights (FRG)
- Bridges with weight classifications
- Gas stations, fuel, POV reserves
- Type vegetation (scrub, orchards, nursery, evergreen, deciduous)
- Identification of how many stories a building is and if it has a cellar
- Subways

3.2.6 DECISION SUPPORT AIDS (Future Requirement)

By application of artificial intelligence techniques, data on embedded Soviet weapon system capabilities, doctrine and tactics, and integration with Intelligence networks, Fire Support networks, and the Air Defense Artillary network, decision support aids could be developed to assist the tank commander in understanding the battle situation and the probable effects of his potential actions.

This is a long term objective which will have substantial interface with all of the on-board systems. However, the nature of that interface is not definable at this time.

4. KEY TECHNOLOGIES AND STANDARDS

The selection of an architecture for M1A1 FCS/BMS is highly dependent upon the current and projected availability of key processing, interface and communication technologies, and their compatibility with equipment already in the system. This section summarizes the current technology in areas of specific concern to this application.

4.1 DIGITAL PROCESSING TECHNOLOGY

The availability of computer processor elements using VLSI and VHSIC technology provide considerable flexibility in processor design, including:

- Bit-slice building blocks, which can be used to configure a processor to unique requirements.
- Fixed architecture commercially available microprocessor and microcomputer circuits.
- Custom VLSI and VHSIC processors designed to a specific architecture.

The bit-slice approach has been applied in many diverse military processor applications. Typically bit-slice computers require a significant number of "glue chips" to complete a function. High speed processors can be developed and integrated into complex architectures using this technology. The penalty associated with this, however, is generally increased size and power requirements. When compared to VLSI and VHSIC technology processors, the greater number of components required to build a Bit-slice processor also increase life cycle costs.

Commercially available processors and microcomputers offer a significant cost advantage at the component level over custom hardware. However, the lack of fixed standards (for example, 1750A Instruction Set Compatibility) and the issue of long term availability of candidates within this group makes this family of processors generally undesirable for application in production military equipment. As with the current M1 computer, large chip inventories must be established during the limited production life in order to assure long term supportability of fielded equipment.

The final and most technology growth oriented category for consideration are VLSI and VHSIC processors which are designed for a specific user's (e.g., DOD) architecture. An example is the MIL-STD-1750A Instruction Set Architecture which has been implemented in both VLSI and VHSIC design rules. Both approaches offer substantial advantages over more traditional MSI/SSI (Medium Scale Integration and Small Scale Integration) technology, since the physical features sizes are substantially smaller allowing much more dense components to be developed.

Perhaps the greatest single benefit derived from the move towards smaller feature size is a corresponding increase in processing speeds. This advantage is evident when VHSIC is compared to VLSI and, similarly, when VLSI is compared to MSI/SSI. Key parameters for the three technologies are compared in Table 4-1.

The differences between the 3.0 micron VLSI features and the 1.25 micron VHSIC feature geometries not only yield lower power, size, and weight, but increase speed 2 to 3 times. The smaller VHSIC geometry results in shorter circuit paths which enable higher oscillator (timing) frequencies as well as fewer chips. Reducing chips also eliminates the number of buffers that are required to support chip-to-chip communication.

Both VLSI and VHSIC designs allow single board computers to be packaged as Line Replaceable Modules (LRM) which can be installed in an expandable chassis with standardized backplane interfaces. Table 4-2 compares characteristics of a typical MIL-STD-1750A processor for VLSI and VHSIC.

VLSI 1750A Processors

The single board VLSI computer can be procured today. In this configuration it can be imbedded as a Line Replaceable Module (LRM) or packaged with other boards to provide additional features. The single board VLSI processor can be obtained with substantial on-board RAM memory, bus interfacing, or other types of processing. If an imbedded concept is to be used, however, standard internal communications buses must be defined (see Section 4.2).

Application of CMOS (Complementary Metal Oxide Semiconductor) technolog in the development of VLSI chip sets has provided some significant advantages over more traditional (MSI/SSI) integrated circuit technology. Three-micron features allow for improved packaging density, particularly with the development of compaction optimization software which can complement a standard CAD design to increase junction densities. The application of these advanced tools has resulted in the development of chip sets which feature Low power consumption and operation over the full military rated temperature range. With the reduced number of components and interconnects, it would seem reasonable that the VLSI computer MTBF will be much higher when compared to more traditional technologies.

Taking as an example the Delco Systems VLSI chip set, a total of 15 chips (12 different designs) have been developed to support the 1750A Instruction Set single board CPU with memory. A single board 1/2 ATR card is available which can provide both the CPU and 192K of memory. Control features built into a custom RCU (Resource Control Unit Chip) allow multiple processors to share memory.

This design uses a proprietary bus communications interface, but can be converted to a standard bus once internal bus standards

Table 4-1. Comparison of Processor Circuit Technologies

TYPICAL 1750A PROCESSOR:	SSI/MSI	VLSI(*)	VHSIC
Parts Count	43	1	0.6
Size	8	1	1
Weight	4	1	1
Power	10	1	0.6
Connections	5	1	0.6
Speed	0.5	1	2-3
Cost	5	1	1-1.5

(*) - All Values Are Normalized To VLSI Technology.

Table 4-2. VLSI and VHSIC Single Board 1750A Processors

	VLSI	VHSIC PHASE I
Minimum Throughput (DAIS Floating Pt. Inst. Mix)	1.0 MIPS	3.0 MIPS
Size (SEM-E): Length Width Depth	 6.41 In. 5.88 In. .58 In. Max.	 6.41 In. 5.88 In. .58 In. Max.
Power	6.3 Watts	3.8 Watts
MTBF (CPU only)	72,000 Hrs.	(Greater)
Feature Size Requirement	3 Micron	1.25 Micron
Component Connections on CPU Board	Low	Very Low
Cost (LCC)	Low	Low
Clock Speed	6.25 MHz	25 MHz
Maintenance Support	2 Level	2 Level
Compatibility With LRM/Expandable Chassis Concept	YES	YES

are released. Expansion to the SEM-E configuration (see Section 4.2) will allow space for these interface chips. It may be possible to interface the standard VLSI chip set with the VHSIC standard bus interface chips currently being developed under government contract. This would eliminate the need to develop VLSI standard bus interface chips. Figure 4-1 illustrates the technology transition being discussed here.

As currently developed, these 15 chips provide a full 1750A CPU, complete memory and input/output interface, and a comprehensive BIT and external test interface. No additional "glue chips" are required. The substantial reduction in components yields an estimated MTBF of 72,000 hours for the CPU and 29,000 hours for the CPU with memory under benign conditions.

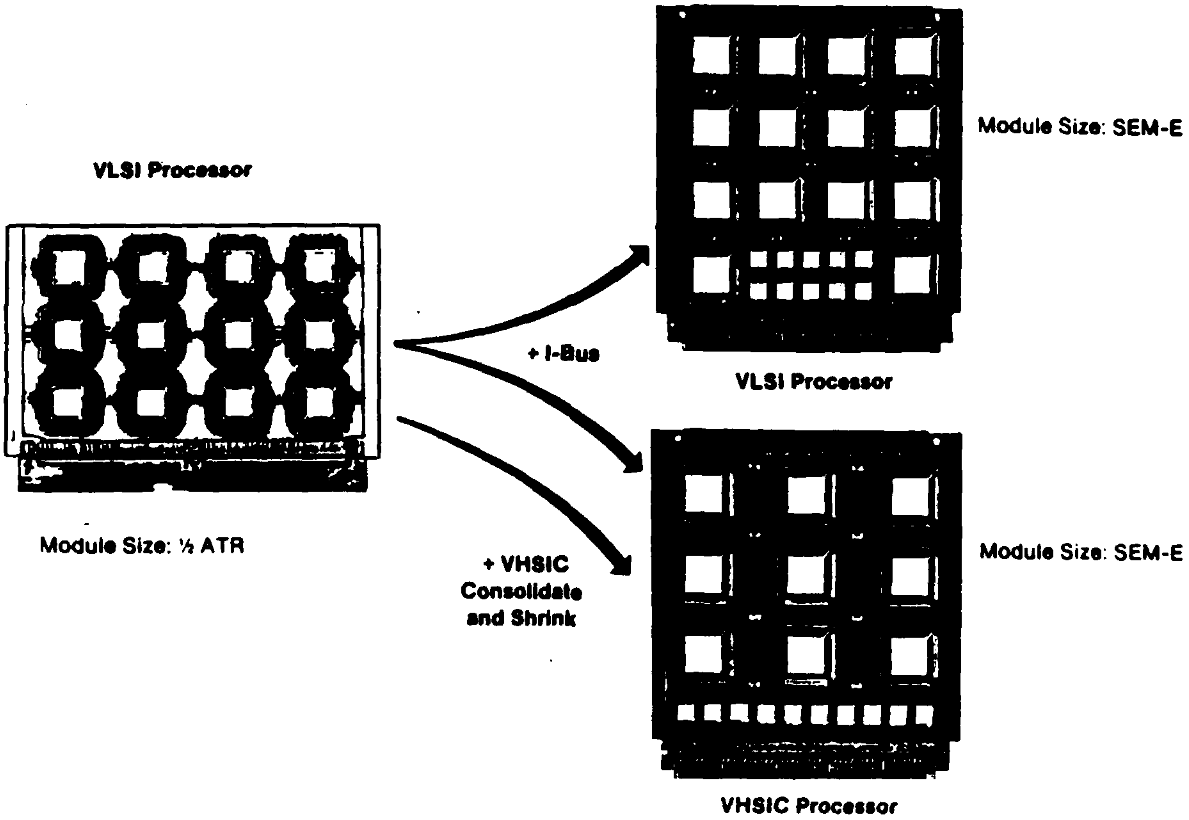


Figure 4-1. Technology Transition - VLSI to VHSIC

VHSIC:

Development of this technology has been actively supported on a tri-service basis through the VHSIC Manufacturing Technology Program and the VHSIC Technology Insertion Program. The Technology Insertion Programs supplement the basic technology research programs and were established to assure that VHSIC development would have practical application in meeting Defense Department processing needs into the 21st century. The strategic importance of VHSIC has been clearly demonstrated by the Pentagon supporting its tri-service development on a highest priority basis.

1750A VHSIC chips built to Phase I standards are scheduled for production in mid-1986, with modules planned for limited production by mid 1987, and full production of modules by mid-1988.

1750A VHSIC component specifications require that the module set meet or exceed the requirements for VHSIC Phase I class technology including:

- At least one feature size (or junction width) of 1.25 micrometers or less
- An On-chip clock rate of at least 25 MHz (unless performance requirements permit relaxation).
- Operational temperature range of -55 C to +95 C with a goal of -55 C to +125 C.
- TTL compatible inputs and outputs, where appropriate
- Total dose --- 5x10^4 rads (Si)
- Transient/upset -- 10^7 rads (Si)/S, 10 nanosecond pulse
- Transient/permanent damage -- 10^8 rads (Si)/S, 10 nanosecond pulse.
- Neutron/permanent damage -- 10^11 neutron/cm^2 , 1 MeV equivalent.

VHSIC Phase 2 component specifications decrease the feature sizes to .5 micron and increase clock rates to 100 MHZ. A VHSIC module may consist of one or more boards controlled by a single controller communicating over the computer communication network. Examples of the modules under VHSIC development which have potential for application in the M1 include:

1. An array processing module for processing which is relatively data-independent; involving real, repetitive, generally fixed-size blocks of data.
2. A complex vector processing module for processing which is more data-independent; involving complex, repetitive,

generally fixed-size blocks of data.

3. A data processing module for scalar processing and data-dependent decision making (1750A ISA).

4. A memory module for bulk memory storage.

More information regarding the characteristics of these modules may be found in references 9, 10, and 11.

4.2 ELECTRONICS INTERFACE

Electronics interface technology is a major factor in the complexity of the architectures of modern combat vehicle designs. Although the cost and performance of the "intelligence" in control systems have improved with the evolution to digital processing, the problem of interfacing to sensors and drive systems has become more complex and costly.

The need for much greater data flow within future systems, such as the BMS, virtually precludes a long term reliance on dedicated physical hardware for individual data items. Multiplexed digital networks can provide the required performance, but the communication standards and the technologies for interfacing to the external world are still in the early stages of their evolution.

This section reviews the interface technologies that are significant to the fire control and BMS systems that could be fielded over the next several years. Table 4-3 describes elements of the interface technologies that are discussed in this section.

4.2.1 DEDICATED INTERFACES

Combat vehicle electronics systems have traditionally been designed around star type architectures, where all of the required data flow is achieved by direct point-to-point wiring of analog signals and/or digital logic lines. There are currently also several serial digital interface standards that are used for direct communication between digital processors.

Although the long term trend for combat vehicle system architectures is toward data bus communication systems (e.g., Vetronics), systems for the next decade will continue to be dominated by dedicated interfaces and their associated electronics.

4.2.1.1 Analog Interface Electronics

Analog electronic interfaces occur in many places due to the inherent analog nature of most sensors and actuators currently in use on combat vehicles. The most common interfaces are dc analog to environmental sensors, oprator controls, and power drives, along with ac analog to resolvers and synchros used for angular measurements.

Table 4-3. Electronic Interface Technologies

ELECTRONICS	DEVICE	TECHNOLOGY	PACKAGE	RANGE	RATE	500 Hz	POWER	COST	Notes
A/D Converter	ILC Data Device Corp. ADC00404	Hybrid		12 bits	500 KHz	1000		$50	Successive Approximation
	Ferranti Semiconductor ZN447			8 bits	100 KHz	200		$9	Successive Approximation
	Micro Power System MP7684	CMOS	28 pin DIP	8 bit	20 MHz	40000	300 mW	$275	Flash Converter (Video)
	Hybrid System Corp. HS9516B-6	Hybrid		16 bit	10 KHz	20		$450	Successive Approximation
D/A Converter	Analog Devices HAS 1204	Hybrid	40 pin DIP	12 bit	500 KHz	1000	2.2 W	$340	
	Honeywell, Inc. HDAC 97000	ECL		8 bit	200 MHz	400000	750 mW	$40	
Discretes (48 High Level)	Circuit Module	Bipolar	3"x4"x1"				5 W at 70%	$500	
Synchro/Digital 3 Arc Minutes +/- 1 Bit 400 Hz	Hybrid Module	Bipolar	1"x1.5"				1 W	$500	
Resolver/Digital Converter	ILC Data Device Corp. RDC 19190	Hybrid	2.1"x2.1"	10-16 bit	360Hz-22KHz	44		$150	1.3 minutes accuracy
Digital/Resolver Converter	ILC Data Device Corp. DRC 10520	Hybrid	32 pin triple DIP	16 bit			2 VA Drive		1 minute accuracy
MIL-STD-1553B	ILC Data Device Corp. BUS-66300	Hybrid	78 pin	NA	NA	NA	60 mW	$120	MIL-STD-1750 Interface
	Circuit Technology CT3231M		Flatpack	NA	NA	NA		$300	Dual Transceiver

There are three basic approaches to interfacing analog inputs and outputs with combat vehicle control systems:

(1) Analog signals are routed to analog servo controllers and computers, and servo actuators are driven via dedicated analog lines

(2) Analog signals are routed via dedicated wires to a digital processor and converted to a digital format for processing within the module. The processed information may then be made available to other computers in the system via digital bus or dedicated lines.

In a similar way, the control command values are converted from digital to analog format at the processor and sent over dedicated lines to drive the actuator.

(3) Analog signals are gathered and converted to digital format near the source and are made available to processing elements through a system interconnect bus.

At the actuator, a module attached to the system interconnect bus converts digital signals addressed to it into analog signal formats as required to drive the actuator.

Analog to Digital Converters (ADCs)

On tank systems, servo controllers require sampling frequencies of no more than approximately 500 Hz. Currently available 16 bit successive approximation ADCs have a conversion frequency of about 10 KHz, which means at least 20 separate analog channels could be serviced by a single ADC.

There are three primary methods of analog to digital conversion applicable here:

(1) Dual Ramp - The dual ramp converter is a two stage process. Initially, a charge proportional to the input voltage builds up on an internal capacitor over a constant time. This charge is then bled off the capacitor at a constant rate so that the amount of time to disharge the capacitor is proportional to the total charge. A counter times out the discharge, and the value on the counter is proportional to the input voltage.

This method is inexpensive and very accurate. However it is also extremely slow and would only be used for signal with very limited dynamics.

(2) Successive Approximation - The successive approximation converter consists of a counter, a digital to analog converter, and an analog comparator. Each bit of the counter is independently set by the converter, and the

output of the counter is sent to the DAC. The output of the DAC is compared to the input signal, and if it is greater than the input voltage, the bit being tested is reset to 0. Working from the most significant bit to the least significant bit, the effect on the test voltage compared to the input voltage is made. After the least significant bit is tested, the counter value is passed out as the ADC value.

This method is the most commonly used since the conversion rate is relatively high, (up to 10 KHz for a 16 bit conversion) it is moderately priced, and has a high accuracy. It is ideally suited for the degree of accuracy and speed necessary for the servo control loops used within combat vehicles.

(3) Flash Converters - The flash converter is the most expensive method of doing conversion and also the fastest. Essentially, it consists of set of analog comparators and a precision reference voltage with a precision voltage divider network. The outputs of the comparators are sent through a digital encoder to give a packed, binary value. Each voltage step to be sensed requires its own converter. The cost rises exponentially with precision required. For an 8 bit value after conversion, 256 separate comparators are required.

The flash converters can work at a rate of up to 20 MHz. They are typically used in video applications where digital signal processing is required on video signals. Except for this case, there are no applications in the combat vehicle where the additional cost is justified for using a flash converter.

Digital to Analog Converters (DACs)

There are several methods for digital to analog conversion, but the most common method weights each digital bit with a current proportional to the value of that bit. The currents are summed and then converted to a voltage output level. This method is accurate and the speed is dependent on the technology used. For example, Honeywell has recently released an 8 bit DAC using ECL technology with a conversion rate of 200 MHz. More typically available are converters using hybrid technology which have 12 bits of accuracy and a conversion rate on the order of 100 KHz.

Synchro and Resolver Interfaces :

Synchro/resolver technology is used extensively in combat vehicles for angular position sensing in the gun and sight servo systems. Both synchros and resolvers work on the same principle of AC voltage transfer between a rotor and a stator. The stator is a fixed shell within which the rotor can move rotationally. An AC reference signal is sent through a winding on the stator, and an AC voltage is generated on the windings of the rotor. The rotational position of the rotor with repect to the stator is determined from the ratio of the voltages coming from the rotor windings to the reference voltage at the stator.

A synchro has three wires coming from the rotor and the voltage between any two wires has a defined mathematical transfer function based on the angular position and the reference frequency. A resolver has two pairs of wires coming from the rotor, the voltage between one pair being proportional to the sine of the rotor's rotational position and the voltage across the other pair being proportional to the cosine of the rotational position. The servo and resolver voltages can be easily transformed between each other using a Scott 'T' Transformer, and so further discussion will be limited to resolver methodologies.

Resolver to Digital Converters (RDCs)

There are several methods of resolver to digital conversion, however only one is commonly used in commercial RDCs. In the real time trigonometric converter, a digital counter (or successive approximation register) generates a digital value which is converted to a sine and cosine analog value. These values are then combined with the resolver values to provide two analog signals proportional to :

$$\cos(T)\,\sin(P)$$

and

$$\sin(T)\,\cos(P)$$

where T is the angle from the resolver and P is the digital angle from the counter. The analog difference of these angles is then generated, producing a signal proportional to :

$$\cos(T)\,\sin(P) \;-\; \sin(T)\,\cos(P) \;=\; \sin(T - P).$$

The sign of this value then determines whether to increment or to decrement the digital counter (or set the bit under test in a successive approximation register). This loop continues until the analog value is nulled.

Although this method can be performed in a continuous fashion, the common method is to sample the waveforms at the peak of the reference wave and hold the analog values of the reference wave, the sine wave, and the cosine wave so that the conversion can be done using these DC values rather than the instantaneous AC values. Since reference frequencies are on the order of 400 Hz, and current converter technology allows conversions to take place on the order of 10 KHz, there is very little performance degradation as a result of this simplification.

Digital to Resolver Converters (DRCs)

The digital signal to be converted to resolver values is first split into a quadrant selector and then the trigonometric value. The first two bits of a digital value determine which of the four quadrants this angle is in. The quadrant determines the signs of the trigonometric values derived from the remaining bits.

The bits for determining the trigonometric values are sent to two function generators, one of which creates an analog value proportional to the sine of an angle between 0 and 90 degrees, the other creates an analog value proportional to the cosine of an angle in the same range.

There are two primary ways of performing this conversion. In one method, each bit in the digital word controls a switch which allows a weighted portion of the reference voltage to pass through to the output. This weighting is done either through a precision resistor network, or through weighted tapping of a transformer coil (the reference voltage is an AC signal).

The second method uses a ROM or similar digital lookup table to convert the digital input angle to its digital function value (sine or cosine). This digital value is then sent to a linear, multiplying DAC using the AC reference voltage as its analog input.

After being generated, the sine and cosine values are inverted based on the quadrant selected. These two values are the final AC signals and are made available on the two pairs of resolver lines.

4.2.1.2 Serial Digital Interfaces

In its simplest form, digital communication can be accomplished with point to point logic level lines, each of which is dedicated to a single bit of data. These are analogous to the dedicated analog interconnects discussed earlier.

However, digital lines can also be easily multiplexed to allow several pieces of data to "time share" a limited number of physical lines. The standard types of interfaces include serial and parallel links either of which can be dedicated to a single interface between two units, or support multiple units. The characteristics of the standards most suitable for combat vehicles are summarized in Table 4-4 and are discussed further in the remainder of this section.

RS232/449 Serial Channel:

The EIA RS232 and the RS449 standard interfaces are both electronic standards which define the interconnection of devices and the transfer of information at the bit and byte (8 bits) level. Additional encoding or protocol must be defined by the user. The ASCII character code is the accepted encoding practice at the byte level, but for higher levels of protocol in a network there are few standards, and they are used only by a limited number of manufacturers.

Table 4-4. Digital Communications Standards

	DEDICATED CONNECTIONS		NETWORKS / DATA BUS					
	RS 232/449	RS-422	MIL-STD-1553B	PROPOSED MIL-STD-1773	IEEE-488	IEEE-802.5	HSDB (Preliminary)	IBUS (Preliminary)
TYPE	Serial Bi-directional Point-to-Point	Serial Bi-directional Point-to-Point or Multi-Drop	Serial Bidirectional Multi-User	Serial Bidirectional Multi-User	Byte Serial, Bit Parallel, Multi-User	Serial Ring	Fiber Optic Bus	Multi-level Multidrop Word Parallel
DATA NETWORKS	Single Transmitter Single Receiver	Single Transmitter Multi-Receiver	Controller/Multi Remotes	Controller/Multi-Remotes	Single Transmitter Multi-receiver	Token Access	Token Access	Single Transmitter/Multi -Receiver
CLOCKING	Asynchronous	Asynchronous	Asynchronous	Asynchronous	Asynchronous	Synchronous	Synchronous	Asynchronous
BIT RATE	300 Bits/Sec. to 19.2K bps	Up to 10 Mega bits/sec.	1 Megabits/Sec.	10 Megabits/Sec.	250 Kbps to 1 Megabits/sec.	4 MegaBits/sec.	20 MegaBits/sec.	0 to 25 MByte/sec
ENCODING	3 to 25V = 1 -3 to -25V = 0	Differential Voltage	Bi-Phase Manchester	Bi-Phase Manchester	Open Collector or Tristate	Differential Manchester	?	Tristate
MESSAGE BANDWIDTH 6 WORD MESSAGE 32 WORD MESSAGE	 160 Hz 30 Hz	 To 83 KHz To 16 KHz	 4.3 Khz 1.3 Khz	 43 Khz 13 Khz	Variable	 16 KHz 6.0 KHz	?	----
PROTOCOL	Standardized Character Format User Defined Message Format	Standardized Character Format User Defined Message Format	Command/Response Message	Command/Response Message	Master/Slave Handshake	Token Passing Ring	Token Passing	Master/Slave Priority Contention
MESSAGE SIZE (PACKING)	1 Byte	1 Byte	64 Bytes	64 Bytes	1 Byte-up	Established by System Timing Limitations	1-4096 Bytes	0-4096 Bytes
ERROR DETECTION	Parity	Parity	Parity Biphase Bit Count, word Count, User Defined.	Parity Biphase Bit Count, word Count, User Defined.	Parity	32 Bit Polynomial Residue Check	Circular Redundancy Check	Parity/User Defined
ERROR CORRECTION	User Defined	User Defined	Retry	Retry	User Defined	Retry	Retry	Self test/Reset/User Defined
REDUNDANCY	Possible	Possible	Dual	Dual	None	None-See Remark	?	Dual
EXPANDABILITY	None	Good	Good	Good	Good	Excellent	Excellent	Excellent
H/W COMPLEXITY	Simple	Simple	Moderate-High	Moderate-High	Moderate	High	High	Moderate
S/W COMPLEXITY	Simple	Simple	High	High	Moderate	High	High	High
EMI IMMUNITY	Fair	Good	Good	Excellent	Good	Good	Good	----
EMP IMMUNITY	Fair	Good	Good	Excellent	Good	Good	Good	----

These interface standards have been in use for years and are primarily applied where data transfer rates are low and environments are benign. Both are serial, unidirectional, point-to-point interfaces that operate up to 19.2 K bits/sec. The RS232 is asynchronous, relying on each unit to maintain its own clock and the relatively short distances over which the interface communicates. Start bits indicate to the receiver register to store the data, and stop bits indicate the end of message. RS449 has the additional advantage of being able to receive both synchronous and asynchronous information.

Physically, the interconnect consists of a shielded cable with between 4 and 25 signal wires, depending on the range of signals selected for use from the standard by the manufacturer. Connections are made with a 25 pin, 'D' format, subminature connector. Since a separate cable must be provided for each communication channel; weight, cabling diameter, and connector space can become significant factors when there are many communication channels to be provided.

The RS232 channel was designed primarily for the transfer of text between processing elements and slow terminals, such as display screens, character printers, and modems. This channel may be of use in dedicated equipments where performance is not critical and the environment is benign, such as diagnostic equipment. However, its slow speed, sensitivity to harsh environments, and restriction to point to point wiring, make it a poor choice for general communication in a combat vehicle.

RS422 Serial Channel :

Like the RS232 interface, the RS422 interface is an electronic interconnection standard which does not specify message protocol beyond the bit and byte levels. However, unlike the RS232 standard, the electrical specification allows the RS422 to be used in a multidrop configuration. This means that a single trunk line may be used to interconnect several modules. This capability is widely used in industrial networks which connect several devices in a proprietary network for communication and control.

The RS422 specification calls for a voltage differential electrical signal specification across two shielded, twisted pairs. This reduces the EMI sensitivity and allows longer interconnects. An RS422 cable can be considerably smaller than an RS232 cable since there are only 4 signal lines and 3 shields (each twisted pair has a shield, and there is a shield over both twisted pairs). Connections can be made with smaller connectors and is sometimes done with just discrete wire terminators.

Both the electronic interface and the cabling for RS422 communications are inexpensive and readily available. This interface is already available on some military equipment that may find application on combat vehicles. For example Litton, Kearfott, and Honeywell all have inertial navigation systems with an RS422 interface, and RS422 capability has been called out in the Modular Azimuth Positioning System (MAPS) requirement.

This communication standard could be very useful as a non-critical communication network among several modules where single errors won't have a great impact. Gun stabilization and tracking systems, for example, both require continuous data transfer at moderate frquencies. Isolated data errors can be quickly averaged out of significance, or can be subjected to a reasonableness check and ignored.

4.2.2 COMMUNICATIONS NETWORKS (DATA BUS)

The dedicated interface technologies discussed above typically provide the lowest cost interconnect for simple systems. However, they are not generally compatible with system growth, and quickly become unwieldy as system complexity grows and multiple digital processors are employed.

With the addition of BMS, the M1A1 tank will cross the boundary of practicality for a fully dedicated architecture and must, therefore, consider the use of local area communications networks for some of its intrasystem communications.

Two levels of communication are addressed in this section. The first is the system level, which provides the external connection of electronics boxes that are physically separated in the system. The second level is that of the internal communications within a processor assembly (box). This second level of bus communication will be significant to future systems with the planned development of standard electronic (card level) modules.

4.2.2.1 System Bus

The physical distribution of subsystem electronics units around the vehicle together with their related data transfer requirements results in a need for some form of logical interconnect. This is accomplished through communication networks which have evolved, as systems have become more complex, from relatively straightforward discrete point-to-point interconnects to sophisticated multiplexed data buses.

The advantages normally associated with data buses are:

- o Improved reliability (from fewer interconnects),
- o Reduced physical unit and harness sizes,
- o Decreased weight.

There are certain general requirements for communications networks which must be met for any system. These include:

- o Reliable, noise-free communication.

- Data transfer rates and response times compatible with the functional/physical partitioning.

- Minimum subsystem interconnect cabling.

- Fault tolerant operation without single point failures.

- High survivability from battle damage.

- Reconfigurability and expandability.

- Compatibility with military standards to allow use of existing equipment.

While all of these requirements are important, compatibility with existing or newly emerging standards is particularly important for a number of reasons. Through logical partitioning of subsystem modules, a new system can apply off-the-shelf hardware designed to these standards without major impact to the system. In addition, the use of compatible subsystems and a standard communications network also provides other potential advantages, such as:

- Reduced time and expense for overall system integration and validation

- Better knowledge of the failure modes and effects

- Predictable reliability of the off-the-shelf units

- In many cases, an established parts inventory and repair and support system.

The standard communication networks which appear to have potential application to the M1A1 FCS/BMS system are discussed below (and shown in Table 4-4).

MIL-STD-1553/1773 Multiplex Data Bus

This military standard multiplex data bus is a serial bidirectional, time division multiplex bus which supports multiple users and provides a well defined word format and message protocol. Time division multiplexing is the transmission of information from several signal sources through one communication system with different signal samples staggered in time to form a composite pulse train.

The Mil-Std-1553 Bus was developed to reduce the complexity of interconnecting DOD avionics equipment. It has gained wide acceptance as a standard, and there are numerous military electronics subsystems designed with this interface.

It operates in a command/response mode with one active bus controller and up to 31 remote terminals on a single self-clocking bus using Manchester II bi-phase encoding. The

Manchester format is fairly straightforward; using, for a logic one,a bit which is a positive level (positive voltage) on the bus for the first half of a bit period, followed by a negative level during the second half of the bit period. A logic zero is the exact opposite.

MIL-STD-1553 operates at a 1 mega-bit/second rate, and uses a high noise immunity transmitter/receiver and a single twisted shielded wire pair. The MIL-STD-1773 Bus is a wide band fiber optic cable equivalent to MIL-STD-1553 except that it operates at 10 mega-bit/second bit rate. Due to the higher costs for interfaces and limited program support to date, MIL-STD-1773 is not commonly used. Besides speed, the advantage of fiber optic cabling over wire is that it is excellent in environments where Tempest requirements are specified.

The multiplex data bus functions in an asynchronous command/-response mode using a half-duplex transmission. The bus controller is the unit responsible for the information flow coordination on the data bus. It controls this flow of information by transmitting commands to one of the remote units at predetermined points in time. A bus controller may be a standalone microprocessor based unit or may be a subset of the responsibilities of some unit designated as the bus controller. Current electronics technology allows the packaging of two dual-redundant bus controllers on a single 1/2 ATR or larger card.

In addition to coordinating information flow on the data bus, the bus controller must be able to respond to changes in operational environment. For different modes of operation, responses can be worked out in a predetermined manner. For unplanned events, such as remote terminal failure or battle damage, the bus controller must also provide the capablility for detecting the resulting error on the data bus and taking some action to attempt recovery from the error condition. The ability of this standard to support degraded mode operation has resulted in widespread use for critical military control applications.

The information flow on the Bus consists of messages which are formed by command, data, and status words. The command word is sent by the bus controller and is recognized by the remote terminal (RT) whose address is indicated in the command word. A Transmit/Receive (T/R) bit is provided indicating whether the RT is to transmit or receive data. A subaddress within the RT is given along with the number of 16 bit data words to be communicated. The RT responds on a message basis with a status word handshake which indicates the quality of the data transmittal and the status of the RT at the time of communication.

Broadcast messages can also be transmitted over the bus. However, this message format does not provide positive closed-loop control of bus traffic. In the broadcast mode, data is broadcast by the bus controller or by a RT in reponse to a bus controller command and is received by all RTs on the bus without a positive acknowledgement. While this message type is not used for the transmittal of critical non-reproducible data, it does provide a means for low overhead data transfers if applied carefully.

The basic operating mode of the bus is use of centralized control of information transfers which, in turn, implies a central control system architecture. To provide added flexibility, a special operating mode is provided that allows the bus control function to be passed by the Bus Controller to an RT capable of performing the bus control function. This technique provides for a distributed bus control capability in a distributed processor system.

Although it is technologically a relatively old standard, there are several advantages to the use of the 1553B on combat vehicles:

- o It is a military standard with widespread use.
- o An emerging fiber optics equivalent provides a bandwidth with significant operating margin for high speed BMS and fire control data loops and provides outstanding noise and EMP immunity with a single interconnecting fiber/optic cable.
- o VLSI and VHSIC devices are rapidly becoming available which can perform the bus control and remote terminal functions at lower cost.
- o The basic bus concept allows for subsystem growth without altering the internal vehicle wiring, and it supports hierarchal layering as well as centralized or distributed processor control.

The primary disadvantages of the 1553 for this application are the high bus overhead and limited data rate, and the cost of interfacing devices to the bus. It may be useful for the transfer of significant command and status signals around the system, but the combination of protocol overhead and the low (M-bit/sec) clock rate limit its usefulness within the onboard control systems. Additionally, the cost estimates range between $2000 and $3000 for a complete interface, which will severely limit its widespread application in combat vehicles.

IEEE 488 Network

Developed primarily for short distance (under 20 meters) communications, the IEEE-488 standard is a Byte Serial, Bit Parallel, Multiuser Asynchronous Bus. It is often used as an interface bus between a system and its test support equipment for the purpose of software development and debug, system maintenance, and fault isolation.

A major drawback to the use of IEEE-488 as a system bus in this application is that it was developed as an instrumentation interface for use in benign environments. As such, error detection is limited to parity checking.

This is a *medium speed bus communicating at rates ranging from* 250kbps to 1 megabit/sec, but it carries considerable clock and synch information which adds substantially to the communications protocol overhead. As an asynchronous communication interface, there is also a risk that one device may overload the bus and reduce effective communication to and from other devices. While this candidate bus may limited in a operational vehicle communications network, its broad acceptance by instrumentation vendors may be an asset for depot level maintenance support.

High Speed Data Bus (HSDB)

There is considerable interest in defining a new standard high speed data bus for military applications. MIL-STD-1553 is limited in its ability to transfer at high rates the large amounts of data needed for such systems as fire control, navigation, communications, electronic countermeasure, and image processing. Currently, dedicated interconnections are the solution used to overcome data transfer limitations. However, this increases cabling weight and complexity. A high speed, common bus method of interconnection would reduce both of these factors, and allow for straightforward upgrade and expansion.

Recognizing the need for a High Speed Data Bus (HSDB) able to communicate between avionics electronics boxes, the Air Force has supported a Society of Automotive Engineers Subcommittee (SAE/AE-9B) which has begun the development of a MIL-STD-XXXX HSDB Specification. This standard has also been selected by FMC Corporation for its candidate Vetronics data bus architecture.

The HSDB is still under development, but the characteristics described in an early *PAVE PILLAR* report (ref. 12) are listed in Table 4-4.

IEEE 802 STANDARDS

Local area networks (LANs) are currently being examined as a commercial solution to high speed data transfer problems between computers and other digital devices separated by moderate distances. The IEEE 802 committee on local area network standards has been trying to establish communication standards which manufacturers can meet and communicate with, but which also allow easy implementation in silicon using VLSI technology. As the standards have been set, integrated circuit manufacturers have been quick to provide chip sets which meet and surpass the requirements.

The advantages of establishing a military high speed data bus standard based on the work already done by the IEEE 802 committee are the potential low cost and wide availability due to the broad support of the standards by commercial and industrial users. Unique military requirements can be accommidated by modifications of exisitng chip sets or by using optional capabilities which already exist in (or can be designed into) LAN support chips (for example, the Intel 82586 LAN controller discussed below).

Three draft standards have been issued by the IEEE 802 committee, and the following paragraphs summarize the key elements of each.

IEEE 802.3 : CSMA/CD using Baseband Technology

CSMA/CD stands for Carrier Sense, Multiple Access with Collision Detection. The "Ethernet" communications network meets this standard. It is a contention methodology, which means that all devices attached to the bus which have a message to transmit must compete for the bus on a first come, first serve basis. If two or more devices try to communicate on the unused bus at the same time, a collision is detected. After each unit waits a random interval of time, retransmission is attempted and another check for collisions is made. This process is repeated until the bus line is free. Line access is probabilistic in this methodology rather than deterministic, which means that it is possible (but very unlikely) for a message to never get accross the bus due to repeated collisions. Intel currently manufactures the 82586 LAN controller which is based on a CSMA/CD methodolgy, but allows the communication parameters to be optimized for particular applications and provides a method of prioritizing messages.

IEEE 802.4 : Token Bus

The Manufacturing Automation Protocol (MAP) standard which is being accepted as a defacto standard by major industrial manufacturers uses the IEEE 802.4 standard as its method of physical transmission. In this methodology, a short message (token) is passed between all stations connected to the bus. This token freely travels until a station ready to transmit a message receives the token. This station changes the token to indicate that the bus is busy, and then puts the message it wants to transmit onto the bus. After the message is transmitted and received by the specified station, the token is returned to the bus as a free token and it circulates until another station is ready to transmit, and marks the token as busy. Although the token method is slightly more complicated, especially at system initiation, the advantage is that line access is deterministic. The maximum amount of time it takes for any station to get access to the bus is fixed, and can be controlled.

IEEE 802.5 : Token Ring

This standard is being supported by IBM in its new network products. The fundamental concept of the token remains the same as above, but the topology of the interconnect is a ring rather than a bus. There are several advantages to the token ring methodology.

- As with the token bus, line access is deterministic, which means that a particular node can always get access to the network within a predefined maximum delay.
- A single twisted pair can serve as the trunk line of the ring (or two twisted pairs for redundancy as discussed below).
- The termination characteristics of the ring at any station connection are fixed, regardless of the number of nodes on the total ring, since only a single transmission line runs between two adjacent stations, and the line is terminated at each end.
- A new station may be added to the ring at a node even while the ring is active.
- A failed node can be electrically removed from the ring even while it is mechanically still attached.

In its generic processor study (ref. 10), Texas Instruments described its Vetronics concept, which adds a second, redundant twisted cable trunk line to its implementation of the IEEE 802.5 token ring. This second line allows the ring to recover from a single break occuring anywhere in the line. This network is used for command level communication between processing nodes within the Vetronics architecture.

Texas Instruments has developed and released a 6 chip set for interfacing to the ring and has reported plans to reduce the count to 3 chips. The chip set is built to military specifications, but hasn't yet been validated. A commercial version is currently marketed for use in a commercial IBM's network system.

4.2.2.2 Internal Bus

In addition to the increasing data transfer demands placed on system data buses, a similar problem exists within functional modules. Typically referred to as an internal bus, these module to module communication buses are required to transfer information between modules within a given function. In the past, these buses were not an issue so long as an appropriate BIM (Bus Interface Module) was included which would convert a supplier's proprietary internal bus to a standard external bus interface.

With the development of VLSI and VHSIC single board computers, however, the need to standardize the internal bus must also become a priority issue. In recognition of this, a development requirement for a standard internal bus (IBUS) was included as part of a recent U.S. Air Force, VHSIC 1750A Computer Development Specification (ref. 12).

The IBUS is intended to interconnect competing resources and I/O devices in a relatively autonomous, circuit switched environment. The IBUS consists of a network of multi-level, multi-drop busses providing arbitrary connections of data processors, array or signal processors, and peripheral devices. IBUS extension beyond a functional module set is intended to be for very short distances.

As shown in Table 4-4 the IBUS is applicable to computing systems in which the total bandwidth required for interprocessor communication can be obtained by interconnecting processors via one or more shared busses. The multi-drop approach minimizes the interconnections, and fully utilizes the available bandwidth.

Duplicate and Redundant paths provide fault tolerant features within the system. These alternate paths would be used in instances where a bus or coupler along a path was suspected of failure. The master can reconfigure the transaction path by changing the set address definition.

Any command can address up to 255 devices on a bus. In addition, the development specification allows for a "Pass Through Mode", where commands may be "piped" to another IBUS within the network.

The specification also describes a broadcast mode which allows a master to write the same data to multiple slaves. Broadcast transactions, however, are limited to a single bus level, so data can not be written to any devices or nodes requiring a bus coupler relay operation.

Each terminal type IBUS interface device has the ability to accept and save the basic set of parameters needed to define the origin or destination of data during a bus transaction. The development specification refers to this basic information as the Stored Address Parameter Set (SAPS). This information is necessary in a read type operation where the direction of data flow on the bus is reversed immediately following transmission of a SAPS read type header. Read and write transactions permit the transfer of up to 4096, 16 bit data words.

Through the standardized internal bus development, a common module concept (as described in the Common Module Fire Control System Study, ARDC contract DAAK10-83-R-0031) can provide expanded capabilities by the simple addition of plug-in, bus-compatible modules. Whereby external bus approaches have allowed Line-Replaceable-Units to be added to a bus, the standardized internal bus approach will allow Line-Replaceable-Modules.

4.2.3 PACKAGING CONSIDERATIONS

Previous development efforts have allowed manufacturers to develop equipment within packages independently defined by each manufacturer. There has been considerable effort made towards establishing some standards for packaging; for example, the

Military Computer Family (MCF) form fit standards; and the Standard Electronic Module (SEM) effort; with the following benefits:

- Interconnection between products from different manufacturers within a common housing
- Support of the philosophy of the "Common Module"
- Reduced cost of common elements (such as housings) due to increased use across modules with different functions
- Reduced handling expenses
- Reduced maintenance cost

A widely used measure for sizing of electronics cards (and the assemblies that enclose them) is the Air Transport Rack (ATR). Standard card sizes include 1/2, 3/4, and full ATR.

Of particular interest to future combat vehicle developments should be a format based on the 3/4 ATR. This card size can support efficient packaging of functional modules required for FCS/BMS, is compatible with current analog electronics technology, and is being strongly supported in VHSIC development programs by all three service branches.

A general specification for a 3/4 ATR module, referred to as the SEM-E format, is close to completion. Some of the key physical features are described below:

WIDTH	5.88 Inches (149.4 cm)
HEIGHT	6.68 Inches (169.7 cm)
STD THICKNESSES	.290 (7.37) .380 (9.66) .480 (12.20) .580 (14.74)
STD CONNECTORS	100 Pin 150 Pin 200 Pin 250 Pin
UNIQUE KEY CONFIGURATIONS	120
MIN MATING/ UNMATING CYCLES	500
MIN LIFE EXPECT.	100,000 Hours

Specifications have also been released for the first set of module functions. These functions are also applicable to military vehicles and the fire control function. Descriptions for a subset of these functional modules directly applicable to the CMFC effort are below:

Scalar Processor: The Scalar Processor will consist of a MIL-STD-1750A Instruction Set Architecture CPU with 256K bytes of dedicated local memory. The Scalar Processor module shall be capable of a minimum 3 million instructions per second (MIPS).

Array Processor: The Array Processor shall be able to process complex arithmetic with the capability of performing 40 million operations per second (MOPS).

Bulk Memory: The Bulk Memory will consist of 16M words of non-volatile memory. It will be used for program storage and bulk data storage.

MIL-STD-1553B: This module will consist of two, redundant MIL-STD-1553B Multiplex Bus interfaces. The bus shall be programable to operate in either Master or Remote mode.

IEEE 488: This module shall have two IEEE 488 Bus interfaces to be used for connection to and control of maintenance equipment.

Dedicated Interface: This module may actually represent a family of modules. The purpose of each module in the family is to provide buffering and control circuitry for interfacing discrete input and output, such as analog, synchro, serial, TTL level, frequency, etc.

Power Supply: The Power Supply modules may actually be a family of modules each of which conditions the vehicle power (input) as needed for operation of the electronic modules (output). Standard modules must be stackable to provide additional power when the power requirements of a chassis exceed the capabilities of a single Power Supply module.

Other Modules: Additional requirements will require other functions to be provided on modules. For example, communications between chassis will require additional circuit level support as standards emerge and the volume of data to be transfered increases. Emerging standards such as the High Speed Data Bus, and a military version of IEEE 802.5 can each be supported by a module. As technologies advance and new functions and capabilities are added to vehicle requirements, new modules can be developed within these Electronic Module specifications. Examples of these would be Video Module, Graphic Processing Module, Signal Processing Module, etc.

4.3 BMS CONTROL AND DISPLAY

Block II M1A1 FCS/BMS has a number of requirements for operational displays and controls for the tank commander and gunner. These include:

Gunner's Sight Control and Display
Fire Control Computer Control
CITV Display and Controls
BMS Digital Messaging Display
BMS Command and Data Entry Panel
BMS Digital Map Display with Overlaid Symbology

Because space is such a premium inside a combat vehicle, and to simplify the soldier/machine interface, operator displays and controls should be shared between functions where practical. BMS messaging, BMS command and data entry, and digital map display with overlaid symbology are logical candidates to share a single display to the vehicle commander.

This section will discuss only the new requirements associated with BMS, since FCS control and display are well known and are not a primary issue in this study.

4.3.1 DISPLAY TECHNOLOGY

Selection of a display screen technology for this application will be driven by several factors, including: Cost; Performance; Compatability with other subsystems and sensors; Readability under all conditions (including direct sunlight); EMI; Reliability; Maintenance; Size; and Technology availability. The driving technical requirements will be related to BMS display characteristics. Recent Ft. Knox studies suggested the need for an 8" (minimum) diagonal screen, with a 500 x 500 display resolution.

Several display technologies are available, including:

LCD (Liquid Crystal Displays)
EL (Thin Film Electroluminescent)
CRT (Cathode Ray Tube)
AC Plasma
Flat Panel CRT

Key characteristics for these technologies are summarized in Table 4-5.

Liquid Crystal Displays (LCD's)

LCD's provide good resolution for this application. LCD's are lightweight, have a very small form factor and operate at low power. LCD panels offer better viewing in direct sunlight than other display technologies. However LCD's require direct light or backlighting (with flourescent tubes) for visibility. A

Table 4-5. Display Technologies

TECHNOLOGY	COST	PERFORMANCE CHARACTERISTICS	ENVIRONMENTAL	SCREEN SIZE	DEPTH (including Electronics)	WEIGHT (including Electronics)	TECHNICAL RISK	AVAILABILITY	POWER	REMARKS
CRT	Medium	Good gray scale Good frame rate Good resolution Good image clarity Color available	Militarized High Maintenance Difficult to nuclear harden	3" - 25"	12"-30"	50-75 lbs	Low	Current	High	
AC PLASMA	Medium	Good gray scale Good frame rate Good resolution Good image clarity Monochrome Only	Militarized Nuclear Hardened option Rugged	10"	2 1/2"	25 lbs	Medium	Current	50 % less than CRT	
ELECTROLUMINESCENT DISPLAY (EL)	Medium	Good gray scale Good resolution Good image clarity Viewable in direct sunlight Sharp, bright pictures	Militarized Rugged	5" x 7"	1 1/2"	15 lbs	Medium	Current	Low	Color Technology under development
FLAT CRT	High	Good gray scale Good frame rate Good resolution Color available		12"	3"	20 lbs	High	1990	Low	
LIQUID CRYSTAL DISPLAY (LCD)	Low	Narrow viewing angle Requires backlighting or reflected light Poor contrast with larger screen sizes Gray scales and color possible	Militarized	up to 12"	1 1/2"	15 lbs	Medium	Current	Very low	

disadvantage of LCD's is performance degradation at lower temperatures. Large LCD screens are relatively difficult to manufacture, and LCD's can only be viewed from a narrow angle. Poor contrast may present other viewing problems. Color LCD's are now available, and are used in commercial portable televisions, but only with small screen sizes.

Electroluminescent (EL) Displays

EL displays provide high brightness, low power consumption, very small form factor, operation over the military temperature range, shock resistance, and response time adequate for video. EL screens are gaining wider use in commercial applications (automobile dashboards and portable computers), and increased volumes are reducing costs. EL screens have sufficient brightness to be viewable in direct sunlight. Multicolor EL screens (currently only in the development stage), utilize a stacked phosphor approach with no reduction of resolution. Good gray scale EL displays are commercially available now. However, the screen sizes and resolutions required for color BMS displays are not yet commercially available.

CRT's (Cathode Ray Tubes)

CRT's offer very mature technology with sufficient resolution, gray scale or color presentation, and frame rates suitable for combat vehicle application. Conventional CRT displays are an acceptable choice for a near term BMS display, and a CRT is currently utilized in the CITV display. CRT's typically require more maintenance than other technologies because of critical alignments and fragile components. CRT's also require a larger form factor and more power than any other display technology evaluated.

AC Plasma Panels

AC Plasma panels are comparable in cost and performance to standard CRT's, but plasma displays do not offer color. However, AC plasma panels are more rugged, require less maintenance, less space & lower power, and can be nuclear hardened.

Flat Panel CRT's

Flat panel CRT's provide many of the advantages of traditional CRT's, with reduced size and more rugged construction. This technology is relatively new, and will not be available for this application for several years.

4.3.2 DISPLAY ORIENTED OPERATOR INPUTS

The multi-function nature of the BMS display function requires program selectable control over data inputs. One approach that provides considerable flexibility in this area is that of "Touch Screen" sensing.

The use of touch screen technology directly on the display screens will enable simplified selection of choices and data entry for the operator. Noncontinuous controls and operations not typically performed under stress, and selections requiring many discrete choices will utilize the touch screen. Conventional controls close at hand should be utilized for critical and continuous operations more likely to performed under high stress conditions. The preferred design would utilize the advantages of each control technology in an optimal combination.

Integrating a touch screen with the operator display will allow processing of operator input for several functions: text, graphics, and control selection. Touch screens also provide the capability for greatly increasing the number of software assignable operator selections. For application in the M1A1 BMS system, the touch screen will be required to be reliable, have sufficient resolution for use with terrain map graphics, not be affected by environmental extremes, and not impede the visibility of the display screen.

The use of a touch screen for interaction with the terrain map display will require a high resolution touch screen system. Operation "Gloves-On," will require a technique of averaging the contact area to define the desired point. Adjustablity of this averaging function will create the desirable feature of line drawing of various line widths. Some of the types of expected touch screen interaction with BMS include: defining positions on the map (friendly, enemy, etc.) with appropriate symbol designators; designating map positions for BMS system reporting and calculation assist functions (range, angle, obstacles, etc); simple drawing of tactical plans; and control selection of BMS functions (communications, automatic reporting, function selection, and data input).

As shown in Table 4-6, there are three primary technologies currently used for touch screens (Resitive-Membrane, Capacitive & LED).

Resistive-Membrane Touch Screens

Resistive membrane touch screens currently have the highest available resolution for touch screens (up to 4000 x 4000 points). Resistive screens utilize a flexible outer layer of Mylar that is deformed when touched to contact an inner layer which defines the point of contact. This Mylar outer layer can be scratched by a stylus or dirt. Resistive screens tend to limit the optical transmission of the display somewhat because of absorption by the Mylar and other layers of the resistive screen, which may also distort the display color. Resitive screens require more pressure to activate than other technologies. Resistive membrane touch screens curve with the CRT face so parallax is not a problem. Environmentally, resistive screens, if not sealed well, can form condensation between their layers.

Table 4-6. Touch Screen Technologies

	Resistive - Membrane	Capacitive	LED
Resolution (Typical)	Discrete = 16 x 16 Analog = 4,000 x 4,000	Discrete = 16 x 16 Analog = 256 x 256	25 x 25
Parallax Error	no	no	yes
Stylus Limitations	none	Must be conductive	Must be perpendicular to screen
Durability Considerations	Coating wear and scratching	none	Critical alignment
Optical Clarity	50% light reduction		
Tactical Response Required	Requires pressure to deform Mylar layer	Light touch	Proximity & light touch
Environmental Considerations	Humidity	Sensitive to temperature & humidity changes	Dust and strong ambient light
Cost	Approx. $2,000	Approx. $1,500	Approx. $1,500

Capacitive Touch Screens

Capacitive screens can be provided with either a limited number of discrete predefined touch pads etched into the display surface, or by an analog system that provides higher resolution - up to 256 x 256 points. Capacitive touch screens utilize a thin outer layer of resitive coating directly applied to a glass surface over a display device. Capacitive screens are activated by only a very light touch, due to capacitive coupling between a finger or conductive stylus and the screen coating. Capacitive screens may be affected by temperature and humidity changes (unless electronic compensations are employed).

LED (Light Emitting Diode) Touch Screens

LED touch screens have low resolution (limited by the number of individual LED's that can be arranged around the display screen). LED touch screens do not appear to currently have adequate resolution for the BMS application. LED screens do not require any pressure or contact, but merely to break the light beam between the LED transmitter and receiver. However, LED touch screens can introduce a parallax error where the light beams are located far above a curving CRT face (this becomes very evident at the edges of the screen). Environmentally, LED screens can be affected by dust and strong ambient light.

4.4 LOCATION, ORIENTATION, AND VEHICLE DYNAMICS

Both the fire control and battle management functions require sensing of vehicle position, orientation, and/or inertial dynamics. Table 4-7 summarizes the types of data and their uses for M1A1 FCS and BMS.

The basic technologies available for establishing this data are ground-based radio, satellite based radio, and inertial. The characteristics of these are summarized in Table 4-8.

Of particular interest to an integrated FCS/BMS vehicle architecture is the use of inertial technology, since a single set of gyros and accelerometers in the inertial measurement unit can be used for multiple purposes within both the FCS and BMS. In fact, a single turret-mounted inertial reference unit could feed data to several software modules to provide all of the data types shown in Table 4-7 except hull yaw rate and vehicle driving speed (which is assumed to be measured directly from the power train).

Prior to BMS, automated vehicle navigation/position location was desirable but not required for close combat vehicles. Since this capability, when considered on a standalone basis, can add several thousand dollars to the cost of a vehicle, it has not been implemented on a wide scale. While a relatively high cost factor still exists, the differential cost to the vehicle can be partially offset by using other systems processors for computation and by the elimination of other vehicle equipment if a sensor sharing architecture is adopted.

Table 4-7. Position,Orientation, and Dynamics Data Requirements

DATA TYPE	USED BY:	APPLICATIONS/REMARKS
Vehicle Position:		
Map Grid Position	BMS	Provides location data; used for map referencing; reference data for navigation and force positioning, monitoring other vehicle locations, and establishing target locations.
Altitude	BMS	Cross reference to map and features data
	FCS	Part of the ballistic fire control solution
Vehicle Orientation:		
Heading	BMS	Required for navigation; combined with target range and vehicle position to calculate absolute target position.
	FCS	Can be used for ballistic compensation if data is available; accuracy effects do not justify adding a sensor for this purpose alone.
Roll	BMS	Used for coordinate transformation of relative target and/or feature positions to absolute coordinates.
	FCS	Turret roll (cant angle) is required for ballistic solution.
Pitch	BMS	Combined with LOS relative elevation angle to predict target and/or feature location.
	FCS	Combined with LOS relative elevation to predict target altitude for ballistic solution; a small effect for surface and low altitude targets.
Vehicle Dynamics:		
Heading (Yaw) Rate (*)	FCS	Hull yaw rate is required for turret stabilization under mobile operation.
Roll Rate (*)	FCS	Turret roll rate can be used to improve turret stabilization under under some mobile operating conditions; not cost effective if only used for this purpose.
Pitch Rate (*)	FCS	Turret pitch rate is required for gun stabilization under mobile operation.
Vertical Acceleration (*)	FCS	May be required to stabilize enhanced armament; can be used to assist gunner tracking under mobile conditions.
Lateral Acceleration (*)	FCS	May be useful in stabilizing (highly unbalanced) turrets with improved frontal armor.
Longitudinal Acceleration (*)		
Vehicle Driving Speed (*)	FCS	Can be used in ballistic solution to adjust muzzle velocity; can be used to assist gunner tracking under mobile operation.

(*) All of these parameters are used indirectly by BMS if inertial navigation is implemented for position location.

Table 4-8. Applicable Technologies - Position, Orientation, and Dynamics

TECHNOLOGY	CHARACTERISTICS	EXAMPLES
Radio (Ground Based)	Line of Sight Accurate Relative Position (15 M) Cooperative, Multi-User Jam Resistant - Spread Spectrum Digital Communication Integrated with Message Structure No Vehicle Attitude Data	PLRS/JTIDS
Radio (Satellite Based)	Jam Resistant Accurate Position and Velocity Non Cooperative, Receive Only All Land Area Coverage No Vehicle Attitude Data Common Geographic Coordinate System	GPS
Inertial	Jam Proof - Non Radiating Self Contained Measurement Of: Position Velocity True Heading Attitude Attitude Rates Vehicle Accelerations Time Dependent Accuracy	IRNS MAPS

PLRS/JTIDS - Position Locating and Reporting System / Joint Tactical Information Distribution System
GPS - Global Positioning Satellite System
IRNS - Inertial Reference Navigation System
MAPS - Modular Azimuth Positioning System

The key to achieving this capability is a repartitioning of the traditional inertial navigation system data flow and processing. To achieve reasonable levels of navigation accuracy, systems such as those listed in table 4-9, typically sample and (where applicable) torque the inertial instruments at rates of 500 to 1000 Hertz. This data rate would also provide sufficient bandwidth for the stabilization functions referenced in table 4-7. Although this data rate is not normally available to the external world from current navigation systems, there is no technical reason that it could not be provided.

Two basic approaches can be considered with respect to this repartitioning. One is to have a current navigation system (IRU/computer) modified to provide the required data and rates at an output port. The other approach would be to separate the IRU functions (sensing and instrument torquing) from the navigation computations. This would result in a lower cost inertial hardware package, the navigation software could be implemented in another multi-function computer, along with other processing that uses the same data.

The final cost of implementing inertial technology on close combat vehicles will be proportional to the required navigation accuracy. The accuracy required for fire support is represented by the the Modular Azimuth Positioning System (MAPS) performance described in table 4-9. Without considering the cost offsets referred to above, such navigation systems might cost in the range of $20,000 to $30,000. However, BMS for the M1A1 can probably operate with much looser specifications, more along the lines of the VNAS system. This could reduce the cost substantially.

From a fire control perpective, M1A1 tanks which implement this technology will be able to eliminate the current cant sensor and turret pitch rate gyro, and they will not have to add separate acceleration sensors to stabilize the expected highly unbalanced enhanced turrets and weapons. Additionally, they can have improved performance on the move due to the inherent availability of additional dynamics data (cant, pitch, roll rate, etc.) that is basically available for "no cost" performance improvements in the fire control software.

If cost becomes an overiding limitation, a combination of inertial and radio technology can be used within small units to provide the position data required to support the BMS functions.

Table 4-9. Inertial Systems Data

NAME	COMPONENTS	DATA INTERFACES	SIZE Length	SIZE Width	SIZE Height	WEIGHT Lb	POSITION ACCURACY Horiz	POSITION ACCURACY Vert	HEADING ACCURACY (Mil)	ATTITUDE ACCURACY (Mil)
Litton LLN-83 IR/NS	Inertial Reference Unit	RS 422	14.5	8.5	8.4	28	0.25%	0.25%	1	0.5
	OCU	1553B	10.2	6.5	2.8	9				
	O/ACU	RS232C	7	6	2.5	4				
	EDU	ARINC-575	8.3	5.4	3	3				
	OTU		6.6	5.4	3.8	3				
Litton LLN-84 MAPS	Dynamic Reference Unit	Dual RS 422	15.1	10.75	8.7	35	0.25%	0.1%	1	1
	Control/Display Unit		7.25	8.5	4.84	9				
	Vehicle Motion Sensor		5	3.8	3.5	6				
Kearfott LNS	Heading Reference Unit		14	9	8	25	0.25%	0.25%	1	
	Computer Display Unit		7	13	7	25				
	Distance Transmitter Unit		2	2	3	0.5				
	Map Display Unit (Opt.)		25	20	8	55				
Kearfott AHRS	Unit	1553B	11	7	7		N/A	N/A	9	1.8
Kearfott MAPS	Dynamic Reference Unit	RS 422	15.05	10.7	8.7	?	0.25%	0.1%	1	0.5
	Control/Display Unit		8	4	2.5	?				
	Vehicle Motion Sensor		5.4	4.1	3.8	?				
Kearfott Multi-sensor Measurement Unit	Unit		2.9	6.3 (Diam)		3.5				
Honeywell H-726 MAPS	Dynamic Reference Unit	RS 422	15	10.75	8.7	40	0.25%	0.1%	1	0.5
	Control/Display Unit	(Rad Hard.)								
	Vehicle Motion Sensor									
Lear Siegler VNAS	Vehicle Reference Unit		284.5 Cu Inches			10	2.0%	?	18	?
	Nav Display Unit		74.3 Cu Inches			2.5				
	Vehicle Heading Indicator		20.3 Cu Inches			0.7				
	Distance Meas. Unit		83.4 Cu Inches			1.8				

5. ARCHITECTURAL CONSIDERATIONS

The current and projected functional requirements for BMS/FCS (as described in section 3) introduce the need for substantially more computation, data flow, and display capability than is currently available in the M1 series tanks. The individual technologies described in the preceeding section have the maturity and performance capabilities required to meet those functional requirements. However, a major challenge for advanced FCS/BMS is how to integrate them into future M1-based turret systems.

Up to a certain level of electronic sophistication, the problems of combat vehicle integration are relatively straightforward and forgiving. To this point, combat vehicles have had to accomodate relatively few electronics boxes which were performing straightforward, mostly linear control functions using mostly analog electronics. With the rapidly expanding scope and sophistication of BMS and FCS, however, the vehicle integrator must now face many of the same cost/weight/volume/complexity issues that have challenged the aircraft industry for the past two decades.

This discussion will reflect some of the applicable integration experience of that industry in establishing guidelines for an architecture for the battle tank that exploits available electronic technology and provides for growth within the practical constraints of M1 budgets and schedules.

5.1 GENERAL

There is no doubt that the architectures of combat vehicles such as the M1 tanks will be dominated by digital technology in the near future. However, there are a number of practical issues that will limit the practical rate of transition. This section will discuss some of the key hardware architectural concerns related to turret-based electronics for combat vehicles.

The general capabilities and tradeoffs of analog and digital processing are summarized in the following subsection. Additional key issues relate to the distribution of digital processing functions given the current limitations for interface and interconnect, the standardization of designs for growth compatibility, and the effects these changes will have on traditional supplier roles and system partitions.

5.1.1 ANALOG VS DIGITAL PROCESSING

Nearly all of the FCS-related processing in fielded vehicles is currently implemented in the form of analog electronics. The single notable exception to this is the ballistic computer in the M1 tank.

The primary reasons for the dominance of analog electronics have been lower cost and the throughput limitations of low cost digital processors, which have only recently reached acceptable performance levels for combat vehicle control problems. The cost advantage of analog electronics lies primarily in the ease of integration with the electro-mechanical devices commonly used for combat vehicle fire control.

Analog computation, by virtue of its parallel and continuous processing characteristics, is useful for high bandwidth control problems with analog interfaces, relatively well behaved load dynamics, and limited dynamic ranges. Thus, it is still the most cost-effective approach for such functions as line of sight stabilization.

The primary disadvantages of analog computation are reliability, the lack of flexibility, and the high weight and volume per unit measure of computational performance.

Digital processing is clearly the way of the future for combat vehicles, and an all digital turret (i.e., Vetronics-based) may be achievable within the next 10 years. Historically, computational throughput and cost have been the limiting factors in applications of this nature, although system interface is now becoming very significant.

All of the processing requirements for the current M1 functions and performance levels can be achieved with relatively low cost processors using military standard instruction set architectures and LSI or VLSI circuit technology. The emerging requirements for signal processing can be met with newly developed VHSIC circuits which are planned to achieve practical production rates within the next two to three years.

The major limiting factor to digitizing more turret functions is the problem of interfacing to the (primarily analog) outside world and the distribution of large amounts of data between points-of-need. The TACOM-sponsored Vetronics program is attempting to define standards and develop the necessary high speed data buses and low cost interfaces. However, the practical implementation of these technologies is still many years away and not compatible with early application in the M1A1 Block II schedules.

The requirements for the remainder of this decade must, therefore, be met by "hybrid" turret electronics architectures which retain analog control for some functions, but in which the performance and function growth is implemented in digital form.

5.1.2 DISTRIBUTION OF PROCESSING ELEMENTS

The physical distribution of processing elements within a system will have a major impact on its cost and performance. Analog electronics are typically designed for a unique function and dedicated to a specific, limited hardware interface. The various circuits necessary to perform the required function are typically grouped into a single box in order to minimize cabling and the problems associated with it.

Digital processors are, however, more general purpose in nature, and a single hardware element may be capable of performing a number of substantially different functions. The only limitations are the basic computational power of the processor and the ability to provide the input and output data channels required for performing the functions.

At the extremes, there are two basic approaches to the distribution of digital processing - distributed and centralized.

Distributed Processing follows a philosophy of physically locating the processors at the "point-of-need", as has been traditionally done with analog combat vehicle electronics. The advantages to this approach include:

- o High function processing rates can be achieved because the processor is dedicated to that task.

  This characteristic has been significant in many prior applications due to the throughput limitations of the then-available digital technology.

- o Software efficiency and configuration control are better because the processor is not being time shared or required to do a wide variety of tasks.

The primary disadvantages of distributed processing are:

- o Processors tend to be application specific, which makes it difficult to share burdens in the event of a processor failure (i.e., graceful degradation).
- o The number of processors increase, which creates additional cost and increases the system volume and power requirements.
- o With the trend toward standardization, processors will exist at a few discrete throughput levels. Unless a function happens to match exactly, a portion of the inherent computational power of the processor may be wasted.

One Vetronics contractor is investigating the use of a large number of standardized processors to control both the data interfaces and to conduct processing of the required control functions in a truly distributed fashion. This removes any concerns about the ability for graceful degradation. However, the techniques for distributing intelligence in this fashion are still quite theoretical and will require considerable time to perfect.

At the other end of the spectrum is centralized processing, which follows the philosophy of locating all of the processors in a common box. Communication with the points-of-need is via a system data bus and/or direct point-to-point interconnect.

The advantages of this approach are:

- The number of processors required by the system is minimized by time-sharing across functions.
- Remaining processors can share the burden in the event of a processor failure.
- It is well-suited to processing growth, particularly that associated with extracting more performance or function from existing system data.
- For a given level of system processing, this generally will have the lowest processor production costs.

The disadvantages of centralized processing are:

- It requires higher data rates for the system interconnect. This may exceed the capacity of current data bus technology.
- It may lead to more cabling in systems that require point-to-point interconnect in addition to data buses.

In practice, neither of these approaches is entirely satisfactory for combat vehicle BMS/FCS applications. The most appropriate architecture is a combination of these, in which a limited number of "pockets of centralized processing" are distributed in the system.

This "Federated" approach is flexible, compatible with the processing requirements of a combat vehicle, and well-suited for growth. In this approach, functions with high data flow rates and those which might share sensor data are grouped into a single processor assembly (i.e., centralized). Some point-of-need processing is distributed throughout the system, but it is basically limited to that required to filter and format data for the system bus.

In the extreme applications of this architecture, a simple combat vehicle (e.g., an IFV) would have a single processor assembly for all BMS/FCS functions, while an advanced tactical aircraft might have 10 or more assemblies operating on various sensors and mission functions.

5.1.3 STANDARDIZATION

The concept of embedded computers is being considered for many military applications. The reason is that many functions which once required "black boxes" can now be performed by a single (or two) board module. A second but equally important reason is that it provides an approach to a system configuration which allows flexibility, growth and low cost system tailoring by insertion or removal of plug-in modules. Practical application of this approach, however, requires standardization of the internal configuration of electronic boxes.

Historically the internal communication within an electronics box (Line Replaceable Unit) was not a system design issue and only the external interfaces needed to be standardized. VHSIC and VLSI technology development, however, has made it possible to place entire functions (even multiple functions) on a single board which can be packaged as a plug-in module.

To accomodate this new generation of electronics, the concept of the expandable chassis with a backplane consisting of a high speed data bus and a standard internal control bus (IBUS) has evolved. This approach requires both the electronics interface and the physical interface to be defined so that cards may be added or removed from the chassis to achieve the performance characteristics desired. With this, future growth can be accomodated by the simple insertion of additional interface-compatible cards.

A key element of the expandable chassis concept is the Standard Electronics Module (SEM.) Combining this standard for the physical parameters of electronics with the electronics bus standards described earlier will allow competitive development and procurement of plug-compatible modules.

There is extensive military support for the development of a physical configuration for these plug compatible modules. The SEM-E configuration appears to be a prime candidate configuration for these modules. This physical configuration will fit into a 3/4 ATR form factor and allows for varying module thicknesses.

Consider an example of how the expandable chassis concept can be applied to accomodate future growth in the M1A1. Current computing requirements for the M1A1 Block II change can be accomplished with a single board VLSI processor module. As M1 FCS and BMS enhancements are incorporated during the next decade, image processing and other processor intensive demands will be established. To meet the higher processor requirements, the standardized expansion chassis concept offers two options:

(1) A VHSIC processor may be plugged into the chassis directly replacing the VLSI processor, or

(2) Additional VLSI processor modules may be added.

The latter approach is currently being applied on the EF111 aircraft to obtain data processing rates in excess of 5 MIPS.

In summary, the advantages of M1 conversion to the standard module concept are exceptional flexibility, expandability and cost savings offering a logical growth opportunity to support advanced BMS and Fire Control processing needs as they develop.

These advantages must be weighed, however, in terms of the current M1, Block II requirements. To do so, the issues of schedule and costs for converting this approach must be considered. Conversion to a standard module format creates some risk in meeting M1 Block II schedule requirements. A planning strategy can be established, however, which would reduce this risk. It would require physical and communication interfaces to be selected so that they will allow a plug compatible upgrade to VHSIC or VLSI as new requirements (e.g., digital imaging) are placed on the M1. The risk involved from a schedule standpoint can be reduced by designing in certain features which are supported by all technology approaches and taking advantage of developments already underway. This would include a physical form factor and a standard bus interface (i.e., the expandable chassis form factor with a standard physical interconnect).

5.1.4 SUBCONTRACTOR ROLES AND SYSTEM PARTITIONING

At this point it is important to consider an additional factor in current design and procurement policies that stands face to face with the pure technical tradeoffs normally considered in studies such as this. That is the traditional contractor roles in tank system development.

In the "pre-electronics" days of tank fire control, the functions being performed were simple and implemented by straightforward optical and mechanical designs. The technologies involved were basically those of power drives for the gun and turret, optics for target viewing, and semi-precision mechanical links to connect the gun and sight. The equipment was procured from companies specializing in those technologies.

As performance requirements grew and electronic controls and linkages developed, the suppliers of these systems added electronics to their designs and provided "integrated" subsystems. And, as new functions were added, new electronics boxes were designed and procured. This was a reasonable technical approach because of the limitations and dedicated nature of analog electronics. From the subcontractor business perspective, it was desirable because of the value added to the product.

As a result of this heritage, it has been traditional in combat vehicles to procure the "intelligence" required for any point-of-need as a package with that item. Thus, power drives are "integrated" with gun and turret stabilization electronics, ballistic computation is in a separate box that is "integrated" with another control and display electronics box, and line of sight drives are "integrated" with sight stabilization electronics - to name a few.

The transition to digital technology that has been occuring in fire control, and will be accelerated by the BMS requirements, does not require this distribution of intelligence. And, in fact, the increasing need to access and share data across these subsystems makes it generally undesirable.

The development of an architecture for advanced FCS/BMS support in the M1A1 should include a re-examination of the traditional procurement partitioning in light of today's technology and system requirements. The familiarity of subcontractors with their traditional products and their desire to retain as much value-added on their side of the interface will usually make the near term costs favor retention of traditional responsibilities. However, the long term benefits of today's technology and anticipated growth may point to other approaches.

The problems associated with growth by "box proliferation" are well known in the defense industry, and include the following which are particularly significant to the M1A1:

Increased equipment weight and volume requirements

Communications and Cabling between subsystems

Maintenance and Training

Spares

Unnecessary redundancy of sensors

Difficult System integration

Bulky interconnections

Not suitable for graceful degradation

Poor framework for growth

Higher cost due to non-standardized components

The M1 has already reached an integration saturation point, and with the addition of BMS, it may be appropriate to undertake a more extensive near term design modification in order to avoid much larger problems in the future.

5.2 M1A1 FIRE CONTROL AND INTERFACES

It was established in preceeding sections that there is a strong and complementary relationship between fire control and vehicle-mounted BMS, and that the interfaces will become even more significant with the anticipated growth in both subsystems. Because of the large number of already fielded systems, any practical solution for implementing BMS and/or growth in fire control must evolve from the current FCS architecture.

This section describes the key characteristics of the M1A1 FCS (including CITV) that must be considered in selecting an architectural approach for BMS/FCS and growth. Since there is no BMS currently on the M1A1, it is not addressed here, although a summary of the preliminary requirements may be found in Section 5.3.

To maintain clarity, the fire control (pointing, moding, and control) functions are discussed separately from the operator interface characteristics (information display and control). Areas that will probably require change due to new requirements or for growth compatibility are also identified.

5.2.1 POINTING, MODING, AND CONTROL

Figures 5-1 and 5-2 illustrate the current fire control architecture for the M1A1 in azimuth and elevation, respectively.

The primary reference device for the M1A1 FCS is the gunner's primary sight (GPS), whose lines of sight are directed by a sighthead mirror and reticle drive assembly. The mirror is independently stabilized in elevation and mechanically linked to the turret in azimuth.

A digital computer calculates the weapon offset angles required to compensate for parallax, ballistics, and (in azimuth) target motion using range, cant, and crosswind data from automatic sensors together with manual inputs for other significant parameters. The computed angles are updated approximately 30 times per second and transmitted to external electronics for servo processing.

The digital computer (CEU) is based on the TI 9989 processor chip, is approximately 4" x 9" x 13" in size, and weighs slightly over 26 lbs. It contains 7 electronics boards - a CPU board, a ROM board, 4 I/O boards, and 1 for 9900-series chip maintenance functions. It was designed as a low cost solution to the M1 ballistic computation problem.

The gun and turret are controlled by electro-hydraulic servos. In elevation, the gun is controlled by a position servo. Resolvers measuring the LOS and gun elevation angles are electrically chained and routed to the turret networks box (TNB). An electronic circuit (DCT) in the turret networks box compares those relative angles to the commanded offset from the computer, and the difference is sent to the gun servo as an error signal. The gun servo then drives the gun to zero out this error, resulting in a continuous repositioning of the gun to the current commanded firing angle. Gyros and base motion sensors are included in the gun servo to improve the dynamic positioning accuracy while the vehicle is moving.

The turret is controlled in azimuth by a rate servo, and since the sighthead mirror is fixed, the turret servo also controls the nominal LOS in azimuth. Lead angles are implemented by moving the

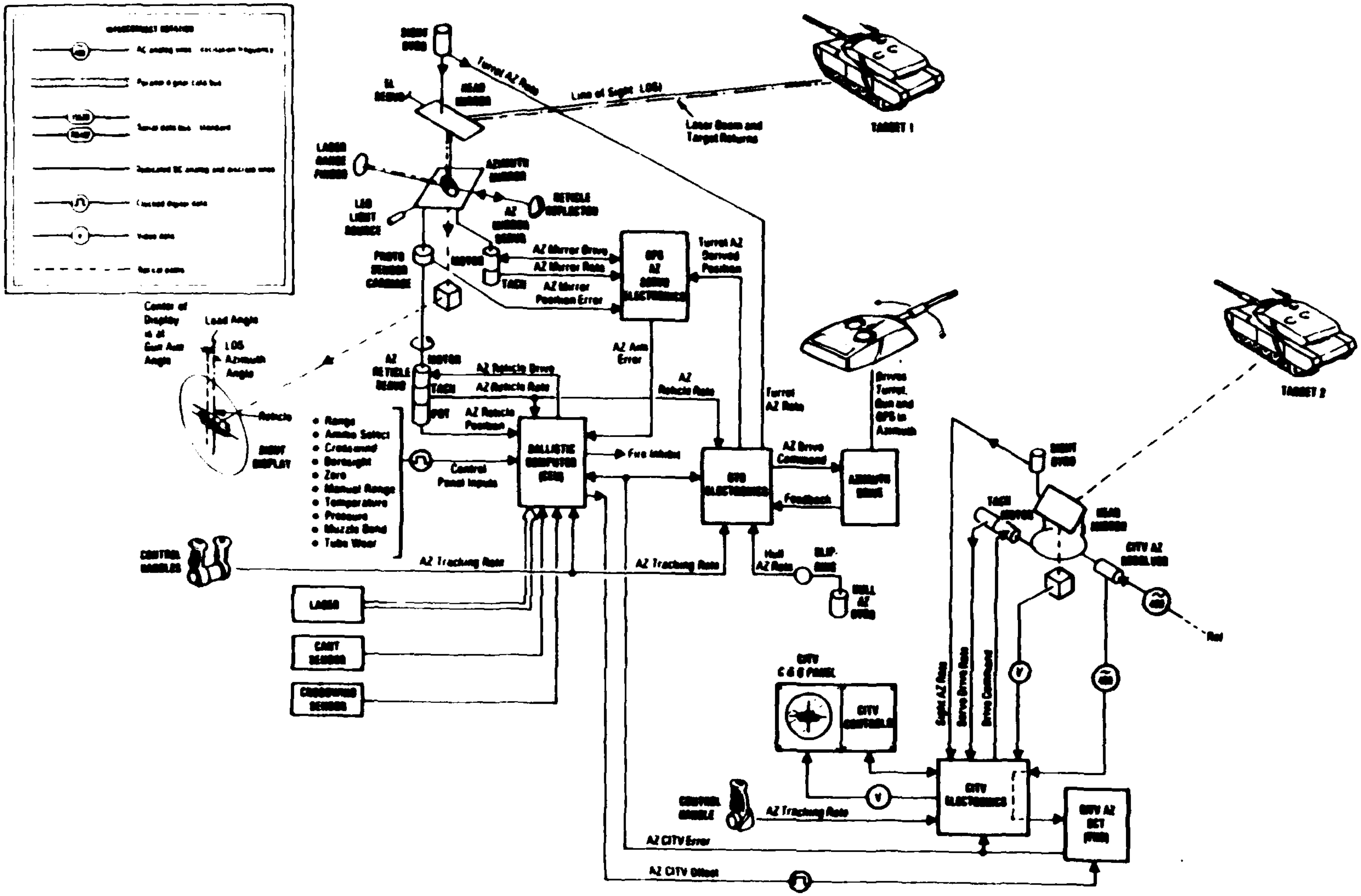


Figure 5-1. M1A1 Fire Control System (Azimuth)

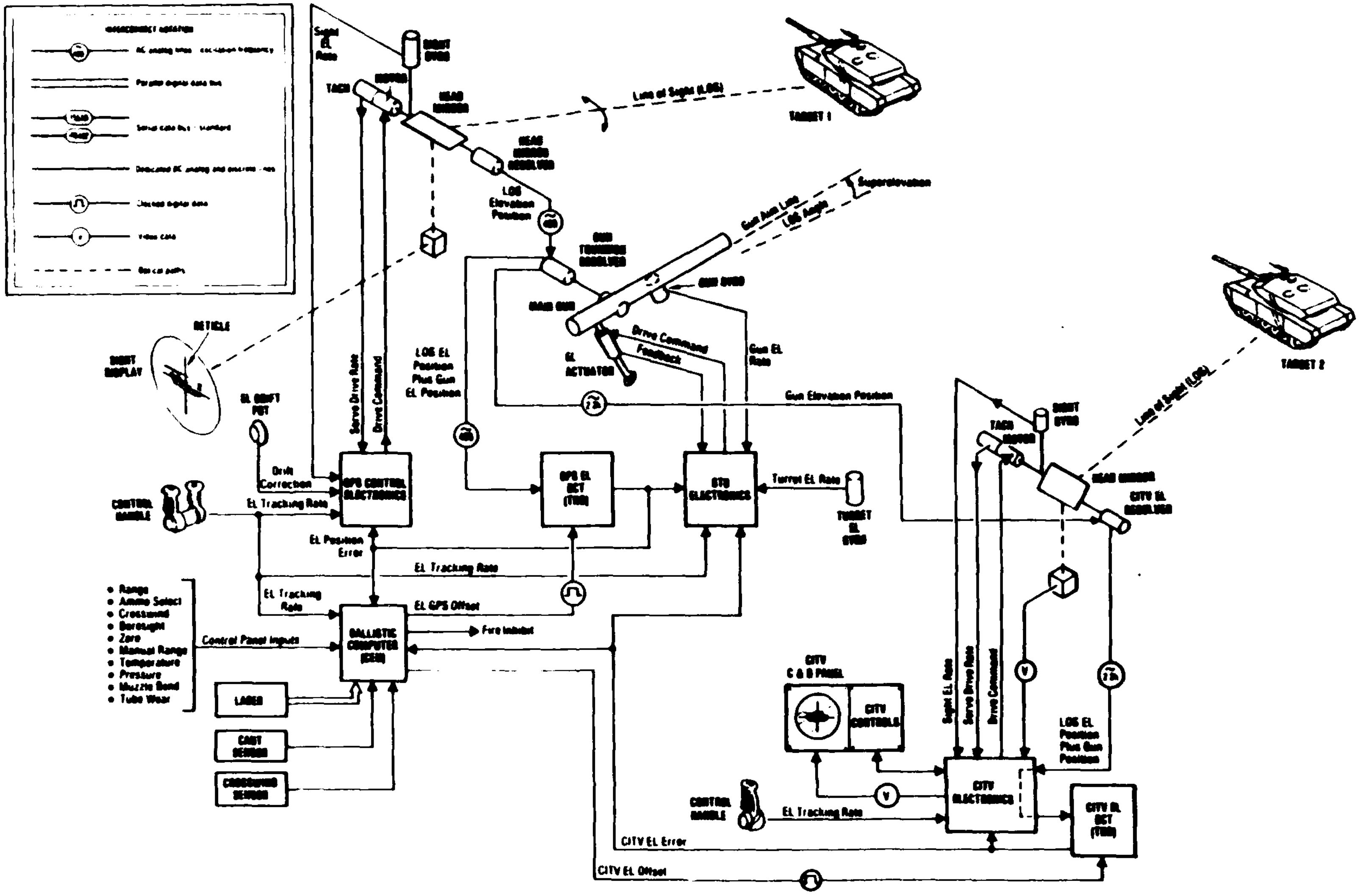


Figure 5-2. M1A1 Fire Control System (Elevation)

reticle within the sight field of view and counter rotating the turret (and sight field of view) to maintain the reticle on the target. Reticle dynamic accuracy under mobile operation is also improved by compensating for the measured turret stabilization error. The reticle drive computations are accomplished in the ballistic computer.

With the exception of the control panel inputs, laser range, and the offset commands, the FCS architecture is essentially a point-to-point analog interconnect. The gun, turret, and sight servos are mechanized as analog electronics. The operators' control handles are hardwired to the gun and sight control electronics. The cant and crosswind sensors are routed to the computer and converted to digital format for processing.

The above architecture is expanded with the addition of the Commander's Independent Thermal Viewer (CITV). The CITV is an independent sight which is controlled by its own two-axis (analog electronics) stabilization system. The system moding allows the CITV to operate independently, to be used as a gunsight, or to designate targets to gunner. When it is operating within the FCS structure, DCT-based position loops (similar to that for the GPS and gun in elevation) are established. To avoid ambiguity in elevation, a second frequency is added into the resolver chain.

As described, the FCS meets the documented performance requirements for the M1A1. However, there is little or no capacity for growth within the current architecture. The current ballistic computer cannot accept much additional sensor processing or substantially improved control algorithms due to throughput limitations of the processor technology being used. The analog compensation circuits for the gun and turret drives may not be adequate for anticipated growth in gun and turret unbalances. Finally, in an advanced turret (with BMS and other growth items) it may occupy too much space for the function provided.

The CITV has been specified to have a growth capability for interface to a MIL-STD-1553B data bus, although the specified data interface appears to be limited to image control and display functions.

5.2.2 INFORMATION DISPLAY AND CONTROL

The basic FCS control and display interface to the operators is quite straightforward, as illustrated in figure 5-3. GPS scene imagery from the day and thermal channels appear in the gunner's monocular eyepiece and is optically relayed to the commander's station via a GPS extension (GPSE). Thermal imagery from the CITV is combined with overlay symbology and presented to the commander on a biocular crt display. The gunner does not have access to this display. Control of the thermal imagers is provided through hard switches located on the GPS and on the CITV control/display box.

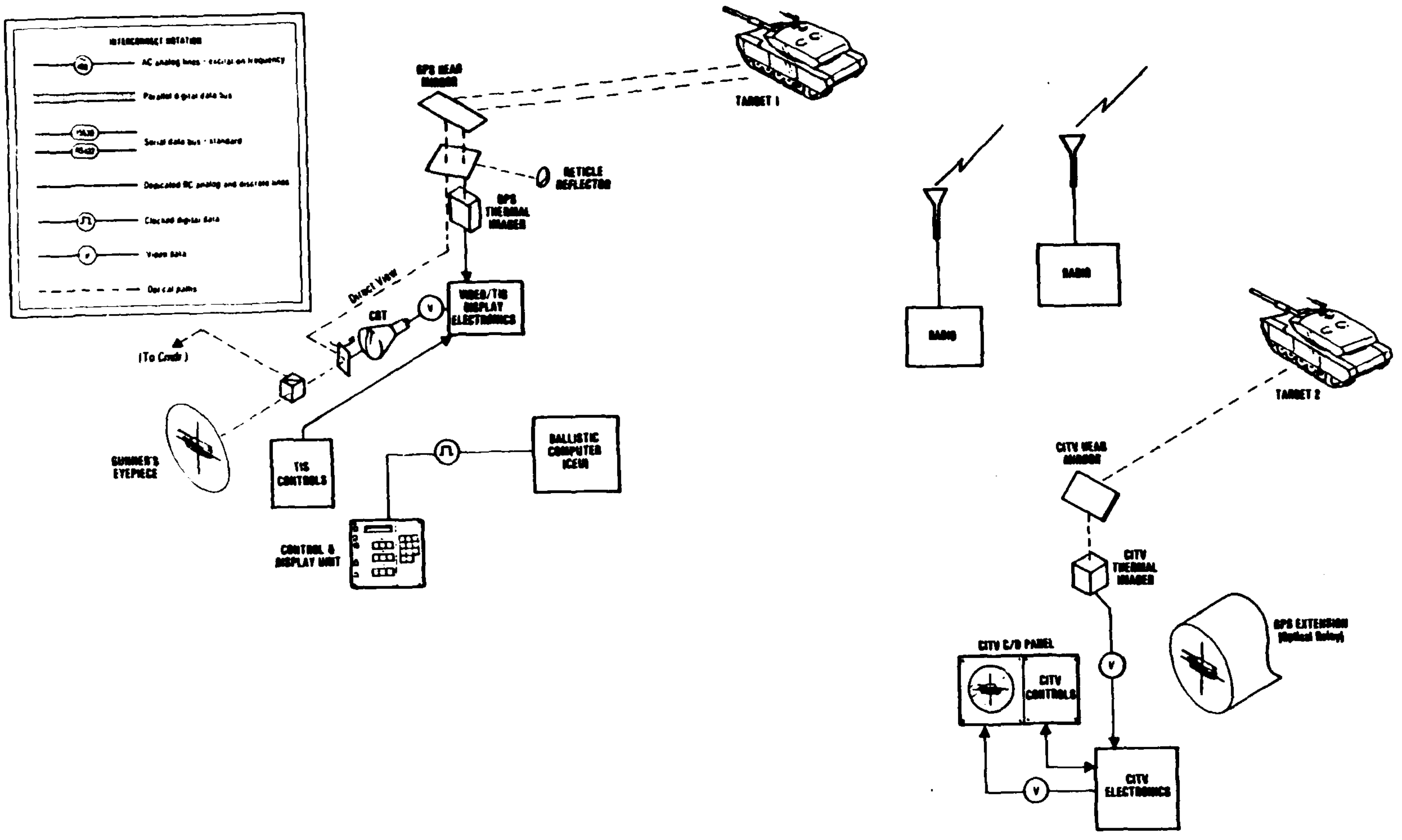


Figure 5-3. M1A1 FCS Operator Interface and Communications

The other major control interface to the FCS is through the computer control and display unit. This panel has a 5 character LED display, numeric keypad, toggle switches, and data select buttons. It is used to control the computer moding, as a control interface during system alignment and zeroing, and to manually insert data estimates for selected fire control parameters.

As currently configured, there is little flexibility in the control/display functions and formats that can be generated. However, Control Data Corporation has recently announced an improved version of the CDU that will provide considerably more flexibility, including (possibly) the ability to display limited BMS data at the gunner's station if the proper interfaces are included.

5.3 M1A1 BMS REQUIREMENTS

The M1A1 Block II Improvement Program (scheduled for production in 1988), has defined some preliminary requirements for a baseline vehicle-integrated BMS capability. These include:

- A Control and Display Panel, including a Video Display for sight imagery and Overlaid symbols, a Video Message Display, and a CITV Control System.
- A MIL-STD-1553 Data Bus with growth potential for remote terminals at all electro-mechanical tank subsystems.
- BMS interface via 1553 data bus to SINCGARS radio system.
- A Digital Map (cassette or video disk storage), and display
- A Heading Reference System
- Identification Friend or Foe System
- A coordinating Processor with growth capability

The following paragraphs briefly summarize the elements of the BMS as viewed in late 1985.

5.3.1 Control and Display Panel

The BMS display, operator input and control functions will be provided within this function. Extensive studies on the Soldier-Machine Interface including the display and control features have been recently performed at Ft. Knox. Features include:

- Video message display - for system prompts and communications with external elements
- Capability for Graphic, symbolic and alpha-numeric display and operator entry of drawings, symbols and text.

Selective control of system and display features to provide operator flexibility of use

5.3.2 Mil Std 1553 Data Bus

To provide an expansion path with flexibility for connection of system elements, a MIL-STD 1553 data bus has been specified for use in communication between BMS system elements, and for interfacing to other on-board systems. Section 4.2.2 of this report includes a discussion of Mil Std 1553 and other interconnection and networking systems. The stated intent is to "allow growth potential to interconnect via remote terminals to all electromechanical tank subsystems."

5.3.3 BMS interface via 1553 data bus to SINCGARS radio system.

SINCGARS radio systems are designated to receive and transmit data generated by or supplied to the vehicular BMS. The BMS system will include a 1553 data bus interface with SINCGARS and data formatting/buffer storage to facilitate data management. Data formats and multi-node net management studies shall be developed along with a digital data management study.

5.3.4 Digital Map (cassette or video disk storage), and display

On-board storage and display (via the BMS display) of digital maps are required. These digital maps, associated symbology overlays and text will form the bulk of BMS related displays and reports. Navigational and operational information shall appear on the display correctly scaled and positioned in respect to the map data. These maps shall provide different scale factors and the display system shall provide the flexibilty of selective display of desired features.

5.3.5 Heading Reference System

A navigational system capable of accepting digital data transmissions of position location or heading reference data from an accompanying unit or vehicle shall be provided. This system shall provide for the varying levels of on-board navigational equipment depending upon level of command and control. The resulting navigational information shall be displayable as required, and available to other BMS system elements.

5.3.6 Identification Friend or Foe System

A system providing identification of other combat vehicles on the battlefield as either friend or foe shall be supplied. It is desirable that the system be completely passive (no energy emission). Less desireable would be an active or an active/transponding cooperative system.

5.3.7 Coordinating Processor

A processing system which controls and coordinates the actions of all BMS system elements shall be provided. It shall include storage capacity for data generated by the above systems plus logistics, maintenance and additional operational information. Sufficient growth capability to handle expanded Data Bus vehicle management, enhanced BMS software, and future artificial intelligence applications shall be provided.

6. ARCHITECTURES FOR M1A1 FCS/BMS

This section describes alternative architectures for incorporating a BMS node into the M1A1. They are evaluated for near term impact and growth in both the BMS and FCS systems.

The architectures are presented in block diagram format and, for clarity, the pointing, moding and control aspects are discussed separately from the communications and information display and control.

Section 6.1 describes an "add-on BMS node" approach, which minimizes near term cost and design impact on the M1A1. It has capacity for growth within the BMS function, but does not address FCS issues, including growth or design changes that may be required as a result of armor and armament enhancements.

Section 6.2 describes an architecture that has greater near term impact on the M1A1 design. This system represents an integrated approach to FCS and BMS processing and addresses some near term fire control problems as well as the new BMS requirements. It is more growth oriented than the add-on BMS approach and provides a mechanism for FCS and BMS changes that will occur in the 3 to 5 year timeframe while retaining much of the current FCS structure.

Section 6.3 describes a bus-oriented approach, which will be required when the longer term performance and functional growth objectives become reality. It is structured around technology that is available today, but may not be cost effective to implement immediately. As shown, the system has the capability for large scale image processing in both the FCS and BMS. The transition from the previously described concepts to this structure is also discussed.

Section 6.4 summarizes the relative merits and shortcomings of each of the above approaches and establishes some recommendations for proceeding with this aspect of the M1A1 Block II program.

6.1 "ADD-ON" BMS NODE

This represents the lowest cost/risk approach for a near-term stand-alone BMS node, and is similar to the approach originally shown in the M1A1 Block II design and integration planning documents (ref. figure 6-1). This architecture addresses only the stand-alone BMS requirements, with the primary focus on the near term. As such, it minimizes the immediate impact on the M1A1 technical configuration and schedule.

The major shortcoming of this approach is that it is developed independent of fire control considerations and is not inherently compatible with expanding the BMS-FCS interfaces. From an integration point of view, this approach is straightforward, and assuming the required turret "real estate" is available, presents no significant technical problems or design impacts to the

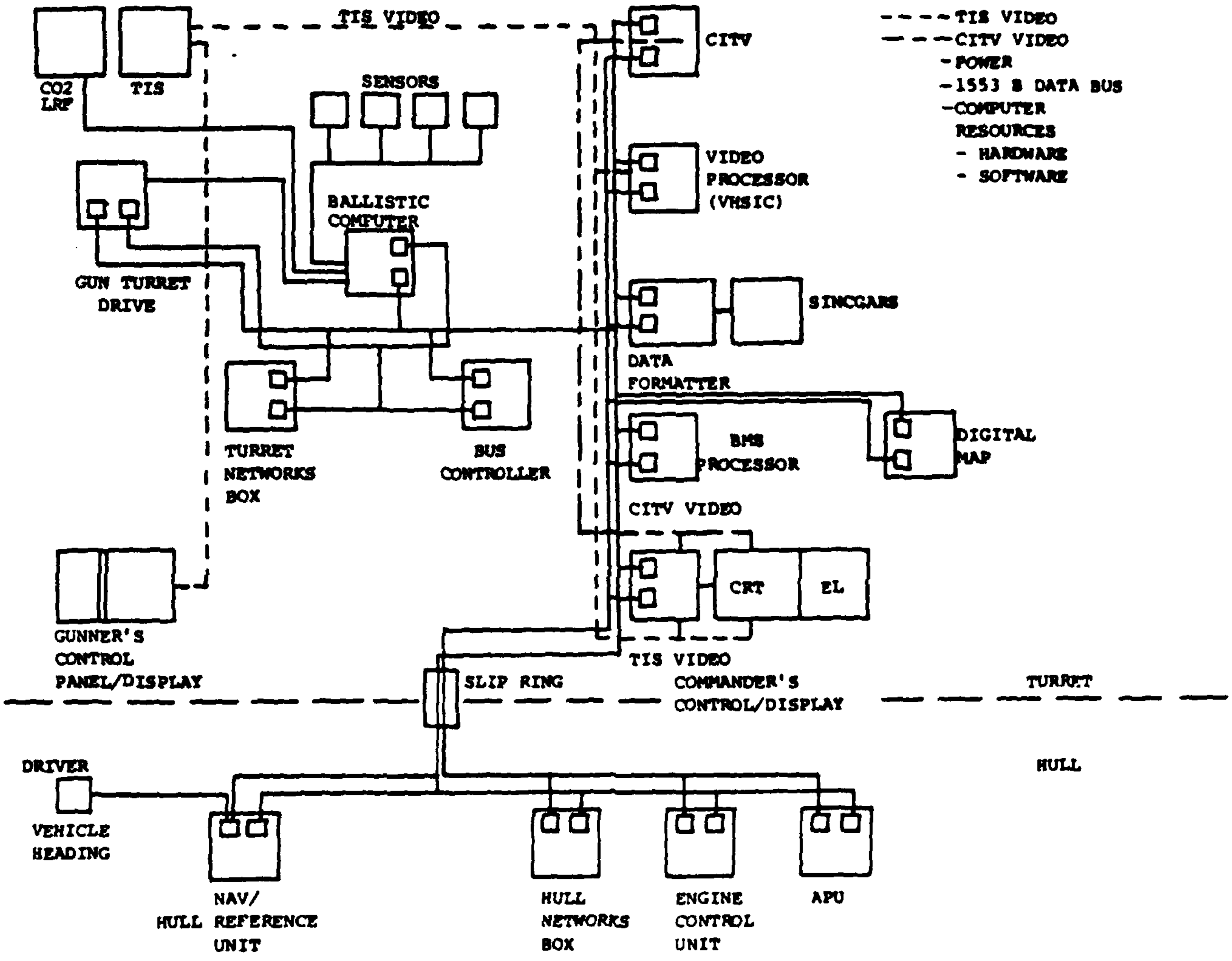


Figure 6-1. Initial BMS Module Concept

current interconnect.

However, it is reasonable to assume that fire control improvements will occur in the near future - most probably with respect to gun/turret stabilization (including barrel dynamics) and firing logic. Additionally, recent VHSIC insertion studies have shown that the ability to engage non-cooperative targets can be improved substantially with more sophisticated reticle control and lead computation. If the BMS and FCS architectures are developed independently, there is a high liklihood that the resulting turret electronics will be nonstandard, costly, unnecessarily complex, and very difficult to integrate.

6.1.1 POINTING, MODING AND CONTROL

Figures 6-2 and 6-3 illustrate the architectures for the Azimuth and Elevation channel pointing, moding, and control functions respectively.

The BMS interfaces to the FCS in only two places: a digital data link to the ballistic computer, which also interfaces to a heading reference unit, and a MIL-STD-1553B interface to the CITV electronics. Only the MIL-STD-1553B and heading reference unit interfaces affect the turret-based control functions.

It is assumed that the vehicle commander will have the capability to slew his CITV to a potential target location as shown on his BMS control/display screen. This architecture uses the 1553B interface capability of the CITV to provide that control function. Upon command from the BMS display, the BMS processor can calculate rates and durations required to slew the CITV to the desired heading. The required moding and tracking commands are then transmitted to the CITV, where its control system responds appropriately. With the addition of tracking commands to the block data list for the CITV 1553B interface specification, it appears that all of the required functions can be accomplished through this interface.

In all other respects, the FCS operates exactly the same as the current M1A1 FCS in both axes.

6.1.2 COMMUNICATIONS, INFORMATION DISPLAY AND CONTROL

The communications and information display architecture for this approach is shown in figure 6-4, together with the interfaces to control these functions. The operator interface to the BMS node occurs primarily through a touch-sensitive multi-function control and display panel, as described by the recent Fort Knox requirements study (ref. 1).

The BMS display is assumed to be a CRT, and is interfaced to the BMS processor through a direct video link and a serial digital line. Consideration was given to including a screen memory and all of the video refresh electronics in the display unit. Since the BMS displays change relatively slowly, this would allow the

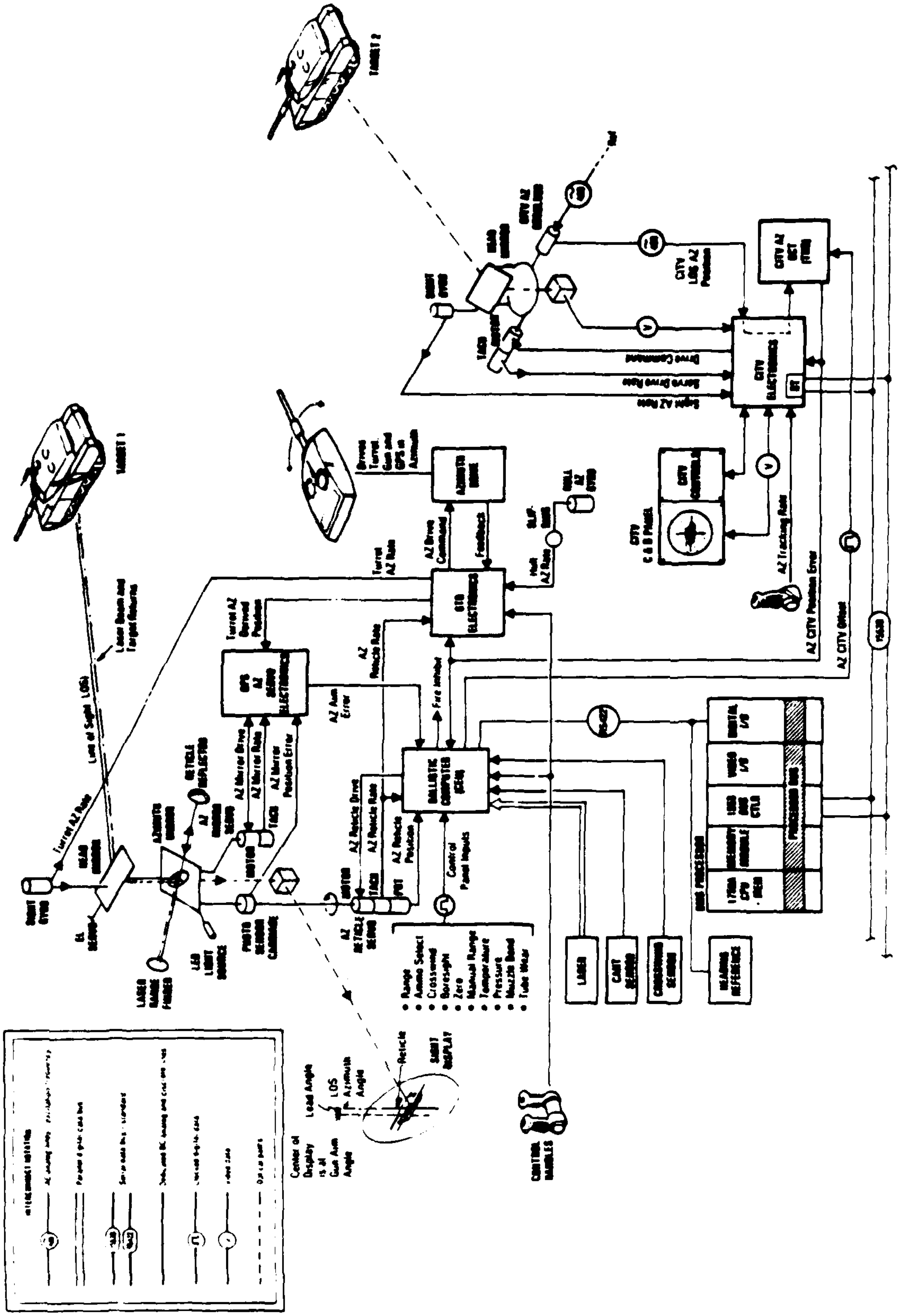


Figure 6-2. Add-On BMS Node (Azimuth)

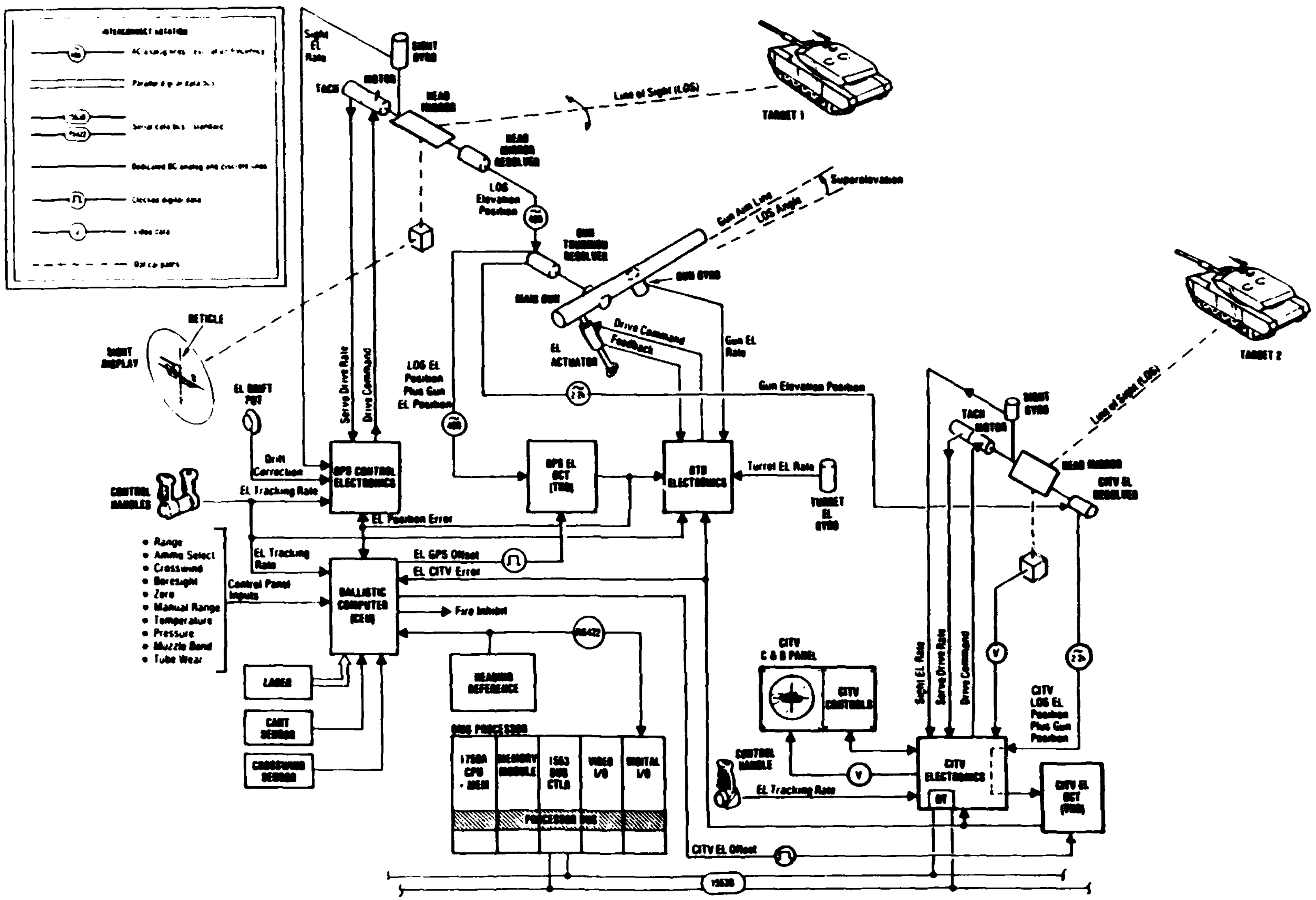


Figure 6-3. Add-On BMS Node (Elevation)

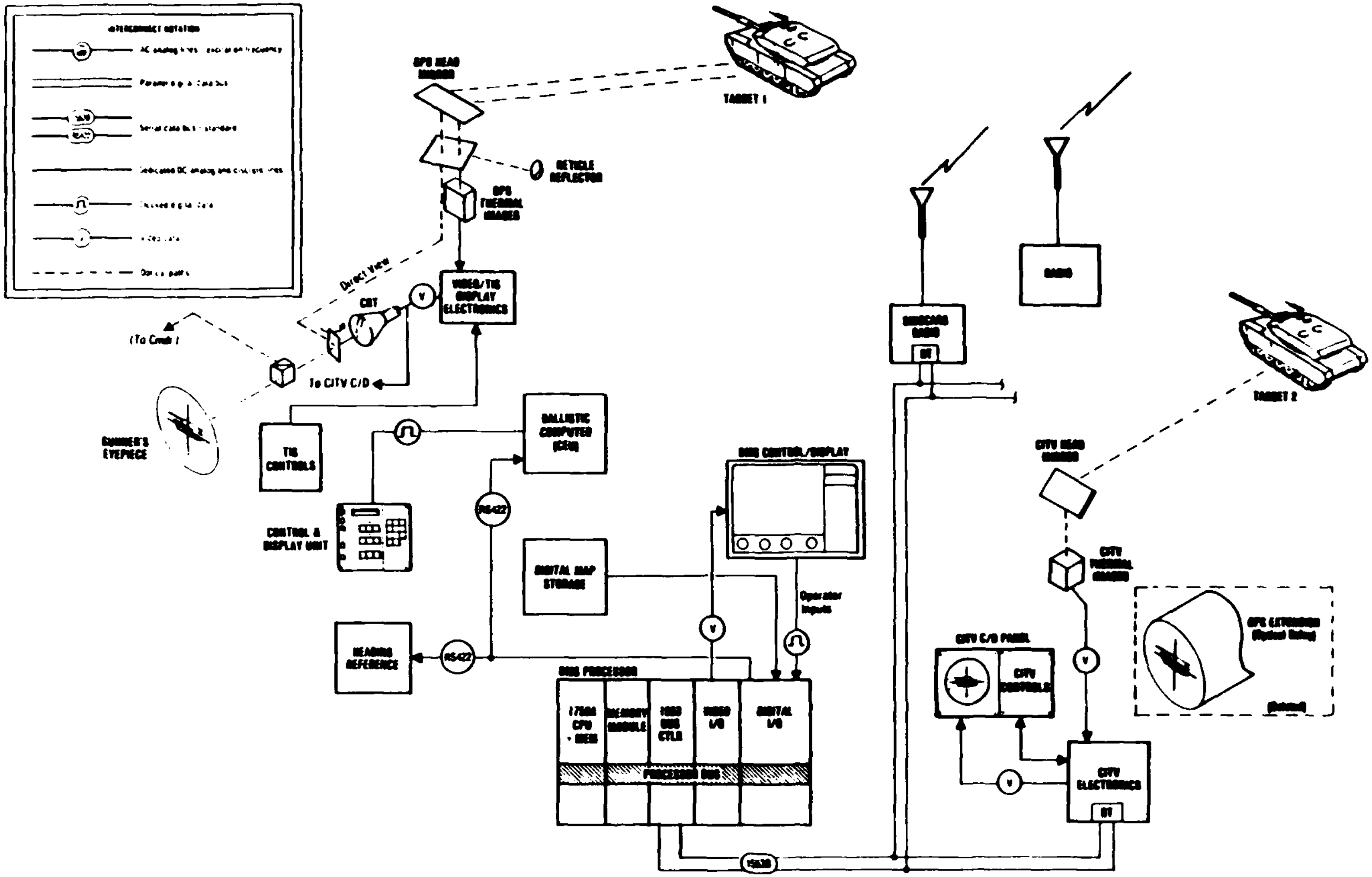


Figure 6-4. Add-On BMS Node Operator Interface and Communications

interface to the processor to become a simple digital link in which only changes to the display would be transmitted as required.

However, this could also limit the flexibility of the system. Specifically, the BMS display could serve as a backup for sight imagery as the system grows. This would require a video frame rate update of the entire screen. The routing of video data will be controlled by one of the primary computers that knows the complete system status and moding, and it appears that a straight video interface would be more straightforward and compatible with both operating modes.

Communications to BMS nodes on other vehicles is conducted through a SINCGARS radio which is interfaced to the BMS via the MIL-STD-1553B bus. Designation and monitoring of frequencies is accomplished through the display panel, and incoming message alerts are displayed on the panel.

Heading reference data for display and use in the CITV control function is derived from an RS-422 data link. A similar link is made to the ballistic computer to gain access to internal computer variables. Initially, it is anticipated that range data will be used for computing target location, and crosswind data may be used in conjunction with NBC detectors to report current and probable future contamination areas.

Digital terrain map data is available from a mass data storage device (e.g., ruggedized or laser disk). The BMS processor accesses portions of this data that are relevant to the current situation and moves them to a working memory, where they can be operated on for video overlay, scaling, and display processing.

The GPS TIS video data has also been routed to the CITV electronics for display to the commander upon selection. This capability alleviates the need to retain the current optical relay from the GPS to the commander's station, which in turn, frees up additional space for integrating the BMS control/display panel.

6.1.3 ELECTRONICS CHANGES

Table 6-1 summarizes the major electronics changes that would result from this architecture, using the M1A1 + CITV as a baseline. Because this is basically a standalone BMS add-on, the bulk of the electronics changes are related to the additional functions being implemented via BMS.

The only hardware changes of consequence to the current FCS electronics would be the addition of a digital data link to the ballistic computer, routing of the TIS video to the CITV display, and the implementation of the CITV 1553B interface, which was initially specified as a growth item for that device. Some minor reprogramming of the ballistic computer would also be required.

Table 6-1. Design Impact: Add-On BMS Node

ELECTRONICS UNIT	REQ'D FOR BASE BMS	GROWTH ORIENTED	CHANGES/REMARKS
Computer Electronics Unit	X		Add a digital data link (RS-422) to the BMS Processor
CITV Electronics	X		Activate the MIL-STD-1553B Interface and add tracking commands to the data block definition.
	X		Modify to accept and display GPS TIS video.
GPS TIS Electronics	X		Modify to send video signal to CITV electronics.
GTD Electronics			No Change.
BMS Processor Assembly	X		New electronics box - approximately 7"x7"x8" Contains CPU/Memory, dual 1553B controller, video and digital I/O.
MIL-STD-1553B Bus	X		New Interface - connects BMS processor, CITV, and SINCGARS radio.
Terrain Map Storage Device	X		New electronics box - 60 MByte video cassette or disk; Approximately 6"x12"x20" (assuming disk).
BMS Display & Control Panel	X		New Electronics box - Approximately 7.5"x7.5"x12" (Assumes minimum CRT configuration)
Heading Reference Unit	X		New Electronics box

The BMS processor is a new electronics assembly which reflects design standards that will maximize its compatibility with functional growth and VHSIC insertion. It will also be able to take advantage of other processor module developments within the tri-services as they become available.

Three primary standards have been assumed for this assembly:

(1) 1750A DoD standard Instruction Set Architecture

(2) IBUS compatible interconnect between the card modules

(3) SEM-E electronic module packaging format

For simplicity, the power conditioning module has not been shown in the system block diagrams. In addition to that, the processor assembly consists of the following electronic modules:

1750A CPU + Memory Module

This is a single card module containing the 1750A CPU, 256 K-words of RAM, and an IBUS control interface. It is assumed to be based on VLSI technology and have a nominal throughput of 1 MIP.

Global Memory Module

This is a single card containing non-volatile electrically alterable memory.

Dual 1553B Bus Controller

This is a single card capable of controlling two dual-redundant 1553B data buses. Only one of the interfaces is active in this configuration.

Video Board

Converts BMS display data to standard composite video format for routing to the BMS display.

Digital I/O Board

Contains serial digital interfaces (RS422) for interfacing to the ballistic computer heading reference, and BMS display units.

The cards are mounted in an expansion chassis (which may contain empty slots for growth) and are connected through backplane wiring. The IBUS compatibility will allow the addition or replacement of existing cards with VHSIC modules when the need arises. The SEM-E format was selected because it appears to be the focal point of several development programs and is compatible with efficient packaging of all of the electronics technologies of concern to this study.

The "Add-On" BMS Node approach does not result in the elimination of any of the existing turret electronics boxes. The changes required on existing boxes should not affect their space claim. The net change in turret stowage, then is the addition of a BMS processor (approx. 7"x7"x8"), a BMS display unit (approx. 7.5"x7.5"x12"), a heading reference unit, and a digital map storage device (approx. 6"x12"x20") - plus the associated interconnect.

6.2 BASELINE INTEGRATED FCS/BMS

This architecture is designed to provide growth capability while minimizing impact on the current electronics boxes. It establishes a baseline from which the high probability FCS and BMS growth paths can be most easily implemented as the required technology matures. It is based on a multi-processor expandable computer assembly housing Standard Electronic Modules and standardized module interface.

This approach reduces the volume occupied by the BMS and FCS electronics elements by integrating both computing functions into a single assembly and employing sensor sharing where possible. The near term impact of this on the M1A1 system design is more substantial than the Add-On BMS approach described above, although the overall technical risk is low.

To maximize flexibility, the proposed processor approach uses the same MIL-STD-1750A computer architecture and packaging concept described above. The chassis is plug-compatible between VLSI and VHSIC technology, and can accept additional modules as system needs grow. The processor assembly concept is compatible with the requirements established in the ARDC-sponsored Common Module Fire Control Study.

The processor uses essentially the same modules as described in the preceeding section, except that it requires the addition of an analog I/O module and uses one additional CPU/Memory module due to the additional computational load for fire control functions.

This architecture brings all major data and control signals directly to the processor assembly. Multiple CPU's are operating within the assembly, and each can access a global (shared) memory and any of the I/O modules as required. All of the modules are interconnected by dual redundant high speed internal buses (IBUS) in the chassis backplane.

There are several significant advantages to this architectural approach:

1. This configuration will be low risk and occupy the least volume for a given level of system computation and memory requirements.

2. Sensor data sharing between various fire control and BMS functions is facilitated. This reduces the number of sensors and net volume occupied by them in the system.

3. Multi-processors plus the availability of all data through the intermodule bus and shared memory provides full computational redundancy for all functions.

4. The standards imposed on this design make it plug compatible with ongoing VHSIC developments. Thus, computation growth can be accomplished by straight module replacement, with no external system impact. The non-proprietary internal bus structure will allow open competitive procurement at the module level.

5. If required, physical expansion of the assembly can be accomplished by initially providing empty module slots or by transferring the modules to a chassis with additional slots and adding the required modules.

The major disadvantage of this architecture from an integration point of view is the requirement for parallel routing of a relatively large number of signals to the processor assembly. The requirement for the baseline system does not appear to be excessive, however. The current M1A1 CEU interface includes 7 dc analog signals and approximately 50 logic level lines. This approach will result in an additional 11 input and 5 output analog signals at the processor interface. Some additional logic level lines will also be required.

On a new system design, the generally preferred approach would be to collect the various signals at other points in the system, format convert them as necessary, and route them to the processor via a data bus or dedicated digital interface. This was not selected in this baseline because (1) the design impact on other subsystems would be greater, (2) there is currently no bus in place on the vehicle that could be adapted for this, and (3) the cost of providing sufficient bus capacity and new interfaces for the major electronics boxes appears to be quite high.

However, as requirements grow, bus technology advances, and Vetronics becomes a reality, conversion to a bus-based control structure must occur, and the impact on the processor [illegible] minimal. In essence, the analog I/O module will be replaced [illegible] bus interface module meeting the external and internal [illegible] standards. This is discussed further in section 6.3

6.2.1 POINTING, MODING, AND CONTROL

The azimuth and elevation channel pointing [illegible] architecture for this approach are illustrated [illegible] 6-5, respectively.

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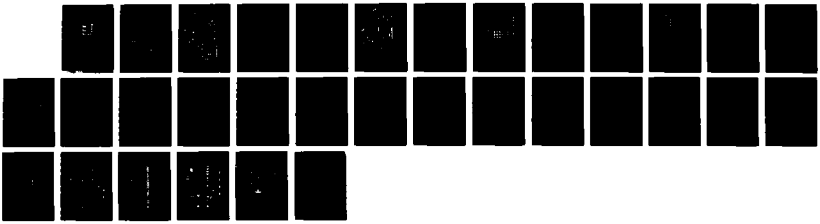

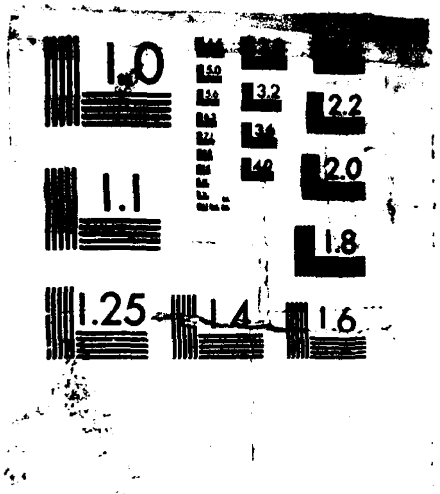

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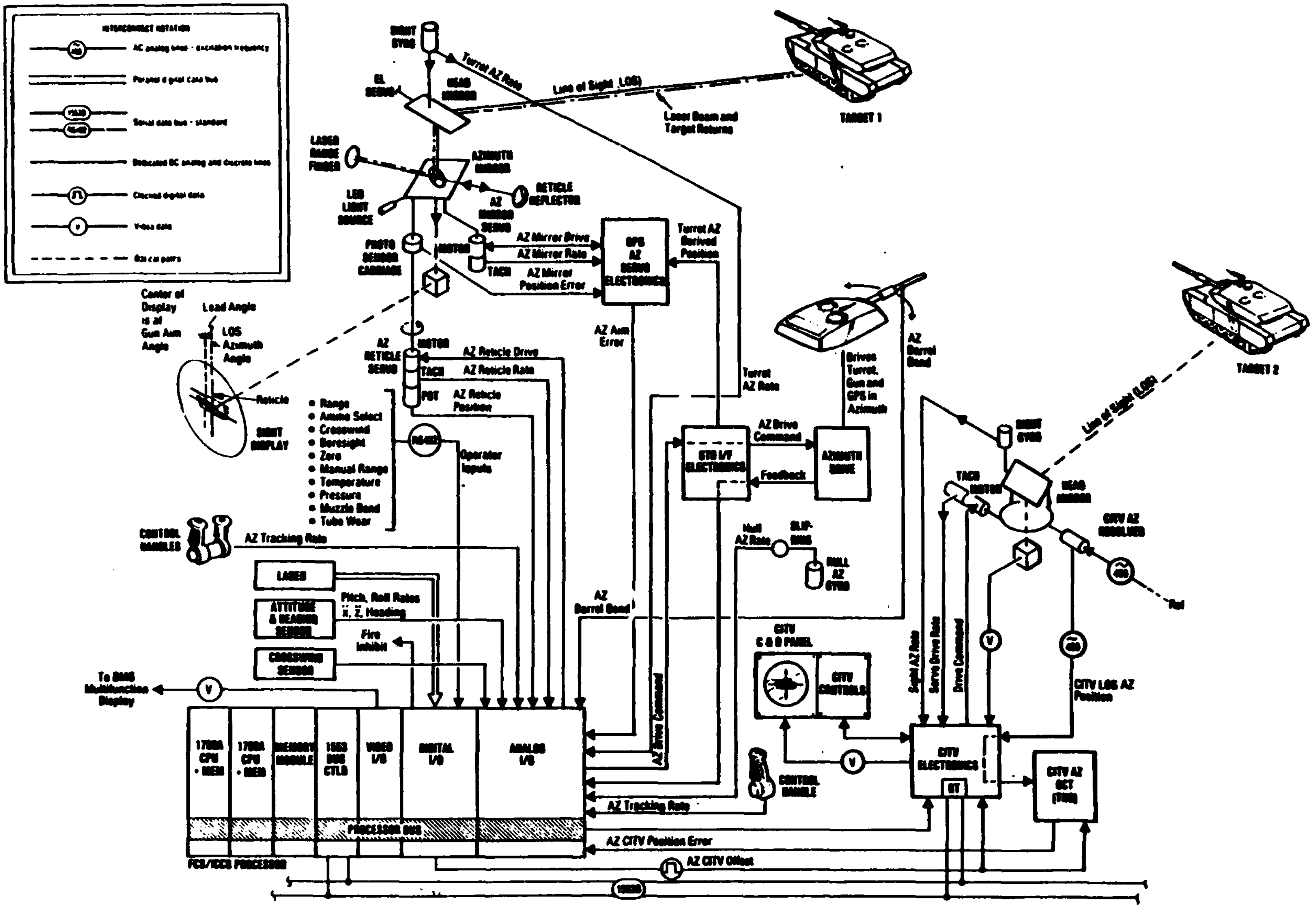


Figure 6-5. Baseline Integrated FCS/BMS (Azimuth)

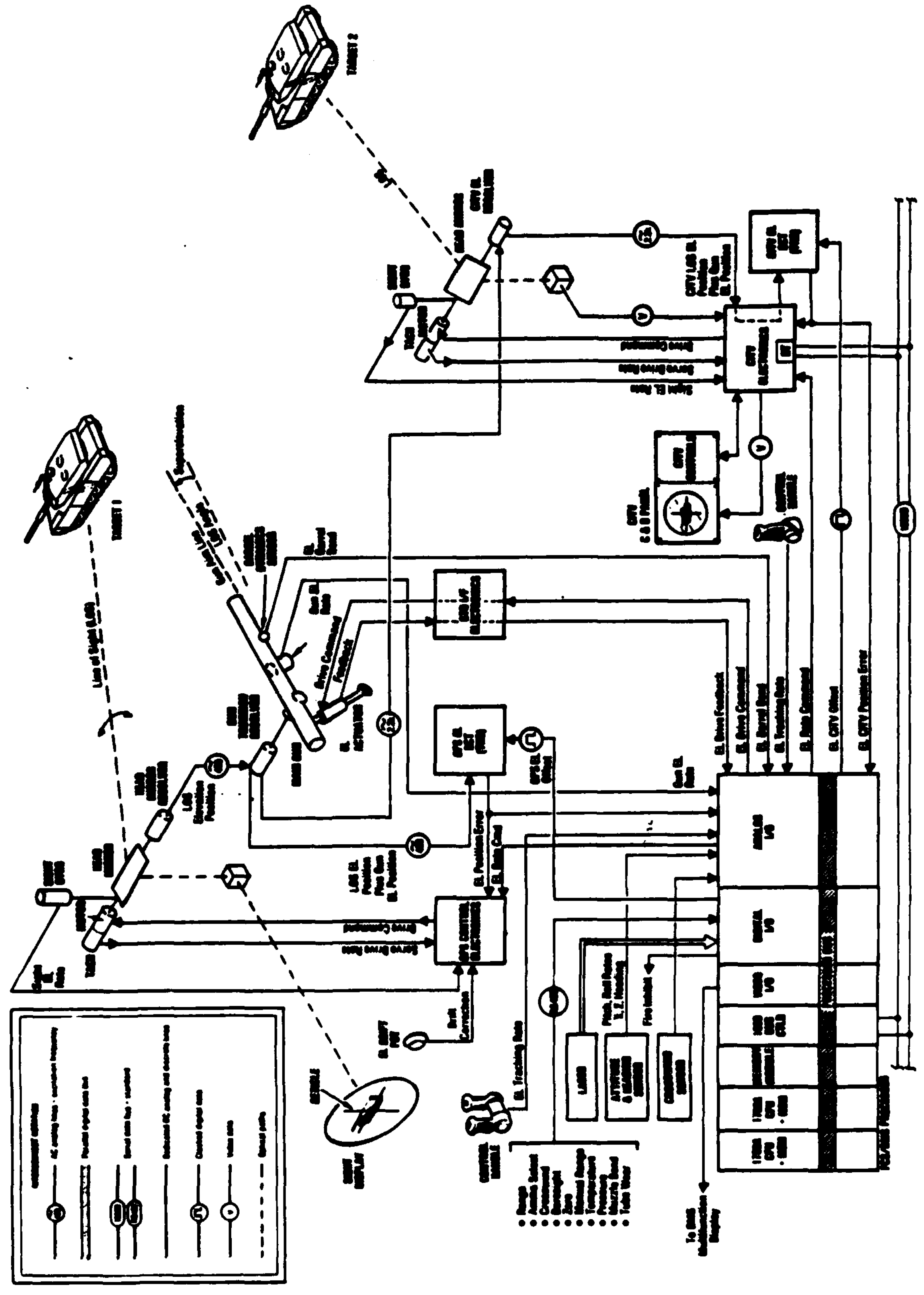


Figure 6-6. Baseline Integrated FCS/BMS (Elevation)

There are some fundamental changes in the implementation of the FCS control functions relative to the current M1A1:

Tracking Command Interface

The commander and gunner control handle tracking commands are routed to the computer, which formats and adjusts them as appropriate before routing them to the GPS or CITV. This approach allows sensitivity to be adjusted as a function of vehicle dynamics and provides an interface for a variety of tracking aids, including linear motion compensation and automatic target tracking.

This also provides a direct access for command response of the sights to stimuli from other subsystems such as the BMS. This interface, for example, would allow the GPS to be slewed directly to a target known to the BMS, without the need to bring the CITV to bear first.

Sensor and Control Interfaces

The analog interfaces to current sensors and control electronics are retained along with the current (resolver chain) sight-to-gun position references and DCT's (Digital Control Transformer's). The performance of these elements is adequate, and the technical and cost risks of converting them to data bus formats with sufficient throughput capability are quite high. The required analog/digital/analog conversions are accomplished in the interface electronics of the FCS/BMS processor.

Stabilization and Line of Fire Control

The sight stabilization electronics remain unchanged. However, improved reticle control algorithms will be implemented in the FCS/BMS processor.

The gun and turret stabilization function has been digitized and integrated into the FCS/BMS processor. This is in response to the need for improved control algorithms to offset the destabilizing effects of improved main armament and higher armor protection levels.

Gun Barrel Bend

The current manual muzzle reference system is supplemented or replaced with a barrel dynamics sensor. If the strain gauge technology currently employed in the Ballistic Research Labs PATS program proves to provide consistent static as well as dynamic data, the current MRS could be eliminated.

Static barrel bend is used to automatically compensate system alignment for changes induced by thermal stress. Dynamic barrel bend is used for stabilization and to compute optimum firing opportunities.

Turret Orientation and Dynamics

A single (new) sensor package is employed to support attitude, heading, ballistics, and stabilization computations. In addition to providing data required by BMS and improved FCS, this allows the elimination of the current static cant sensor and turret pitch rate gyro. For fire control, this provides a dual purpose: (1) it provides dynamic cant and pitch information for ballistic compensation and attitude reference, and (2) it provides turret pitch and roll rates and vertical and lateral acceleration measurements for weapon stabilization. The acceleration measurements are used to compensate the increased unbalances due to enhanced weapons and armor. The turret rates are used for base motion bucking and roll rate compensation.

For BMS purposes this sensor provides the required heading and attitude information for referencing to situation displays and targeting information. In some vehicles, this data can be processing in conjunction with other sensors to provide a complete position location (navigation) capability.

The processing required to convert the basic sensor data into attitude, heading, etc. is resident to the FCS/BMS primary processor.

6.2.2 COMMUNICATIONS, INFORMATION DISPLAY AND CONTROL

The communications architecture for this system is shown in figure 6-7 and is identical to that described in the preceding section, with the processor interface to SINCGARS being through a MIL-STD-1553B data bus.

Similarly, the operator's interface to the BMS functions is via the same multi-function control and display panel. In conjunction with the replacement of the current ballistic computer, however, the gunner's computer control panel has been upgraded to a multi-line electro-luminescent design, as recently shown by Control Data Corporation (figure 6-8). This substantially increases the flexibility of information presentation to the gunner and, as implemented, allows this same equipment to be used for displaying alphanumeric BMS data at the gunner's station.

6.2.3 ELECTRONICS CHANGES

Table 6-2 summarizes the electronics and interconnect changes that would result from this architectural approach. The assumed baseline is M1A1 + CITV as described in section 5.2. Relative to the previously described add-on BMS approach, the major additional changes here relate to removal of the current ballistic computer, digitizing the gun/turret control laws, replacing some sensors with higher performance multi-function elements, and integration of the new software.

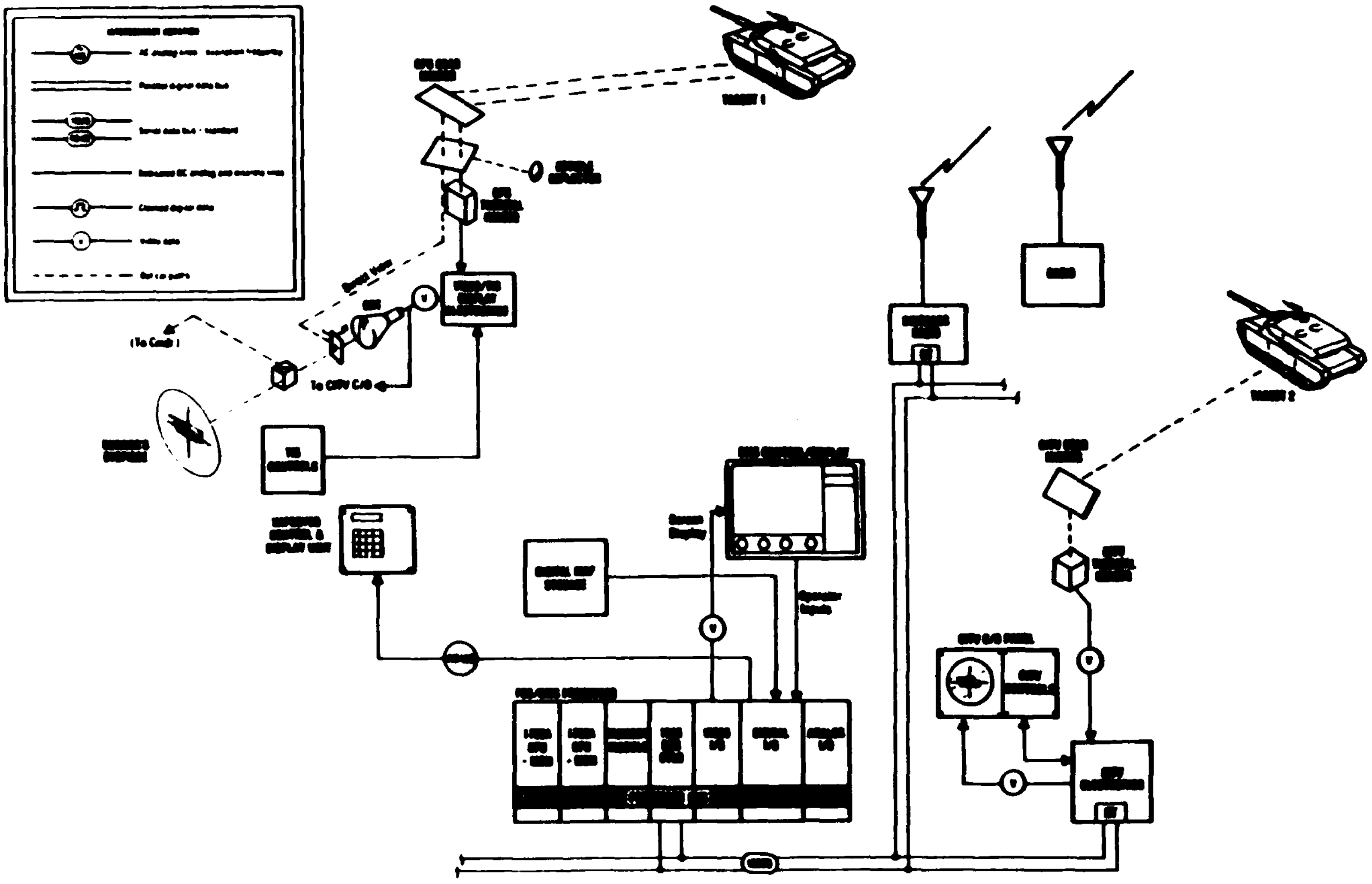


Figure 6-7. Baseline Integrated FCS/BMS Operator Interface and Communication

Table 6-2. Design Impact: Baseline Integrated FCS/BMS

ELECTRONICS UNIT	REQ'D FOR BASE BMS	GROWTH ORIENTED	CHANGES/REMARKS
Computer Electronics Unit		X	Replaced by FCS/ICCS Processor.
Computer Display Panel		X	New design - based on CDC improved CCP concept. RS-422 interface to FCS/ICCS processor. Use for both FCS and BMS data display.
CITV Electronics	X		Activate the MIL-STD-1553B interface and add tracking commands to the data block definition.
	X		Modify to accept and display GPS TIS video; Accept tracking commands from computer.
GPS TIS Electronics	X		Modify to send video signal to CITV electronics; Accept tracking commands from computer.
GTD Electronics		X	Simplify - remove compensation and switching electronics.
Hull Rate Gyro		X	Reroute to FCS/ICCS processor.
Turret Pitch Rate Gyro		X	Eliminated.
Cant Sensor		X	Eliminated.
Muzzle Reference System		X	Add dynamic muzzle reference sensor and route signals to FCS/ICCS processor.
FCS/ICCS Processor Assembly	X	X	New electronics box - approximately 7"x7"x10". Contains CPU/Memory, dual 1553B controller, video and digital I/O, analog I/O.
MIL-STD-1553B Bus	X		New interface - connects BMS processor, CITV, and SINCGARS radio.
Terrain Map Storage Device	X		New electronics box - 60 MByte video cassette or disk; Approximately 6"x12"x20" (assuming disk).
BMS Display & Control Panel	X		New Electronics box - Approximately 7.5"x7.5"x12" (Assumes minimum CRT configuration)
Attitude & Heading Reference Unit	X	X	New Electronics box - Route signals to FCS/ICCS processor.

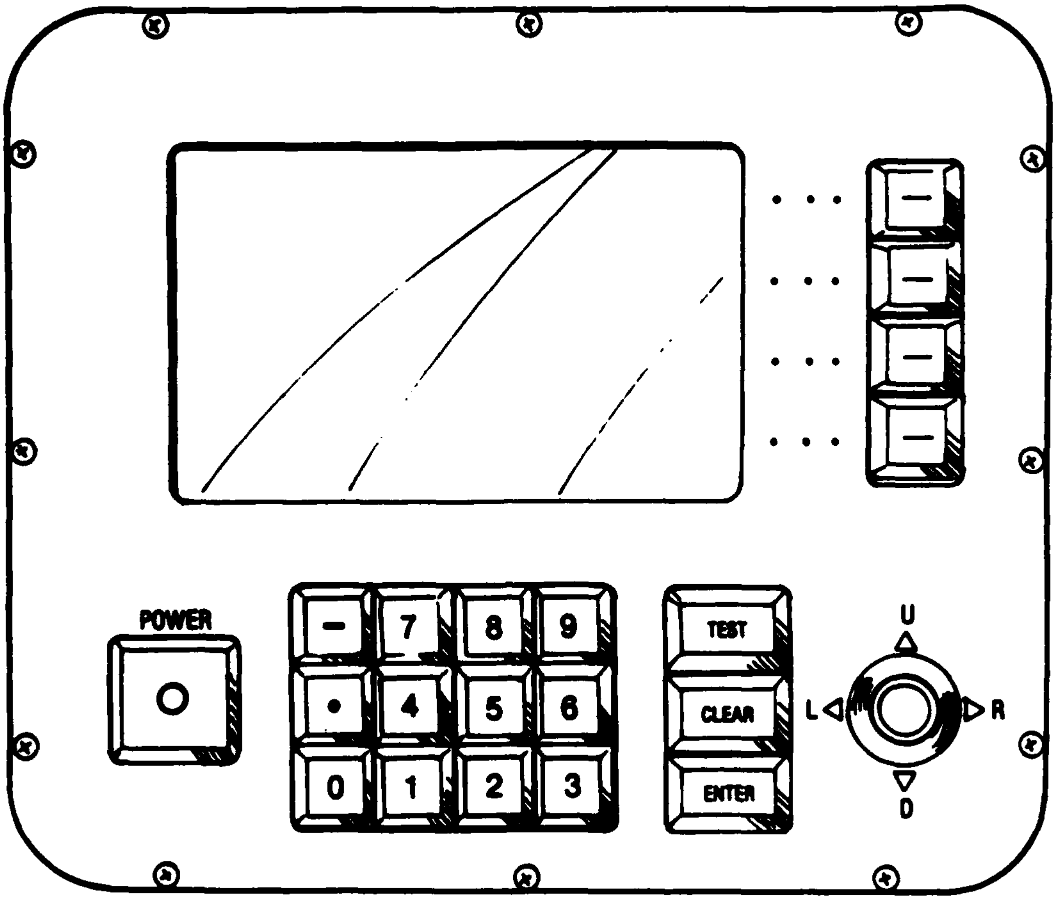


Figure 6-8. Improved Computer Control Panel

The current fire control computer system is replaced. The current interfaces to the computer remain much the same, but have been expanded to include required gun/turret drive signals and heading reference. The turret pitch gyro and cant sensor have been eliminated because the required data can be derived from the Heading and Attitude Reference sensor.

The FCS/BMS processor is an expansion chassis, mounting backplane connected standard electronic modules. Internal interconnect is through redundant intermodule busses. This was described in more detail in section 5.1.

The Attitude and Heading Reference electronics box contains only the sensors and signal interface electronics. The computation functions normally contained in a standalone system have been incorporated into the FCS/BMS processor to reduce space requirements and provide redundancy.

6.3 GROWTH AND BUS-ORIENTED ARCHITECTURES

The architectures discussed in the preceeding sections have been oriented primarily to the near term requirements for the BMS and FCS, with different levels of consideration for growth. However, an underlying objective was to limit the impact on system electronics and interfaces external to the digital processing functions. It can be seen that, even with only minor growth in capability, the ripple effects through the current system architecture can be substantial. Thus, the attempt was to examine compromises that did not preclude orderly growth while minimizing near term cost and risk.

In the long term, there will be substantial performance growth in both the FCS and the BMS. This will come primarily in the form of more sophisticated processing of data that will already be available on the vehicle (although not necessarily previously available to a computer). Thus, the physical system growth will be largely reflected in expanded data flow and greater computational throughput.

In the FCS, much of the growth will focus on video data processing to further automate the detection, acquisition, and engagement of individual targets. It will include automated search, detection, and cueing of targets; automatic handoff and tracking through the gunsight; and image processing for IFF and damage assessment. In the BMS, there will be substantial increases in the volume of communications, the automation of status and logistics reporting, the development of 3-dimensional battlefield and line-of-sight representations, and the application of artificial intelligence for decision aiding and situation assessment.

The growth in computational throughput associated with these functions can only be realized through the use of VHSIC technology. Both the FCS and BMS will require this technology to achieve the performance levels described above, and there will be substantial sharing of data between the two functions.

This section illustrates a system architecture that is compatible with these high performance levels. It is an upward extension of the system described in section 6.2, and it employs a representative Vetronics-type data bus interconnect in order to show how a near term solution could evolve into such an architecture.

The system described here operates using two primary processors that are VHSIC extensions of those described in the preceeding sections. The module interconnect and physical form factors are identical to those described earlier. The physical configurations of the two processors are identical, and although one is nominally focused on BMS processing and the other on FCS processing, each is capable of performing the other's functions if required.

System control and data distribution occurs through three types of buses. The MIL-STD-1553B bus is used to communicate with the radio nets as in the previously described systems. Depending upon the volume of communication, two separate dual-bus configurations may be required. However, the required controllers for a second bus already exist in the 1553B processor modules, so this would not require additional processor hardware.

Tho video and data buses are patterned after the corresponding elements in a Vetronics concept currently being developed by Texas Instruments. The data bus interface (DBIF) and video bus interface (VBIF) are also assumed to be functionally equivalent to those described by Texas Instruments in reference 10 and illustrated in figures 6-9 and 6-10, which are reproduced from that report. Although specific design characteristics of the FMC Vetronics system differ from this, they are functionally equivalent. Therefore, this concept would be usable with either Vetronics approach.

The DBIF consists of the hardware required to interface with an IEEE 802.5 standard data bus, a host processor, and signal interfaces for other equipment typically used in combat vehicles. It has the capability to reroute signals on the dual ring, bi-directional bus for survivability enhancement. The VBIF can either receive or transmit data to a video data bus operating at 140 MHz. It operates as a repeater on the bus and can reroute data in the same manner as the DBIF.

As illustrated in Figures 6-11 through 6-13, these data bus interface modules, which can be packaged as a single electronics card in the SEM-E format discussed earlier, are used for signal interface and distribution at the major FCS/BMS subsystems.

Functionally, this system differs from the previous system in that a significant video processing capability has been added. VHSIC video processors (consisting of an array processor plus a 1750A scalar processor) have been added to provide capabilities for automatic target search, cueing, and tracking using the video data from either sight and for generating battlefield perspective views for BMS. These functions can be handled in either the primary FCS processor or the primary BMS processor, depending upon equipment status and system moding.

The azimuth and elevation channel pointing, moding, and control architectures are illustrated in figures 6-11 and 6-12, respectively.

Functionally, the control interfaces for both channels are identical to those described in the preceeding section. However, rather than being routed to and from the processor assembly in their natural format, the interface signals for each subsystem are converted in the DBIF and transmitted via the data bus. Electronics and control interfaces within the sighting and gun drive systems remain as described in section 6.2.

Figure 6-9. Data Bus Interface

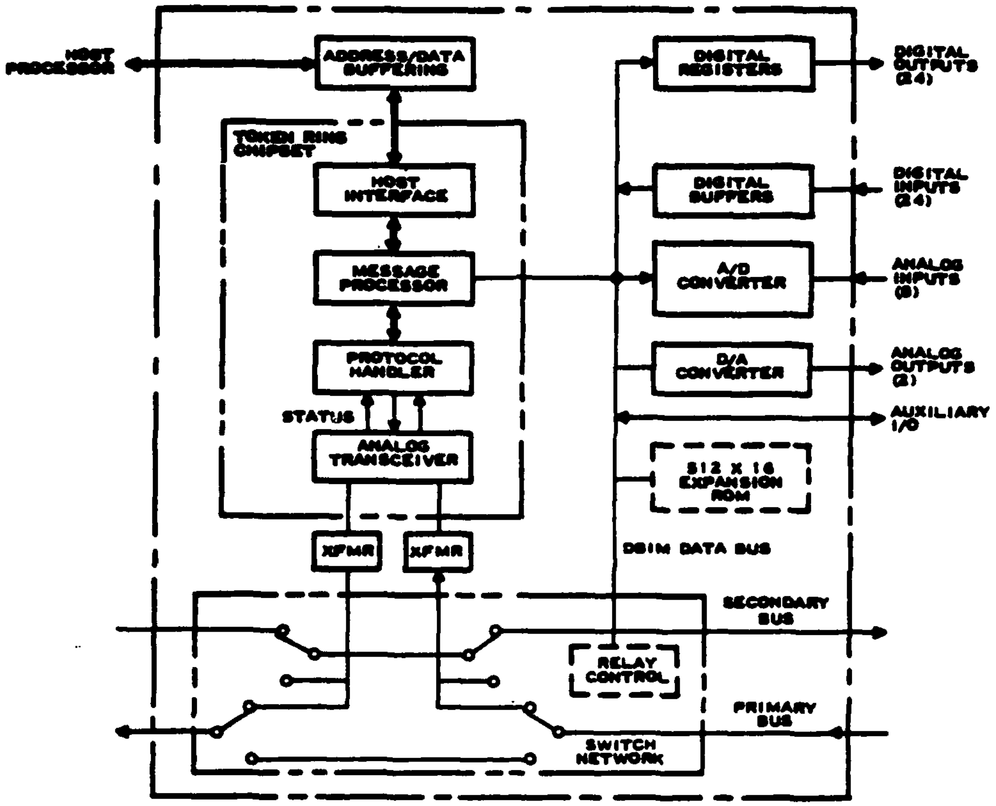
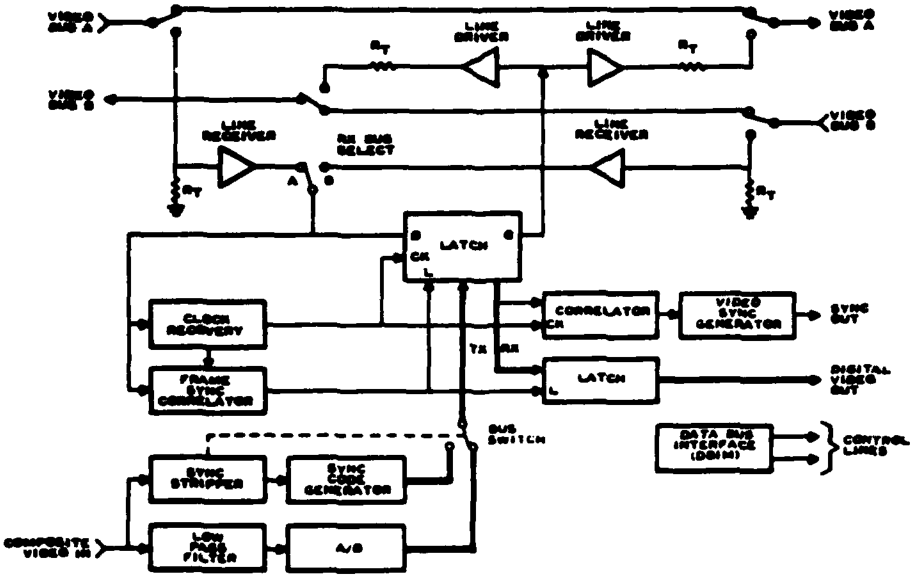


Figure 6-10. Video Bus Interface



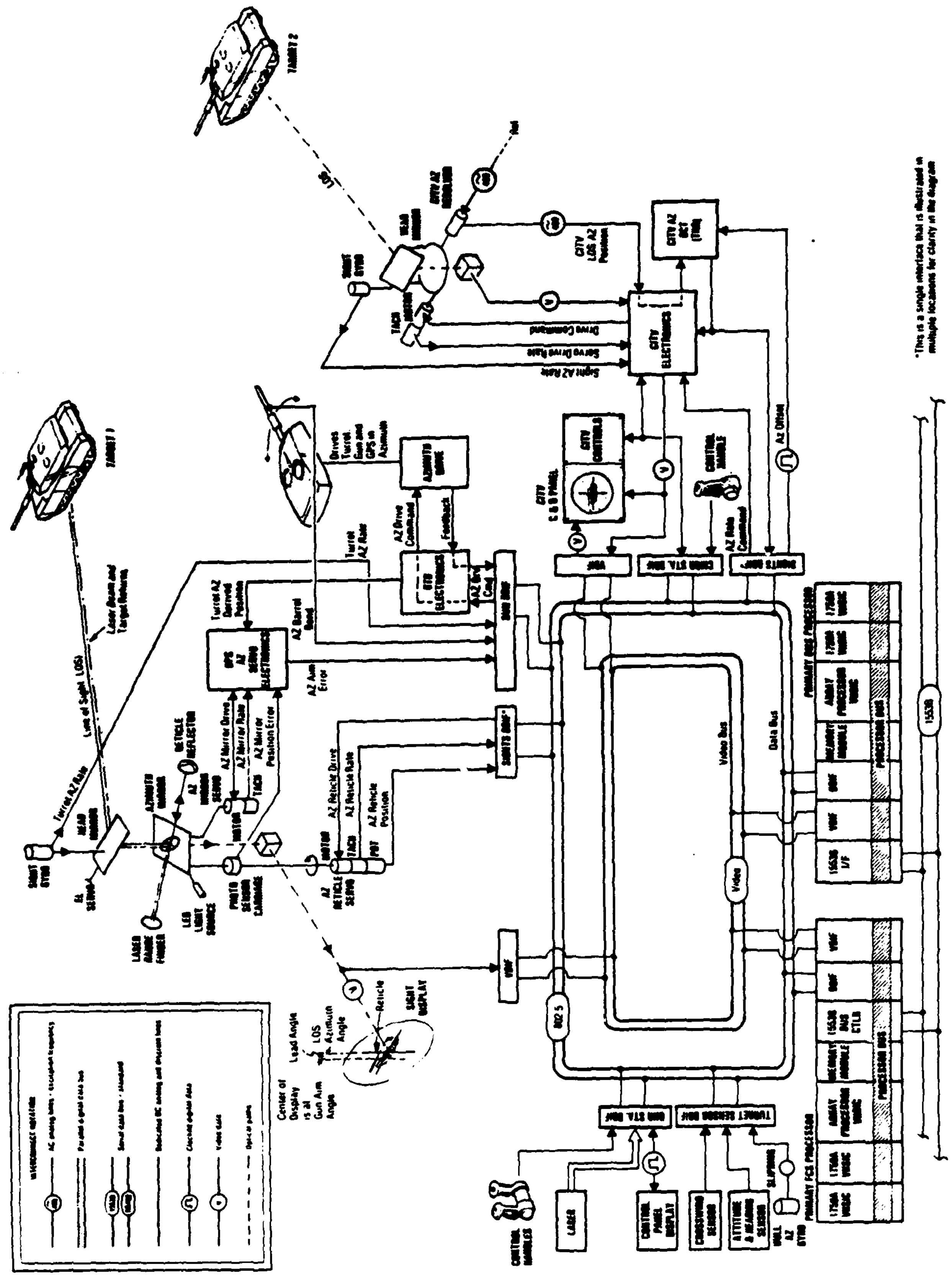


Figure 6-11. Growth/Bus Oriented System (Azimuth)

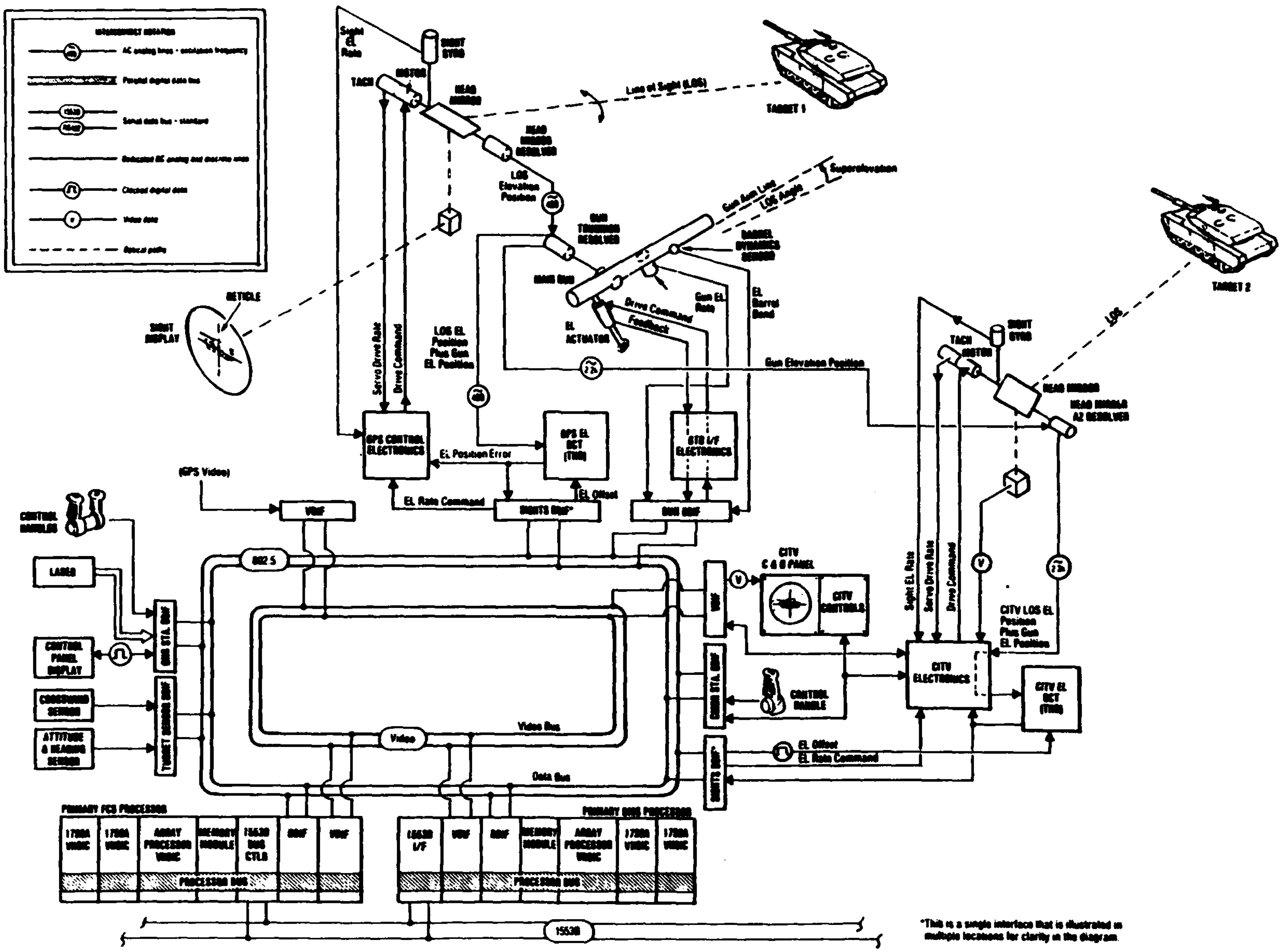


Figure 6-12. Growth/Bus Oriented System (Elevation)

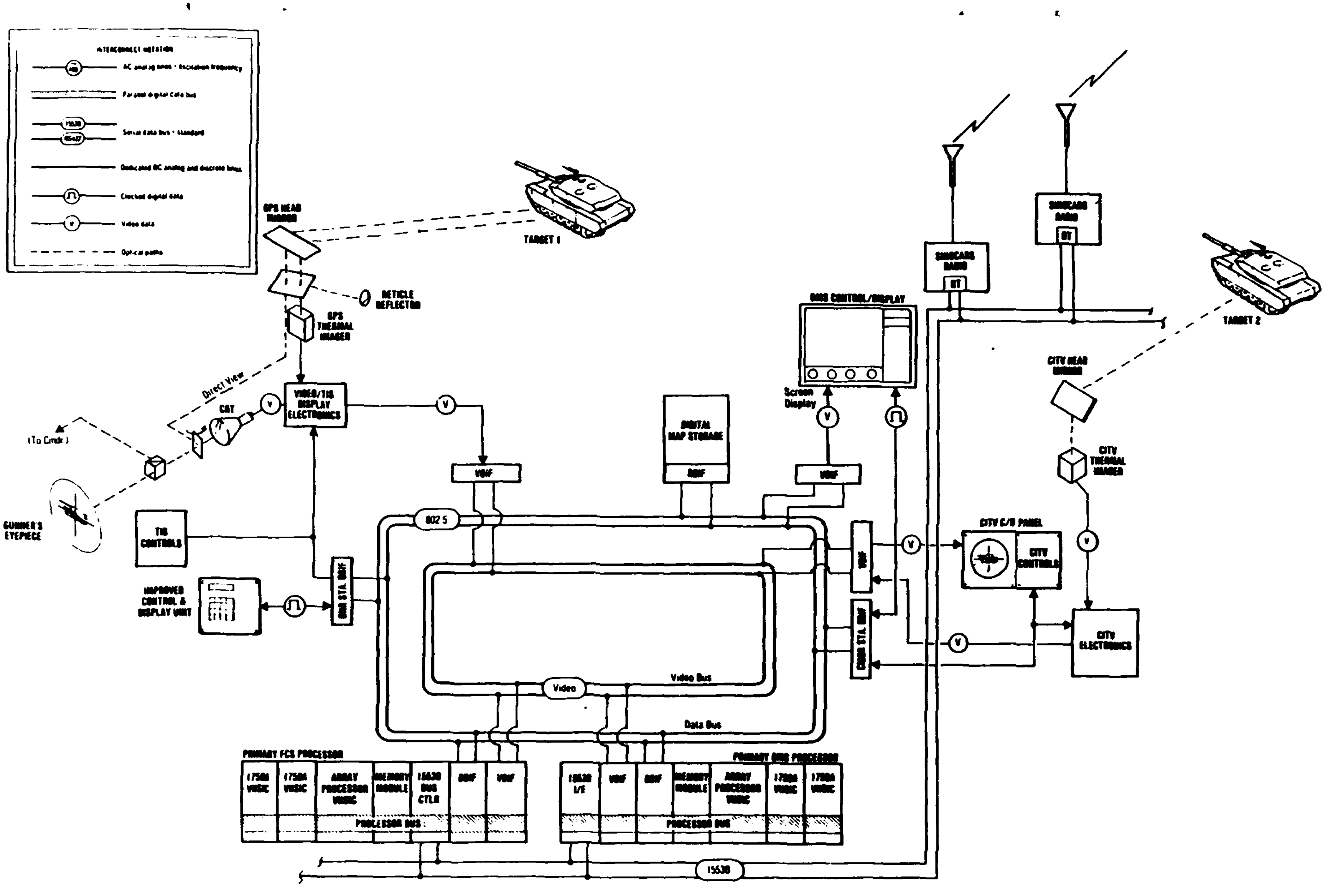


Figure 6-13. Growth/Bus Oriented System Operator Interface and Communication

The communications and control/display interface is illustrated in figure 6-13. As with the control functions, the various signals are interfaced to the data and video buses at the subsystems. Communications with the radios is accomplished with the 1553B bus as before, although it has been assumed that additional equipment may be used due to a higher level of data transfer over a number of networks.

The electronics box configuration for a system configured like this would be similar to that for the system in section 6.2. However, signals would not require routing and direct connection to the main processor assembly. The DBIF and VBIF are each configurable on the standard format electronics cards, and therefore could be configured as free standing interface electronics boxes or be intergated into one of the existing boxes, depending upon the specific physical constraints in each subsystem area.

6.4 RECOMMENDED TECHNICAL APPROACH

Analysis of the current and probable growth requirments for BMS and FCS led to the following conclusions:

(1) The FCS and BMS are closely interrelated. When projecting vehicle design impacts they must be considered together.

(2) Both the FCS and BMS functions will require substantially increased processing capability over the next several years.

(3) The similarity of control, display, and data requirements will allow some vehicle equipment to serve both BMS and FCS requirements.

The M1 tank is already close to its capacity for stowage of additional turret equipment and cabling. Therefore, components which occupy excessive space for the function provided or become redundant when BMS is implemented should become candidates for replacement or elimination. The current ballistic computer, some of the fire control and stabilization sensors, and the gun stabilization compensation electronics appear to fall in this category.

The implementation of any level of BMS capability will require additional processing capability which is not available from any of the current turret equipment. When viewed over the long term, it would be highly desirable that any new processor(s) take maximum advantage of current technology and standardization.

Growth, multi-processor architectures, and a desire to standardize equipment across the widest practical range of vehicles are key issues in processor architecture selection. It is recommended that this program specify the following for any new M1 processors:

(1) Standard Instruction Set Architecture
(1750A Recommended)

(2) Standard Electronic Module Format
(SEM-E Recommended)

(3) Standard Inter-Module Interconnect
(IBUS or equivalent)

(4) Ada High Order Language Support

Standardization on instruction sets, card formats, and the elimination of proprietary internal buses will maximize both the growth compatibility of the design and provide the broadest base for long term competitive procurements. Properly specified, this approach will be compatible with VHSIC developments being sponsored by other programs, and will allow direct integration of those modules as they become available.

All of the concepts discussed earlier in this section presumed the use of such standards.

The "Add-On BMS Node" approach, when viewed strictly from a near term BMS perspective, may appear attractive. It has the least direct impact on existing equipment, has the lowest technical and schedule risk, and would require the smallest near term investment. By employing the processor standards described above, it has the potential for growth in the display and communications area, but does not not address the corresponding changes required in the FCS. This approach would lead to uncoordinated developments in FCS and BMS and would ultimately result in higher development cost and greater integration problems for the total vehicle.

The bus-oriented approach described in section 6.3 represents the cleanest architectural approach. However, it also has the most significant impact on the current hardware, and would require the greatest software development effort. Additionally, it is based on the implementation of Vetronics, for which the related military standards may not be available for several years. Commercial standards (e.g., IEEE 802.5) could be used initially, but there would still be substantial risk to the current schedule objectives. It is recommended that this concept be phased in as the requirements grow and the technology and Vetronics standards become available.

The recommended initial approach is to follow the structure described in section 6.2 (baseline growth-oriented architecture), which is compatible with later growth to Vetronics. This approach requires some substantial changes to the current FCS interconnect, conversion of the current fire control software to a new structure, and the development of digital control laws for the gun/turret drives. The technical risk associated with these changes is low, but the approach is probably not compatible with the current production break-in objectives for BMS on M1A1.

However, it is also clear that the changes described above will have to occur sometime in the not too distant future. Therefore the technical and long term cost advantages of consolidating BMS and FCS changes into a single growth-oriented design change must be weighed against the disadvantages of accepting some slip in the production break in. Those tradeoffs are beyond the scope of this study.

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APPENDIX A:

ACCRONYMS

APPENDIX A - ACCRONYMS

1553	Military Standard Serial Data Bus
1750A	Military Standard 16 Bit Computer Instruction Set Architecture
1773	Fiber Optic Equivalent of MIL-STD-1553
ADC	Analog to Digital Converter
AEI	Armament Enhancement Initiative
AFATDS	Advanced Field Artillery Target Designation System
AMC	Army Materiel Command
APC	Armored Personnel Carrier
APU	Auxiliary Power Unit
ARDC	Armament Research & Development Center
ATR	Air Transport Rack
BIFF-N	Battlefield Identification Friend Foe - Neutral (Used interchangeably with IFF, BIFF)
BIM	Bus Interface Module
BIT	Built In Test
BMS	Battlefield Management System
CEOI	Communication Electronic Operating Instructions
CITV	Commander's Independent Thermal Viewer
CPU	Central Processor Unit
CRT	Cathode Ray Tube
DAC	Digital to Analog Converter
DCT	Digital Control Transformer
DOD	Department of Defense
DRC	Digital to Resolver Converter
EL	Electro-Luminescent
EMI	Electro-Magnetic Interference
EMP	Electro-Magnetic Pulse
ETL	Engineer Topographic Laboratories
FACS	Future Armored Combat System
FCCVS	Future Close Combat Vehicle Study
FCS	Fire Control System
FOV	Field of View
GDLS	General Dynamics - Land Systems Division
GPS	Gunner's Primary Sight
GTD	Gun/Turret Drive (and Stabilization) System
IBUS	Internal Bus Standard (for Module Interconnect)
ICCS	Integrated Command and Control System - Used interchangeably with "vehicle-based BMS node"
IRNS	Internal Reference Navigation System
ISA	Instruction Set Architecture
JTIDS	Joint Tactical Information Distribution System
LAV	Light Armored Vehicle
LCC	Life Cycle Cost
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LHX	Light Helicopter Experimental
LOS	Line of Sight
LRM	Line Replaceable Module
LSI	Large Scale Integration
M1	U.S. Army M1 Main Battle Tank
M1A1	Enhanced Version of M1 Tank
MAPS	Modular Azimuth Position System

APPENDIX A - ACCRONYMS (Continued)

MCF	Military Computer Family
MCS	Maneuver Control System
MIPS	Million Instructions Per Second
MOPS	Million Operations Per Second
MOUT	Mounted Operation in Urban Terrain
MPGS	Mobile Protected Gun System
MSI	Medium Scale Integration
MTBF	Mean Time Between Failures
NBC	Nuclear Biological Chemical
PPPI	Preplanned Product Improvements
RAM	Random Access (Read-Write) Memory
RDC	Resolver to Digital Converter
ROM	Read Only Memory
RT	Remote Terminal
SAPS	Stored Adress Parameter Set
SEM	Standard Electronic Module
SHORAD	Short Range Air Defense
SINCGARS	Single Channel Ground and Air Radio System
SMI	Soldier Machine Interface
SOP	Standard Operating Procedure
TC	Tank Commander
TIS	Thermal Imaging Sight
TNB	Turret Networks Box
UTM	Universal Transverse Mercator; position grid coordinates Northing, Easting, hemisphere, and zone.
V(INT)2	Vehicle Integrated Intelligence
VHSIC	Very High Speed Integrated Circuits
VISTA	Very Intelligent Surveillance and Target Acquisition
VLSI	Very Large Scale Integration
Vetronics	Vehicle Electronics (Data Bus Architecture)

APPENDIX B:

PROCESSING AND INTERFACE REQUIREMENTS

APPENDIX B - PROCESSING AND INTERFACE REQUIREMENTS

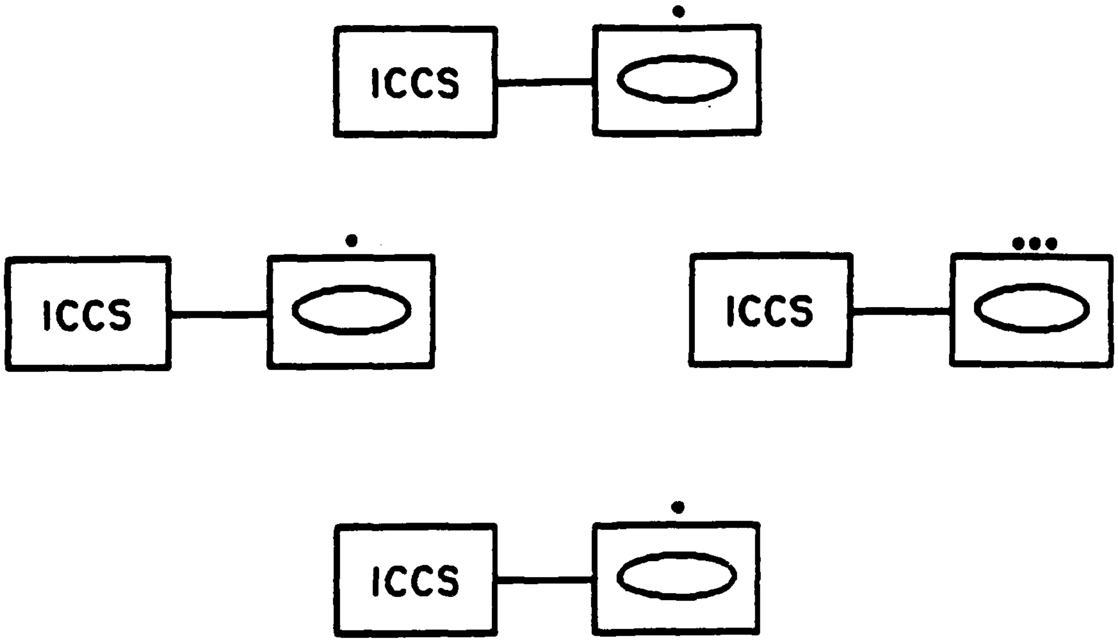
FUNCTION	INPUTS				THROUGHPUT	OUTPUTS			
	PARAMETER	SOURCE	SIGNAL TYPE	SAMPLING RATE (Hz)		PARAMETER	DESTINATION	UPDATE RATE (Hz)	FINAL SIGNAL FORMAT
GUN OFFSETS					Scalar: 30 Kops Array: 0 Mops				
	Range	Laser Rangefinder	Digital	Occasional		Offset Cmd (Az)	Offset Servo	30	Digital
	Crosswind	Crosswind Sensor	Analog	30		Offset Cmd (El)	Offset Servo	30	Digital
	Cant	Cant Sensor	Analog	30		Gun Track Cmd (Az)	Turret Stab Elec.	30	Analog
	Manual Data	Control Panel	Digital	Occasional		Gun Track Cmd (El)	Gun Stab Elec.	30	Analog
	Track Rate (Az)	Control Handles	Analog	30					
	Track Rate (El)	Control Handles	Analog	30					
	Velocity	Odometer	Analog	30					
	Turret Angle	Turret Resolver	Analog	30					
TURRET CONTROL & STABILIZATION					Scalar: 100 Kops Array: 0 Mops				
	Servo Error (Az)	Sight Stab Elec.	Analog	300		Turret Drive Cmd	Turret Drive	500	Analog
	Gun Track Cmd (Az)	FCS Processor	Digital	30					
	Gun Rate (Az)	Gun Gyro	Analog	500					
	Drive Dynamics (Az)	Turret Drive	Analog	500					
	Chassis Rate (Az)	Chassis Gyro	Analog	300					
	Turret Accel (Az)	Turret Accelerometer	Analog	500					
GUN CONTROL & STABILIZATION					Scalar: 100 Kops Array: 0 Mops				
	Servo Error (El?	Sight Stab Elec.	Analog	300		Gun Drive Cmd	Gun Drive	500	Analog
	Gun Track Cmd (El)	FCS Processor	Digital	30					
	Gun Rate (El)	Gun Gyro	Analog	500					
	Drive Dynamics (El)	Turret Drive	Analog	500					
	Turret Rate (El)	Turret Gyro	Analog	300					
	Gun Accel (El)	Gun Accelerometer	Analog	500					
SIGHT CONTROL & STABILIZATION (2 Axis)					Scalar: 150 Kops Array: 0 Mops				
	LOS Rate (Az)	Sighthead Gyro	Analog	500		LOS Drive Cmd (Az)	Sighthead	500	Digital
	LOS Rate (El)	Sighthead Gyro	Analog	500		LOS Drive Cmd (El)	Sighthead	500	Digital
	LOS Angle (Az)	Sighthead Resolver	Analog	300					
	LOS Angle (El;	Sighthead Resolver	Analog	300					
	Track Rate (Az)	FCS Processor	Digital	30					
	Track Rate (El)	FCS Processor	Digital	30					
	Mode Control	FCS Processor	Digital	30					
	Gun Angle (El)	Gun resolver	Analog	300					
	Turret Rate (El)	Turret Gyro	Analog	300					
	Stab Error (Az)	Sighthead Gyro	Analog	500					
	Stab Error (El)	Sighthead Gyro	Analog	500					

APPENDIX B - PROCESSING AND INTERFACE REQUIREMENTS

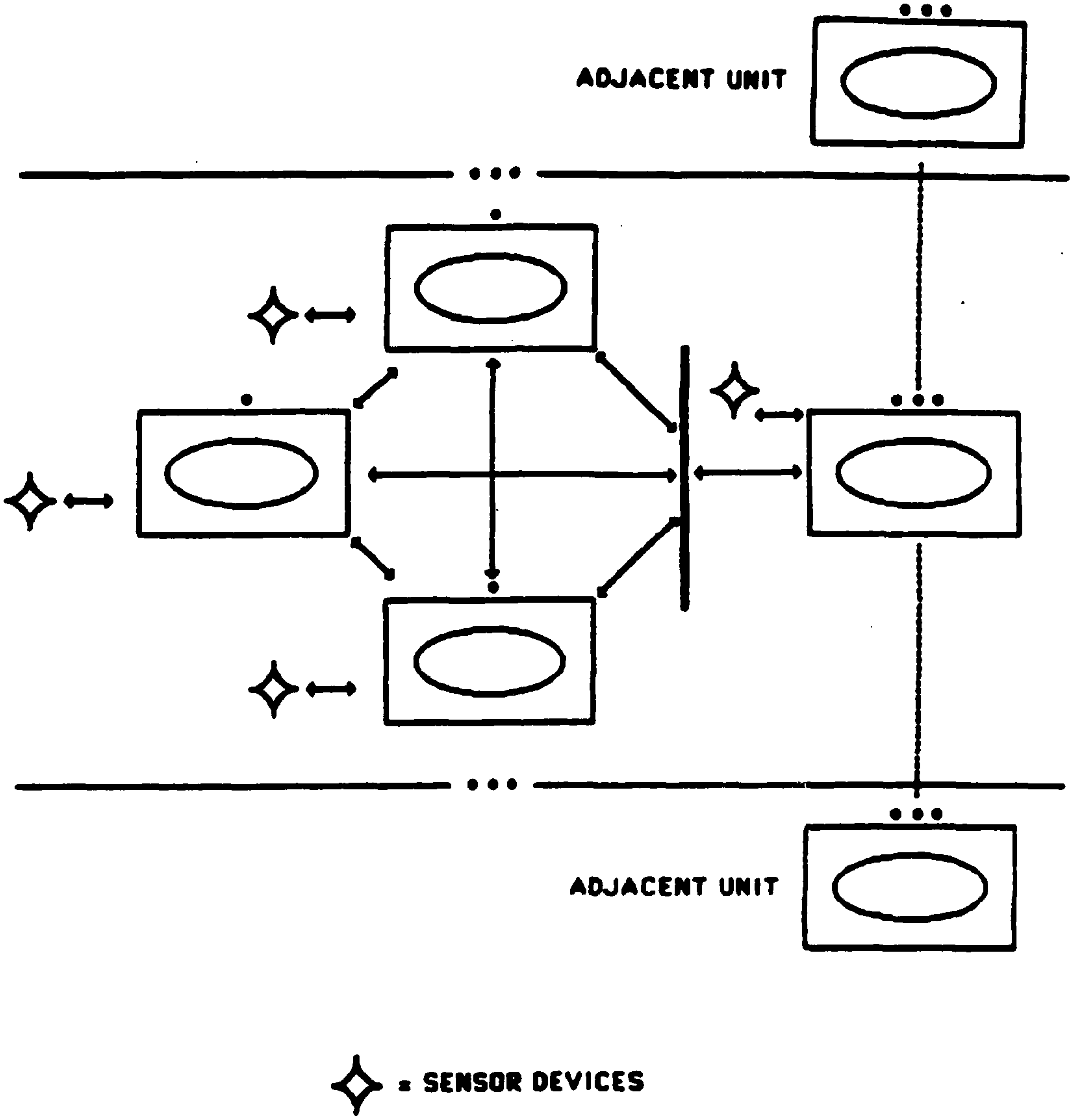
FUNCTION	INPUTS				THROUGHPUT	OUTPUTS			
	PARAMETER	SOURCE	SIGNAL TYPE	SAMPLING RATE (Hz)		PARAMETER	DESTINATION	UPDATE RATE (Hz)	FINAL SIGNAL FORMAT
SIGHTHEAD MIRROR CONTROL (M1 GPS)					Scalar: 80 Kops Array: 0 Mops				
	LOS Rate (El)	Sighthead Gyro	Analog	500		LOS Drive Cmd (El)	Sighthead	500	Digital
	LOS Angle (El)	Sighthead Resolver	Analog	300					
	Track Rate (El)	FCS Processor	Digital	30					
	Gun Angle (El)	Gun resolver	Analog	300					
	Offset Cmd (El)	FCS Processor	Digital	30					
	Servo Drive Rate	Sighthead	Analog	500					
SIGHT (AZ) RETICLE CONTROL (M1 GPS)					Scalar: 50 Kops Array: 0 Mops				
	Track Rate (Az)	FCS Processor	Digital	30		Reticle Drive Cmd	Sighthead	10	Analog
	Reticle Drive Rate	Sighthead	Analog	10					
	Reticle Position	Sighthead	Analog	10					
	Offset Cmd (Az)	FCS Processor	Digital	30					
VIDEO TARGET TRACKING					Scalar: 200 Kops Array: 14 Mops				
	Sight Video Signal	Sight Video	Analog			Tgt Position (Az)	Sight Controller	30	
						Tgt Position (El)	Sight Controller	30	
						Tgt Rate (Az)	Sight Controller	30	
						Tgt Rate (El)	Sight Controller	30	
TARGET AUTO-CUE & SCREENER					Scalar: 5600 Kops Array: 80 Mops				
	Sight Video Signal	Sight Video	Analog			Tgt Position (Az)	FCS Processor	10	
						Tgt Position (El)	FCS Processor	10	
DATA MANAGEMENT					Scalar: 40 Kops Array: 0 Mops				
INERTIAL REFERENCE & NAVIGATION					Scalar: 600 Kops Array: 0 Mops				
	Pitch Rate	Inertial Ref. Unit	Analog	500		Gyro Torque - Pitch	Inertial Ref Unit	500	
	Roll rate	Inertial Ref. Unit	Analog	500		Gyro Torque - Roll	Inertial Ref Unit	500	
	Yaw Rate	Inertial Ref. Unit	Analog	500		Gyro Torque - Yaw	Inertial Ref Unit	500	
	Vert. Accel.	Inertial Ref. Unit	Analog	1000		Accel Torque - Vert	Inertial Ref Unit	1000	
	Lateral Accel.	Inertial Ref. Unit	Analog	1000		Accel Torque - Lat	Inertial Ref Unit	1000	
	Long. Accel.	Inertial Ref. Unit	Analog	1000		Accel Torque - Long	Inertial Ref Unit	1000	
	Speed	Odometer	Analog	10		Position	Displays	1	
						Heading	Displays	1	
PROJECTILE TRACKING					Scalar: 150 Kops Array: 0.2 Mops				
	Sight Video Signal	Sight Video	Analog			Autozero Comp. (Az)	Gun Offsets	1/shot	
						Autozero Comp. (El)	Gun Offsets	1/shot	

APPENDIX C:

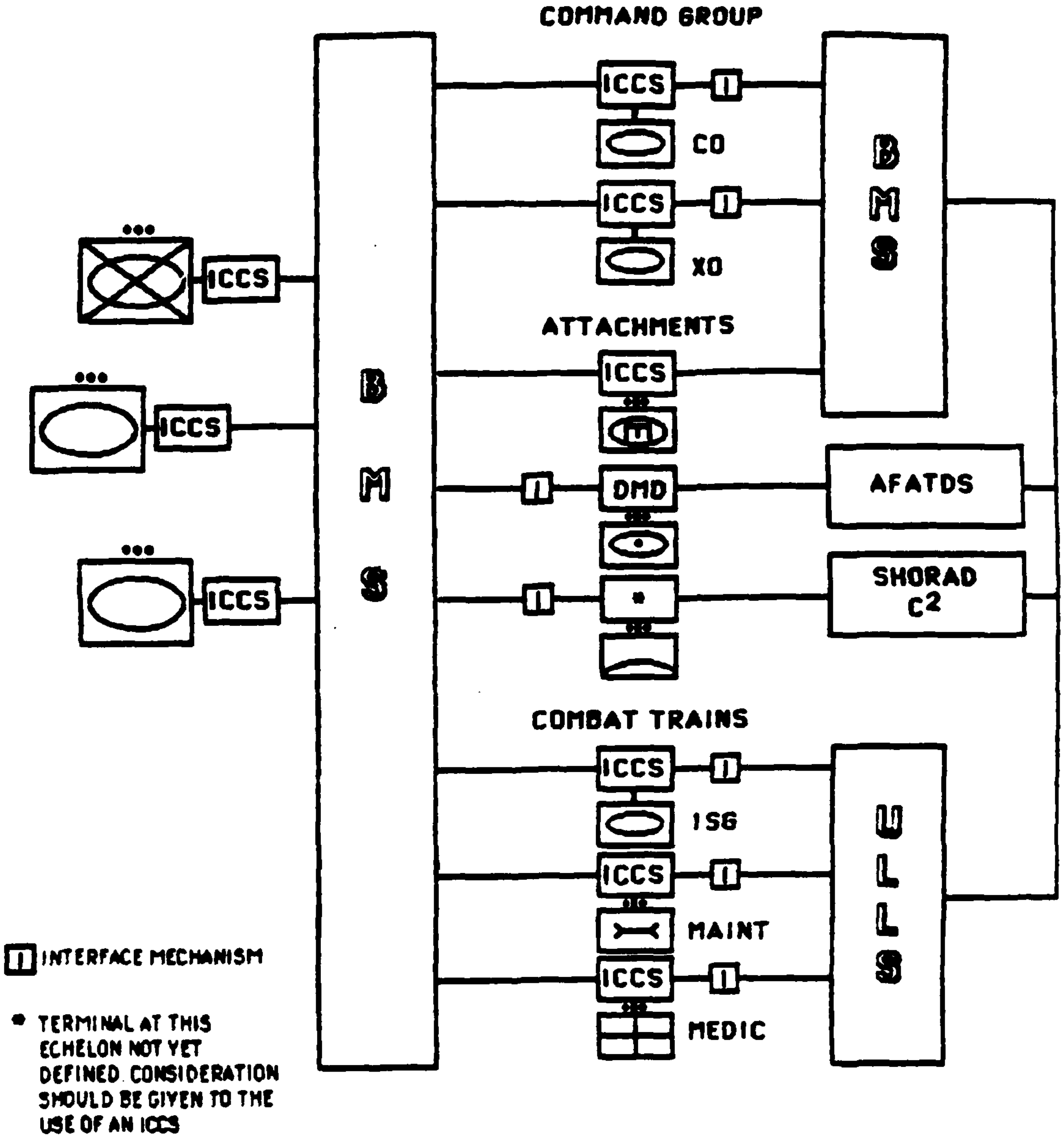
ICCS FORCE DISTRIBUTION AND NETWORK INTERFACE



BMS HARDWARE DISTRIBUTION - PLATOON

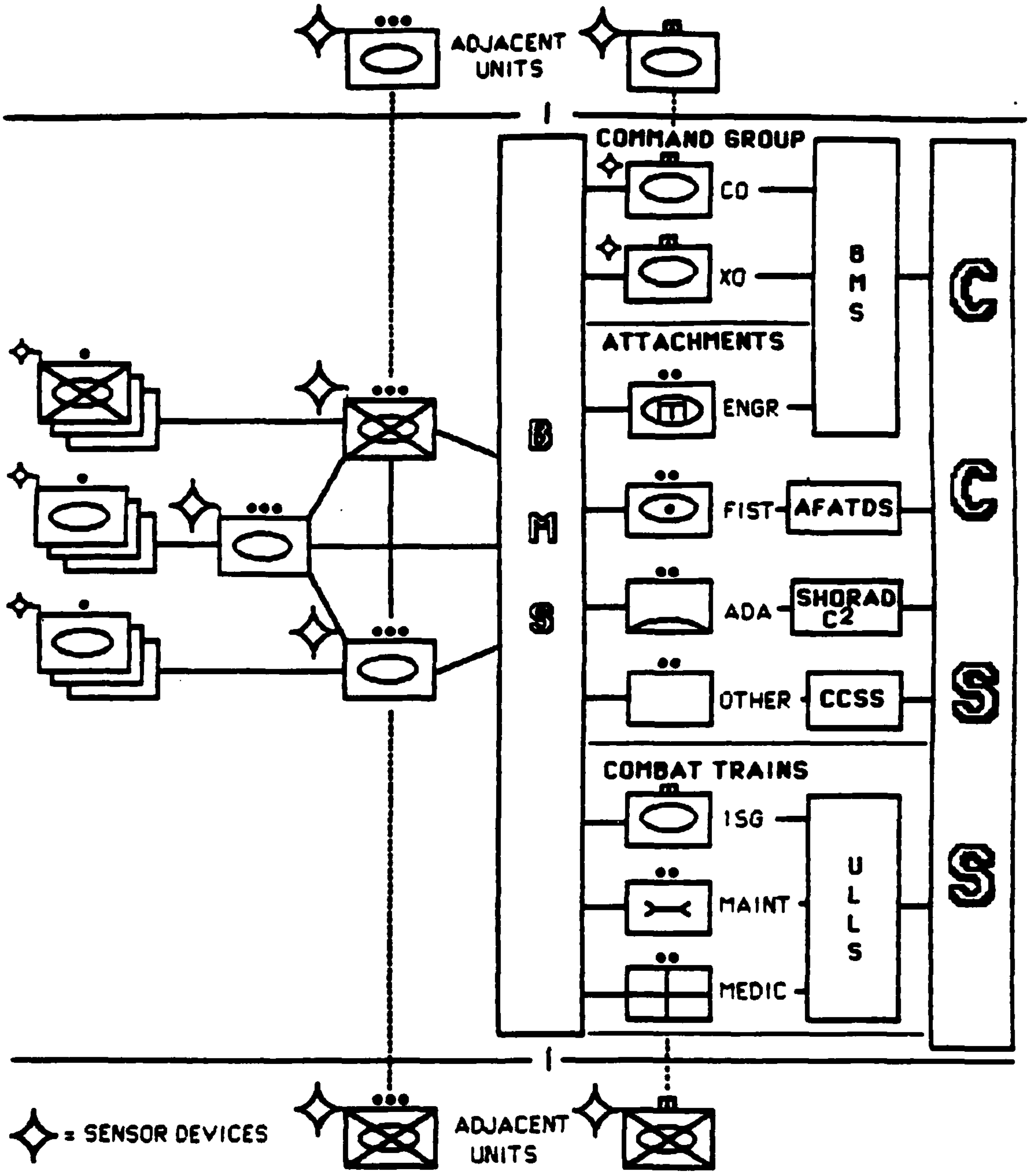


BMS INFORMATION FLOW - PLATOON

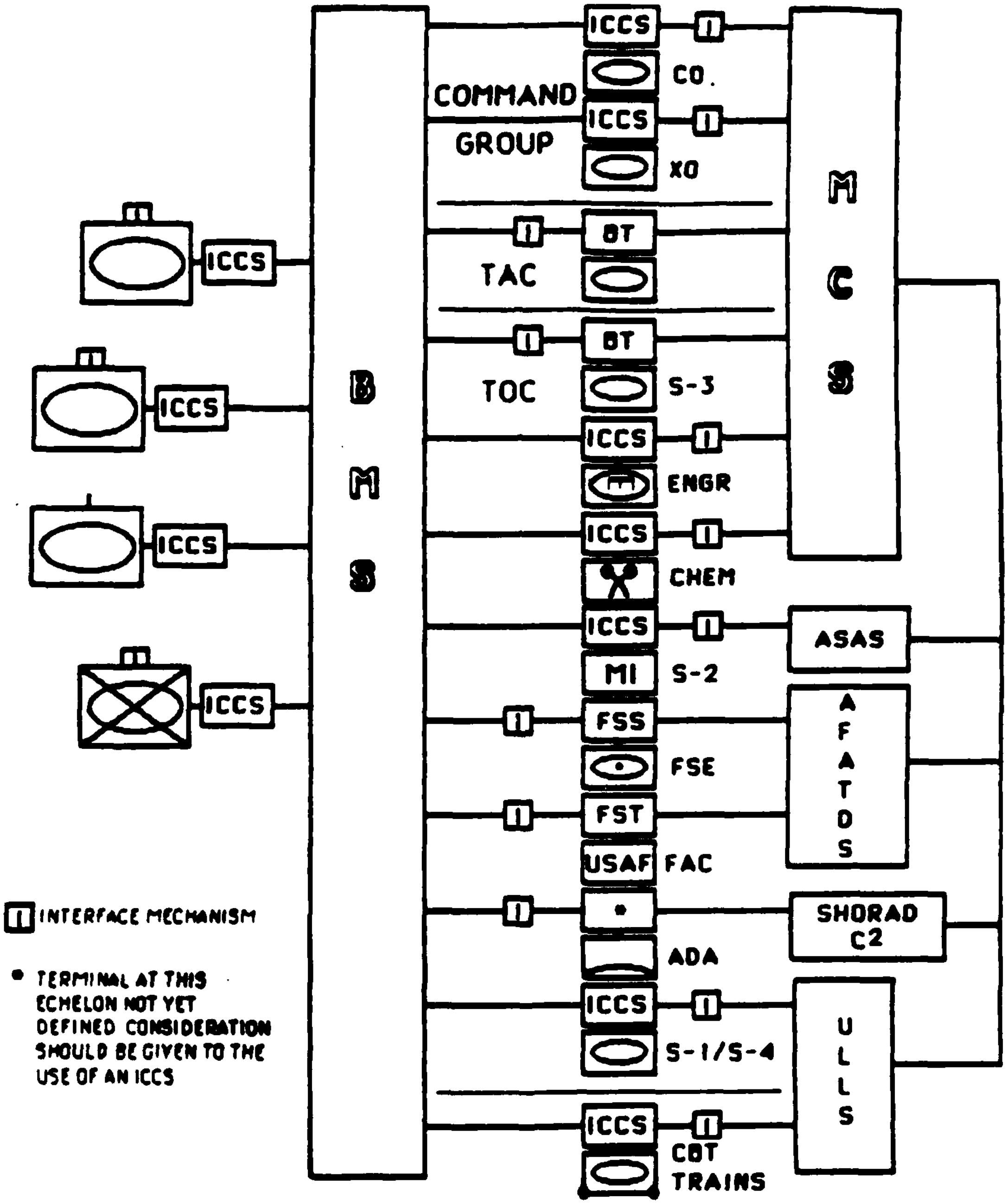


* TERMINAL AT THIS ECHELON NOT YET DEFINED. CONSIDERATION SHOULD BE GIVEN TO THE USE OF AN ICCS

BMS HARDWARE DISTRIBUTION - COMPANY/TEAM



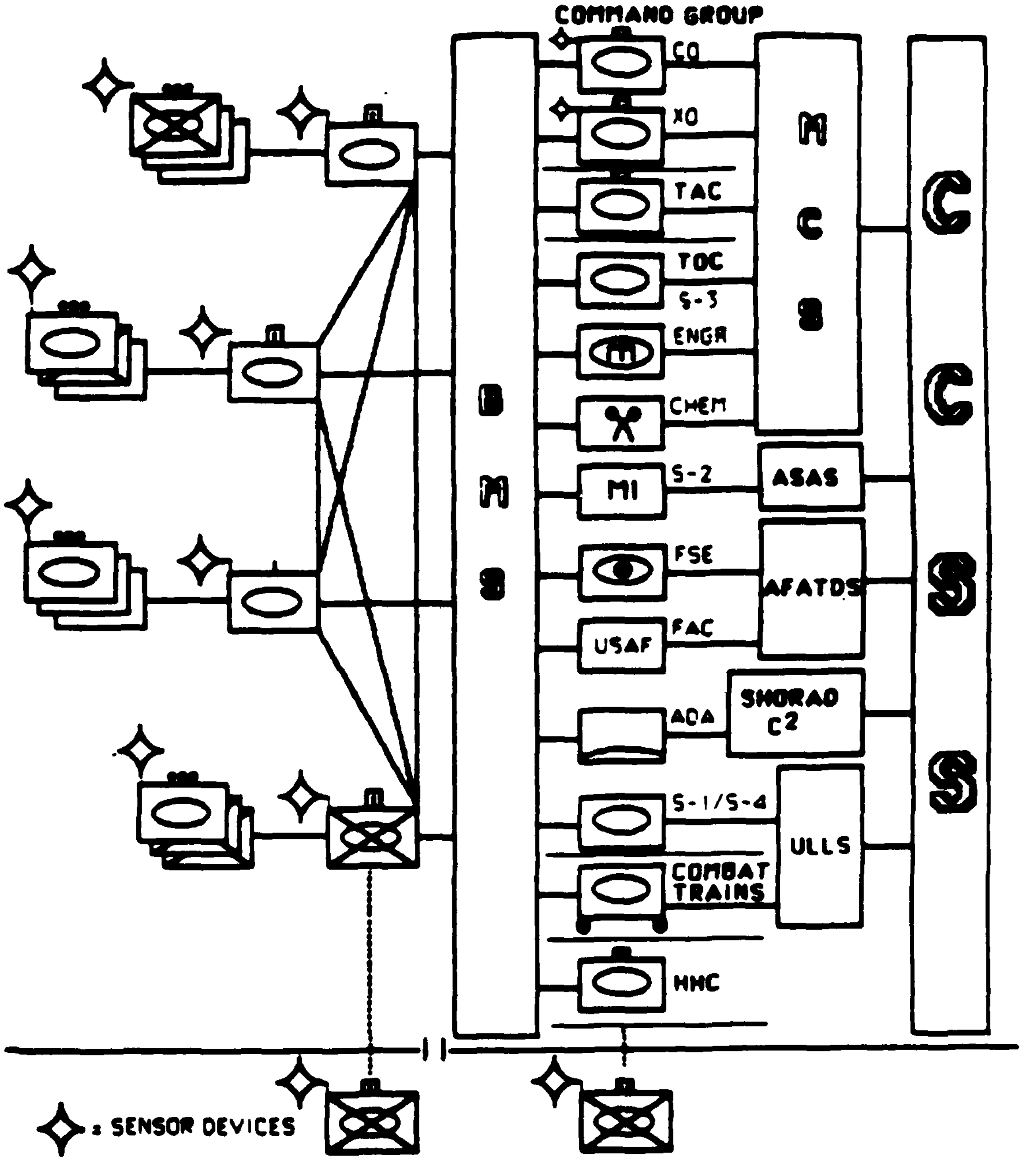
BMS INFORMATION FLOW - COMPANY



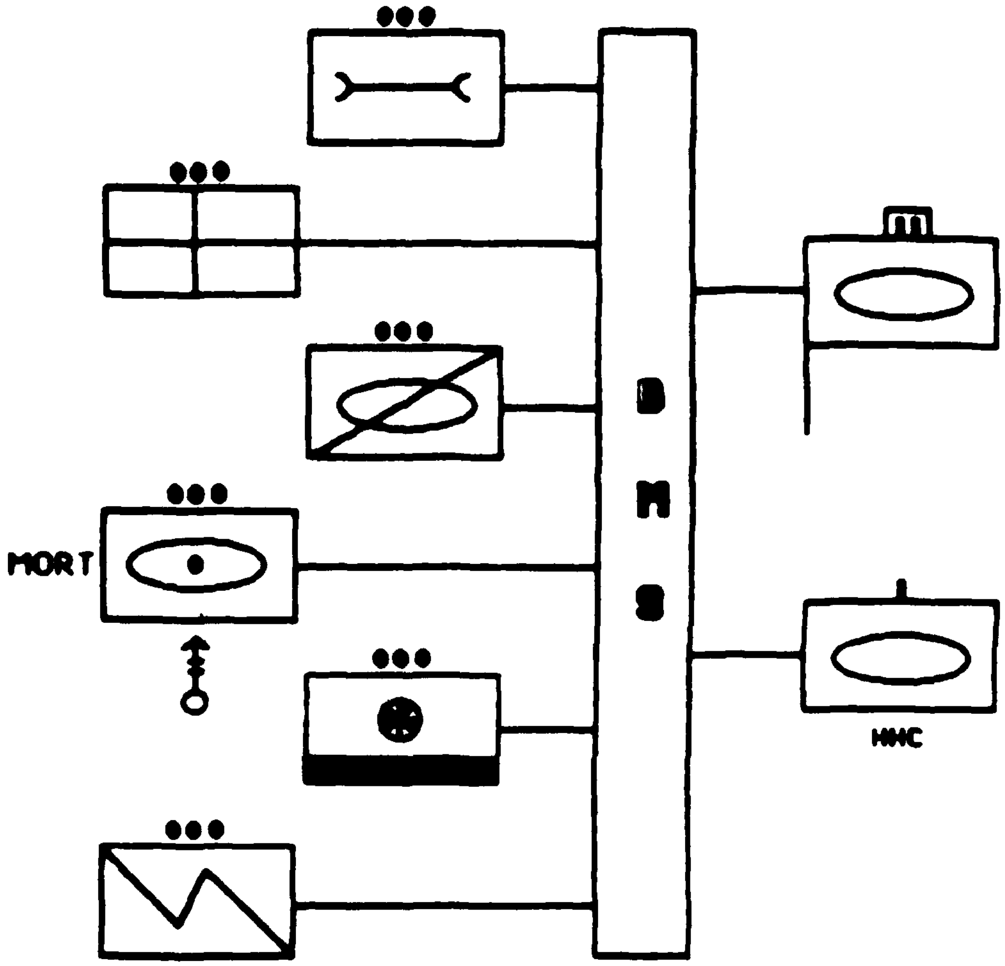
I INTERFACE MECHANISM

* TERMINAL AT THIS ECHELON NOT YET DEFINED CONSIDERATION SHOULD BE GIVEN TO THE USE OF AN ICCS

BMS HARDWARE DISTRIBUTION - BATTALION/TASK FORCE



BMS INFORMATION FLOW - BATTALION



BMS INFORMATION FLOW HHC,ARMOR BN

END

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