MULTIPLE TARGET INSTRUMENTATION RADARS FOR MILITARY TEST AND EVALUATION

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ABSTRACT

Military aerospace test ranges are increasingly being called upon to conduct missions utilizing large numbers of participating units, or targets. Precision, position and trajectory data must be recorded on all participants. In addition, weapon/target engagements must be scored and real-time range safety considerations must be accommodated. This requires precision metric data be available in real-time on all participating targets. One solution to these problems, is utilization of multiple target tracking radars which incorporate electronic beam steering to quickly move from one target to another in sequence. This paper briefly recounts the history of range instrumentation radars, points out some of the advantages of using multi-target radars, and highlights the specifications and design of a multiple target instrumentation radar now being acquired by the U.S. Army for use at White Sands Missile Range and the Kwajalein Missile Range. Key words — radar, multiple target tracking, position measurement, and Phased Array.

INTRODUCTION

The increasing sophistication of weapons systems, and the need to exercise these systems in realistic environments, requires the test provide large numbers of targets, against which multiple weapons are launched. Aerospace test ranges are required to track and record data on the position of each of these targets, as well as to deliver real-time data to range controllers for safety evaluation and control. A number of different technologies are in use or planned for use at major ranges to accommodate large numbers of targets. Radio detection and ranging or Radar, is the backbone of instrumentation at most ranges. However, conventional radars require that a single instrument track a single target. This is impractical when large numbers of targets are to be used. However, most of the advantages of conventional radars can be retained, and a single system can be made to track large numbers of targets thru incorporation of phased array or electronic beam steering technology. The U.S. Army Test & Evaluation Command is currently procuring three radars of this type for use at the White Sands Missile Range. All available technologies were examined and it was concluded that the particular requirements of White Sands Missile Range would be best met through use of Multiple Object Instrumentation Radars (MOTR's). A system was essentially specified from the ground up to meet the needs of DoD and, in particular, White Sands Missile Range. These radars will be fully integrated with existing range instrumentation and provide necessary data at a minimum cost.

DEFINITION OF RANGE REQUIREMENTS – RANGE USERS AND OPERATORS

Requirements for Range Instrumentation derive from "range users". A range user, or range customer, might be a development agency in charge of the development of a new missile, space craft, aircraft, ship, tank, new weapons to go aboard one of these basic carriers, or an improved version of an existing system. A range user can also be an operational organization, charged with development or refinement of a tactic or doctrine for use of a given materiel, or the trainer responsible for maintaining the readiness of bodies of troops. Regardless of his specific purpose, the range user must define his objective, plan in detail how he will accomplish it, and determine exactly what data he will require from the test. His test outline should include the specification of exactly what perimeters must be measured and observed over what performance intervals and to what degree of accuracy he must obtain data in order to evaluate how well he accomplished his original purpose or objective. Having done this, the range user must communicate this information, that is, his technical support requirements to a second group, "range operators".

Range operators are the permanent party at the range. They respond to technical support requirements placed on them, they translate requests for measurement, into the planning for, development of, purchase, installation, test and continued operation and maintenance of the complex instrumentation sites found at most modern ranges. So that they may be ready to support their range users in timely fashion, they must postulate and predict the future requirements of their users, often when future users or their requirements are not definitively known. In such cases, future requirements are based on trends of the past, extrapolated into the future. Ranges today typically must look out 5 to 10 years into the future for trends in weapon design and testing if they are to be ready to support these new weapons on the range when required. In short, it takes almost as long to develop modern test instrumentation as it does to develop the weapons that must be tested.

Technical support requirements take many forms. For example, pre-launch geodetic survey of launch site, overall range communications, metric data (time, space, position, velocity and acceleration measurement in prearranged coordinate systems), data concerning internal missile performance relayed to the ground by secure telemetry links, detection and recording of events such as staging and separation, measurement of the phenomena associated with vehicle reentry into the atmosphere, scoring of a round or missile in relation to a target vehicle, and timing of all events and actions are typical of the types and forms of data that must be measured, recorded and reduced to meaningful engineering language and parameters suitable for performance evaluation. Each of these must be defined in advance and communicated to the range operator by the range user in time to allow the former to work out his support plan.

RANGE INSTRUMENTATION

A test and evaluation organization operating major ranges such as the Army's Test & Evaluation Command (TECOM) has a tremendous investment in range instrumentation. This instrumentation measures a wide variety of parameters; from pressure pulses produced in the chamber of artillery weapons, to precision space position information on high speed aircraft and missile targets. In addition, range instrumentation provides repeatable conditions for testing, such as environmental conditions — hot, cold, humid or electronic countermeasures, or target vehicles that can be made to follow the same path again and again. In this paper, we limit our discussion to the class of instrumentation commonly called, Time Space Position Instrumentation, or TSPI.

Ranges need precision space position measurement in real-time to ensure that potentially dangerous errant behavior of the test articles is detected in time to provide necessary corrections. This is a range safety function. Further position data of the required quantity and quality is provided to the range user to assist in analyzing the performance of each test article. Position data in real-time is also needed to maintain the control of target drones used in the test program and to assure that they are presented to the system under test in a precise and repeatable manner. In addition, accurate position data is often required on two or more test vehicles simultaneously to measure their point of closest approach, known as miss-distance. Such measurements are made to determine the effectiveness of the intercepting device.

Modern test ranges traditionally rely on two basic methods of measuring time space position; optical instrumentation, such as cinetheodolites and tracking telescopes, or radar. Recently, other methods of determining TSPI have come into vogue. These include laser trackers which substitute laser generated ir energy for the rf used by radars, and multi-lateration systems using multiple range measurements to determine position. Each technique for measurement of space position has a valid place in test range operation, and each has its own individual advantages and disadvantages. Again, for the purpose of this paper, we will limit our discussion to Instrumentation Radars. The commonly accepted definition of an Instrumentation Radar is a pencil beam, pulse radar which provides location precision to plus or minus a few meters.

A few of the particular characteristics that distinguish radars above other position measuring instrumentation for use on test ranges are: ability to track an unaided or non-cooperative target, ability to provide data in real time, the data available on the ground at the radar site (rather than in the target vehicle), tracking range is virtually unlimited, accuracy and precision are very good, and geometry problems are minimal in that a single station can produce complete position data. Among the disadvantages of typical radars are: inability to obtain accurate data at low elevation angles, difficulty in acquiring targets that appear without prior information, inability to maintain track on fast accelerating targets at close range due to antenna inertia, and the limitation of one target track per radar.

The appearance of instrumentation radars on test ranges began at about the same time as the earliest testing of guided missiles. Range safety and missile performance evaluation, both created a demand for quality data. Real-time safety data was of critical importance, since even in the remote wilds of New Mexico, missiles that went off-course had to be immediately destroyed. A class of instrument was required to provide accurate real-time tracking and performance data on the object, along with significant characteristics to permit production of high quality post flight data. Early instrumentation radars were typically adaptations of military systems. Perhaps the first instrumentation radar to deserve the name was the SCR-584. The SCR-584 was a military fire control radar which was available as surplus after the Second World War. It was placed into wide use on our test ranges at the beginning of the missile era. Follow-on versions of the SCR 584 are still in use in test ranges today.

By the mid 1950’s, requirements of the test ranges exceeded that available from surplus weapons radars. This drove the design and development of tracking radars that were specifically designed for aerospace ranges. The first instrumentation radar designed from the ground up to meet test range requirements was the AN/FPS-16. The FPS-16 was initially installed at the U.S. Air Force Test Range at Patrick Air Force Base, Florida (characteristics of this and later instrumentation radars are summarized in Table 1).

The FPS-16 used a monopulse tracking technique. The performance of the FPS-16 was a milestone in precision radar design. Every major test range in the United States desired a radar of the FPS-16 class. Today every one of the 57 FPS-16’s (and the transportable version AN-MPS-25) radars is still in operation, including 11 at White Sands. They have been installed in Australia and England on instrumentation ships and are used at test ranges throughout the U.S. Department of Defense and the National Aeronautics and Space Administration as well as other U. S. government agencies. The standard set by the FPS-16 in the 1950’s is still the standard by which range instrumentation is measured today.

Not long after initial deployment of the FPS-16, some range users required even more performance. Higher powered transmitters, larger antennas, longer range tracking capability, data correction for minimization of systematic and tracking lag erruors were all required in the next generation precision radar. The next series of instrumentation radar was the AN/FPQ-6 (or AN/FPQ-18 for the air transportable version). Eleven of these instruments were built and are still used by U.S. ranges. New techniques were incorporated in these radars that maximize gain for a given antenna size, and the use of a general purpose computer as an intergral element was an important trend in instrumentation design.

In the late 1960's the need for additional FPS-16 class instrumentation coincided with the availability of integrated circuit components. This need was satisfied by the design and fabrication of the AN/FPS-105. Also in the late 1960's the U.S. Test and Training Ranges were confronted by future missions requiring high quality radar tracking at various remote sites. The existing FPS-16 instrumentation radars were located in permanent buildings where they had been originally installed. Moving them would be expensive, and the several months down-time that would be required for re-location was unacceptable to the support of ongoing test missions. These forcing conditions coupled with advancing technology gave rise to another new generation of instrumentation radar. These new radars, designated AN/MPS-36, were capable of being moved to a prepared site and placed in operation in eight hours or less by a four man crew without the use of outside cranes or special tools. This radar had high tracking precision, high reliability and built-in techniques to directly measure velocity.

In the mid 1970's the high priority needs of most test ranges for position tracking radars had been satisfied by the FPS-16, MPS-36, and other radars. However, there were many needs that could not be satisfied by the existing numbers of radars available. In addition, many smaller ranges required precision tracking information but could not afford the relatively high price of the then existing systems. Consequently, a new class of instrumentation radar was designed and produced. These offered slightly less precision at a correspondingly lower cost. To keep cost low, many of these radars used antennas and pedestals from surplus military systems, primarily the NIKE HERCULES, and combined these with custom electronics utilizing state-of-the-art computer technology. These radars featured very low operational requirements and very rapid conversion from transport to operate mode. These addressed the needs of smaller service ranges and gap filler requirements at the larger ranges, which already utilized the existing high precision instrumentation radar.

Also in the mid 70's, another trend in testing began to stress many of our ranges. Tactical systems under development were best tested in an offensive/defensive scenario. Testing required a realistic replication of the enemy or the threat. For example, instead of a single air to air missile being fired from a single launch aircraft at a single target (hardly a realistic situation) multiple missiles were tested against several targets. Weapons systems began to have imbedded computers and could recognize individual targets in groups and keep track of missiles launched against each target and kills. Testing such “smart” weapon systems was impossible without large numbers of threat vehicles as targets.

Scenarios of this type often required ten or more targets in the air at one time. Range safety and user data required the commitment of at least one metric radar to each object involved in test scenarios. This was compounded by the fact that target drones were normally flown using control systems integrated with the radars. Often each target would require two or more dedicated radars. Major U.S. ranges quickly found their inventory of instrumentation radar saturated. In addition, the logistics of having single target trackers at the appropriate location presented difficult problems. This was partially overcome by carefully timing the test sequence and having a given radar track more than one object by scheduling a limited time “slot” for each object. This proved a perilous technique often resulting in losses of valuable data by even the most skillful range operators.

The obvious solution to this growing problem was to obtain more radars. An approach that carried the attendant economic impact and the technical operational issues of requiring almost infallible test sequencing. Various other non-radar instrumentation systems, such as multi-lateration were considered, but each had significant and often insurmountable problems when applied in the classical instrumentation radar mode, even though some of these systems do track multiple objects and produce commendable results. Increased operational realism was required by the range user. For example, he was increasingly intollerant of attaching instrumentation aids (beacons and transponders) to the test vehicle. The instrumentation radar can and often does perform its function with no help from tracking aids. That is, the targets are truly uncooperative and require no augmentation whatsoever.

During the 70’s a number of military and commercial electronically steered, agile-beam, phased array radars were approaching maturity. These radars provided multiple target capability, and were seriously studied for possible applications to test range support. The limiting factor on these radars was primarily their extremely high cost. The antenna was typically made up of thousands of phase shifters. Although the individual cost of each phase shifter was relatively low, the large numbers required drove the cost up so that often the antenna of these radars alone exceeded the total cost of previous instrumentation radars.

In the early 1970’s, both the Army and the Navy invested in brass-board systems to determine the feasibility of electronically steered beams for instrumentation radars. The Army program was known as the Application of Radar to Ballistic Acceptance Testing, abbreviated ARBAT. This system utilized an electronically steered beam (Figure 1), however the system was not designed to allow multiple target tracking. The extremely fast movement of the beam allowed this radar to track artillery projectiles crossing in front of the radar. Radars using mechanically driven antennas could not accelerate the antenna quickly enough to capture such projectiles. The Navy program, known as the Multiple Target Instrumentation Radar or MIR, was directed toward the multiple target missile and aircraft scenario problem.

Both the MIR and the ARBAT are in operation today. The ARBAT is tracking artillery rounds at Yuma Proving Ground in Arizona, and the MIR, after being installed at the Pacific Missile Range, is now located at the Naval Air Test Center, Patuxent River, Maryland. Although, both these systems were initiated more than 10 years ago as brass-boards designed to evaluate and demonstrate the potential for electronic beam steering in an instrumentation system, they are both producing vital test data today.

The Army's White Sands Missile Range had been coping with the problems of multiple target test scenarios for many years. Although, to design brand new, electronically steered radars to replace existing single target trackers at White Sands would be extremely expensive, it was determined that no other practical course of action existed. Other test ranges, which had the same problems, joined in a multi-service group to define requirements for a new class of instrumentation radar to be known as the Multiple Object Tracking Radar or MOTR. After several years of intense effort, the Army now has a contract with the RCA Corporation, Moorestown, New Jersey to build three of these radars for White Sands. The contract presently contains an option for one additional radar to be used at the Kwajalein Missile Range in the South Pacific.

THE MULTIPLE OBJECT TRACKING RADAR (MOTR)

A brief description of the MOTR includes the following features:

- The radar is a general-purpose, metric track instrumentation radar that is to be compatible with existing single-target tracking radars, e.g., the FPS-16, MPS-25, and MPS-36. This means it must meet range standards in operating frequency, pulse width, pulse repetition frequency, timing, beacon coding, etc.

- Each radar simultaneously tracks as many as 10 objects.

- The radar provides absolute accuracy performance at least equal to existing instrumentation radars, plus a 2 to 1 improvement in relative accuracy over that obtainable with single-target trackers. This is a very important factor in the measurement of miss-distance where the relative separation is the primary item of interest.

- A major advantage of the radar is that mission tracks can be controlled and observed from a single location, enabling the radar operator to make rapid priority decisions during operations.

- The radar is capable of using one tracked object as a designation source, then acquiring and tracking multiple objects ejected from that source.

- The multiple track feature points to reduced range operation and maintenance (O&M) costs because fewer single-target trackers will be required; surveillance scan capability also provides further operational enhancement and O&M cost reduction.

- A major benefit of the radar's inertialess beam is the ability to track objects with extreme angular accelerations. Large angular accelerations occur during proximity fly-by or lift-off of small missiles. It will track objects having angular accelerations of 25,000 mils/sec/sec.

- Acquisition times of less than one second and real-time data delays under 25 milliseconds are provided.

- The radar offers significant improvements in performance, compared to either the AN/FPS-16 or the AN/MPS-36 radars, when tracking objects at low elevation angles. Near-in angle sidelobes are 10 dB lower than those of paraboloidal reflector antenna trackers, yielding a two-way 20 dB improvement in signal-to-clutter ratios. The important by-product of the lower angle sidelobe is a 3 to 1 reduction in tracking error due to multipath.

- A 50 microsecond pulsewidth capability permits the radar to track at longer ranges, or to track objects with smaller radar cross-sections, or both. System architecture will enable the operator to concentrate radar resources on a single object to achieve maximum tracking ranges, or to maximize tracking performance against multiple objects.

- The radar can be configured in either a mobile or building-installed installation.

- The radar can be completely compatible with range communication and control. It will have the capability of multiple-target drone control.

- A system block diagram (Figure 2) emphasizes a straightforward design and the important interfaces of the radar with the overall range instrumentation complex.

Figure 3 is a photograph of an engineering model of the radar as it will appear in a deployed configuration. The cut-away (transparent) portion of the electronic equipment van shows the interior layout. This is more clearly shown in Figure 4.

Figure 5 provides a summary view and description of one of the two identical control/display consoles shown in the previous equipment van layout.

No attempt is made in this paper to treat the technical details of the radar. However, the equipment represents a major step forward in instrumentation radar –equivalent to the introduction of the AN/FPS-16 in 1955.

The MOTR is likely to be the primary tracking system at ranges well into the 21st century. The radar adds significant technical capability to the test and training communities. It fosters long-term economy by reducing numbers of labor-intensive single-target tracking systems. It provides improved data accuracy, and above all, it provides the tool to accomplish the "real-world" testing that might be limited or even impossible to conduct with present instrumentation systems.

In addition, the design allows for "customization" through add-on features. Presently the following options are being discussed and considered:

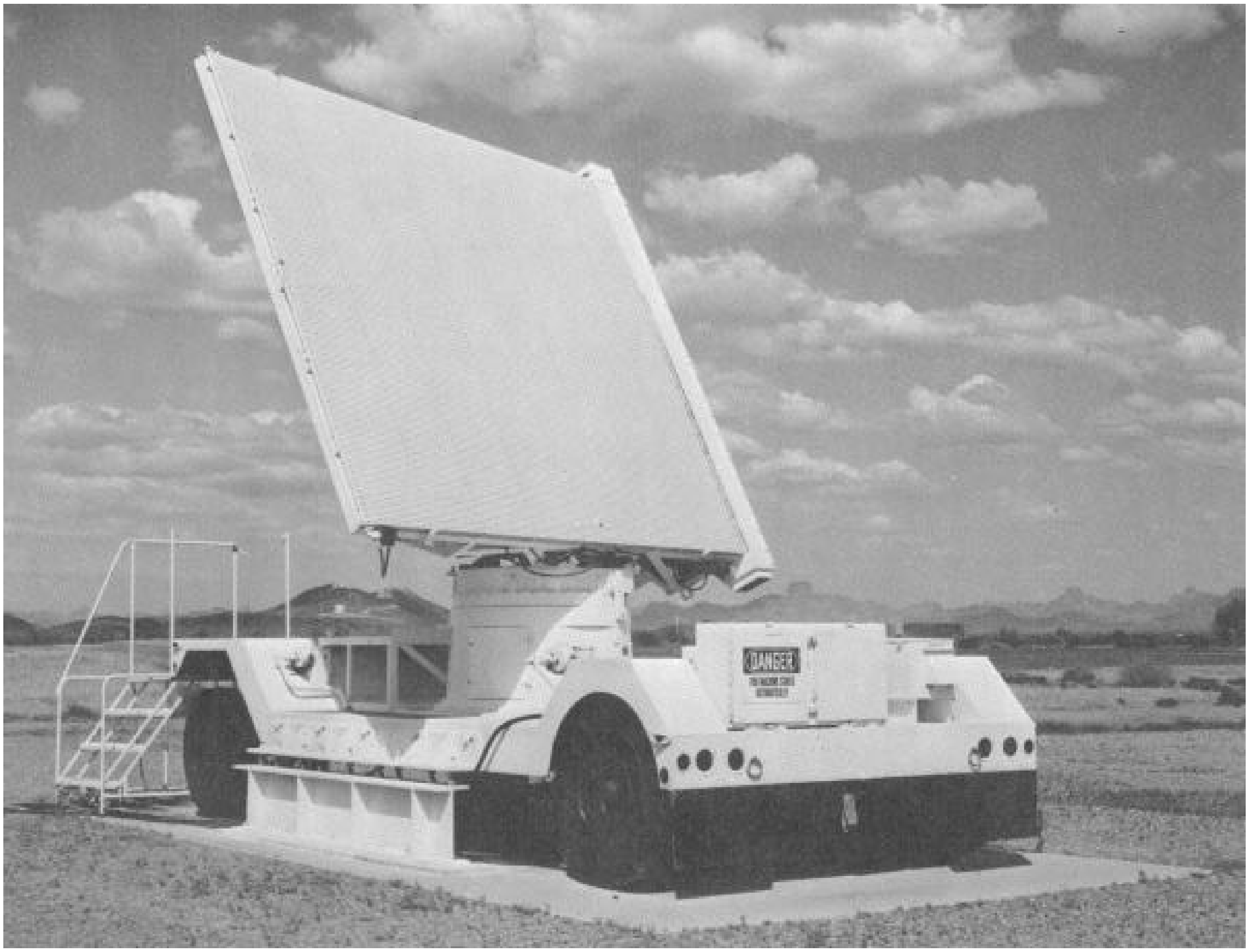
- Multiple Antenna Polarizations
- Nth tine on all targets
- Coherent Integration
- Clutter Supression
- Star and GPS Calibration
- Target Motion Resolution

In summary, instrumentation radars have fulfilled a crucial need for TSPI data on test ranges since the very earliest days of missile research. The evolutionary development of these systems has preceded in stages, and we are just now taking a major step up to a new plateau in instrumentation radar design. The MOTR is the state-of-the-art in instrumentation radars today, and it will have a significant impact on the way testing is to be conducted in the future.

TABLE 1. PERFORMANCE COMPARISON

CHARACTERISTIC	AN/FPS-16	AN/MPS-36	MTTR
Absolute Angle Accuracy* (20 dB S/N)	< 0.2 mil	< 0.4 mil	< 0.2 mil
Relative Angle Accuracy* (20 dB S/N)	0.3 mil	0.6 mil	0.15 mil
Range Accuracy*	5 yds	3 yds	< 1 yd
Range (on $1M^2$ target)	150 NM	190 NM	310 NM (10 µsec PW) 460 NM (50 µsec PW)
Azimuth Rate mils/sec Acceleration mils/seC^2	750 1,020	1,000 400	2,000 25,000
Elevation Rate mils/sec Acceleration mils/sec^2	400 1,020	500 400	1,500 25,000
Range Rate yds/sec Acceleration yds/sec^2	10,000 1,400	20,000 5,000	20,000 5,000

*All values are rms


DANGER

MOTR System Diagram

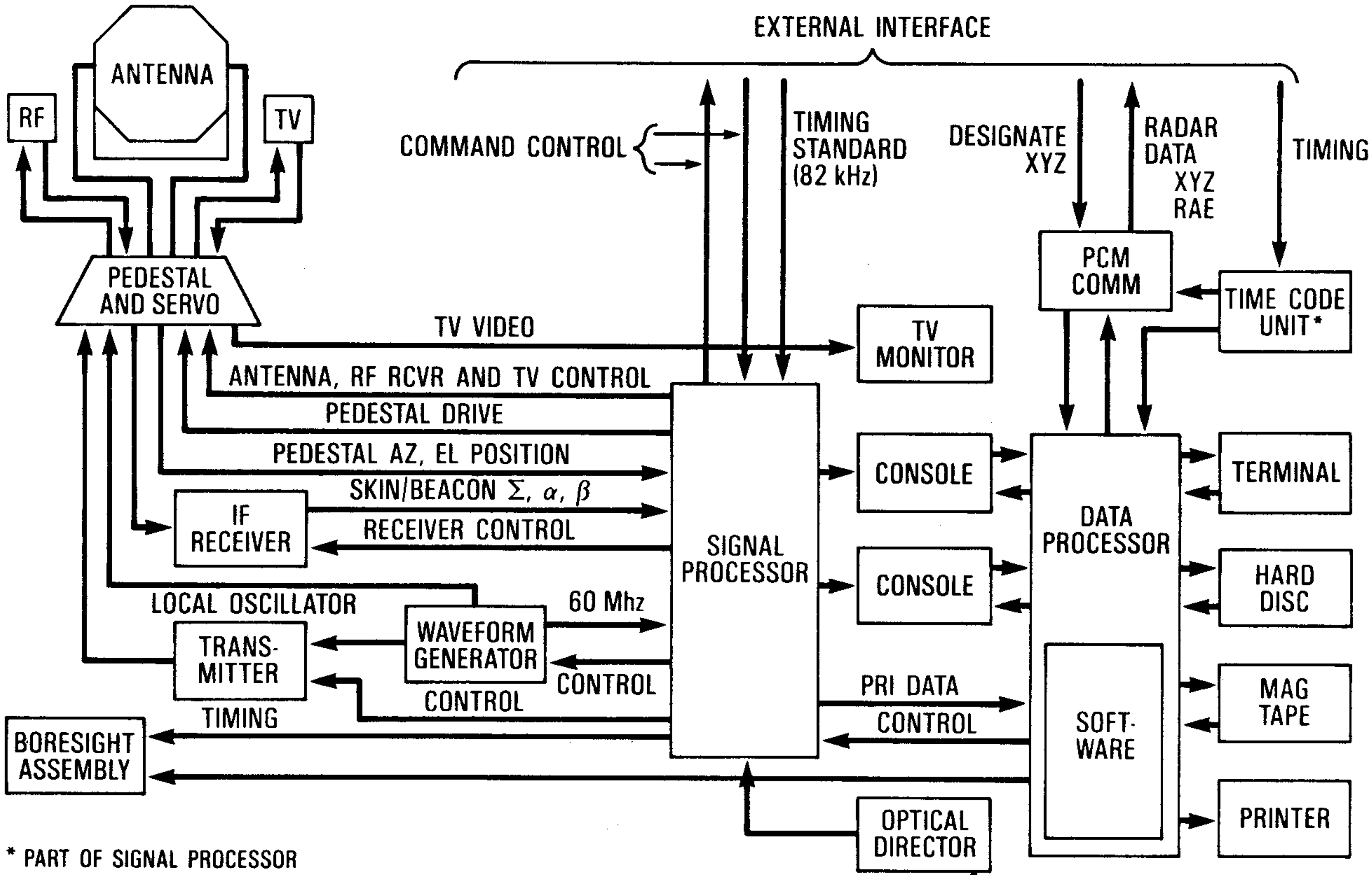


FIGURE 2. SYSTEM BLOCK DIAGRAM AND TYPICAL RANGE INTERFACES

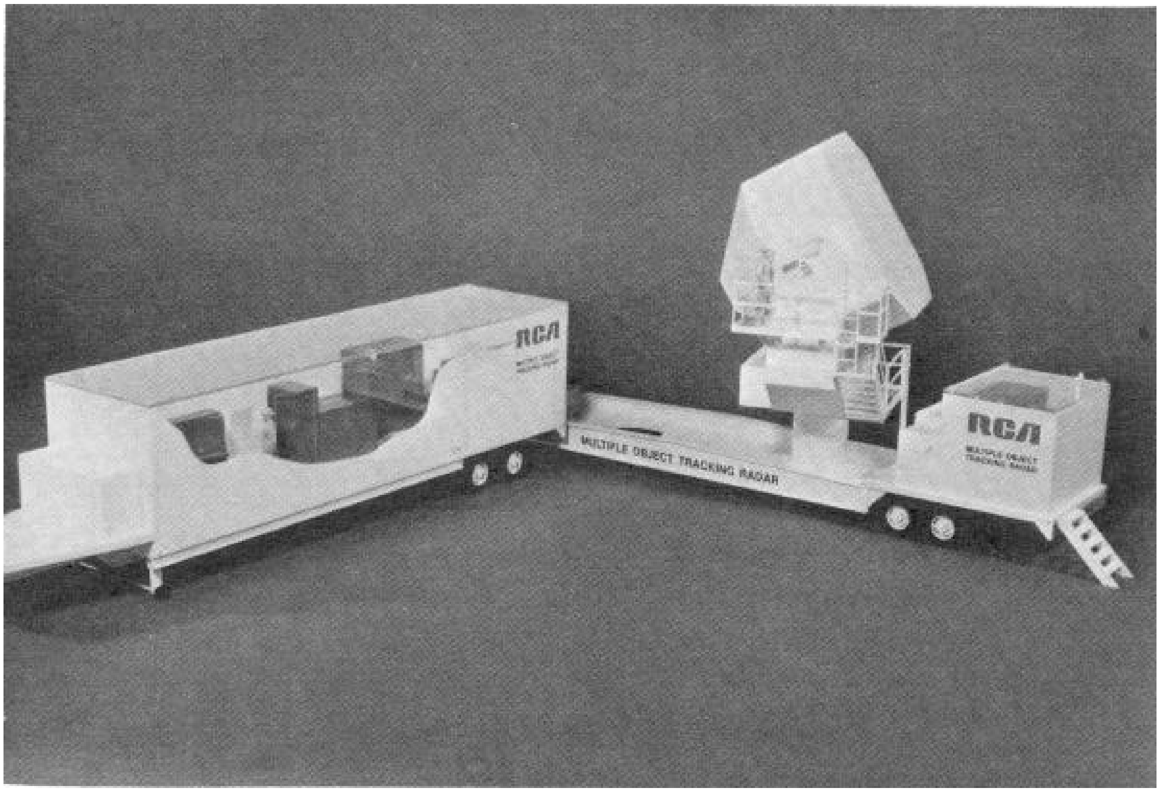


FIGURE 3. ENGINEERING MODEL OF THE MULTIPLE TARGET TRACKING RADAR (MTTR).

Radar Electronics Van Layout

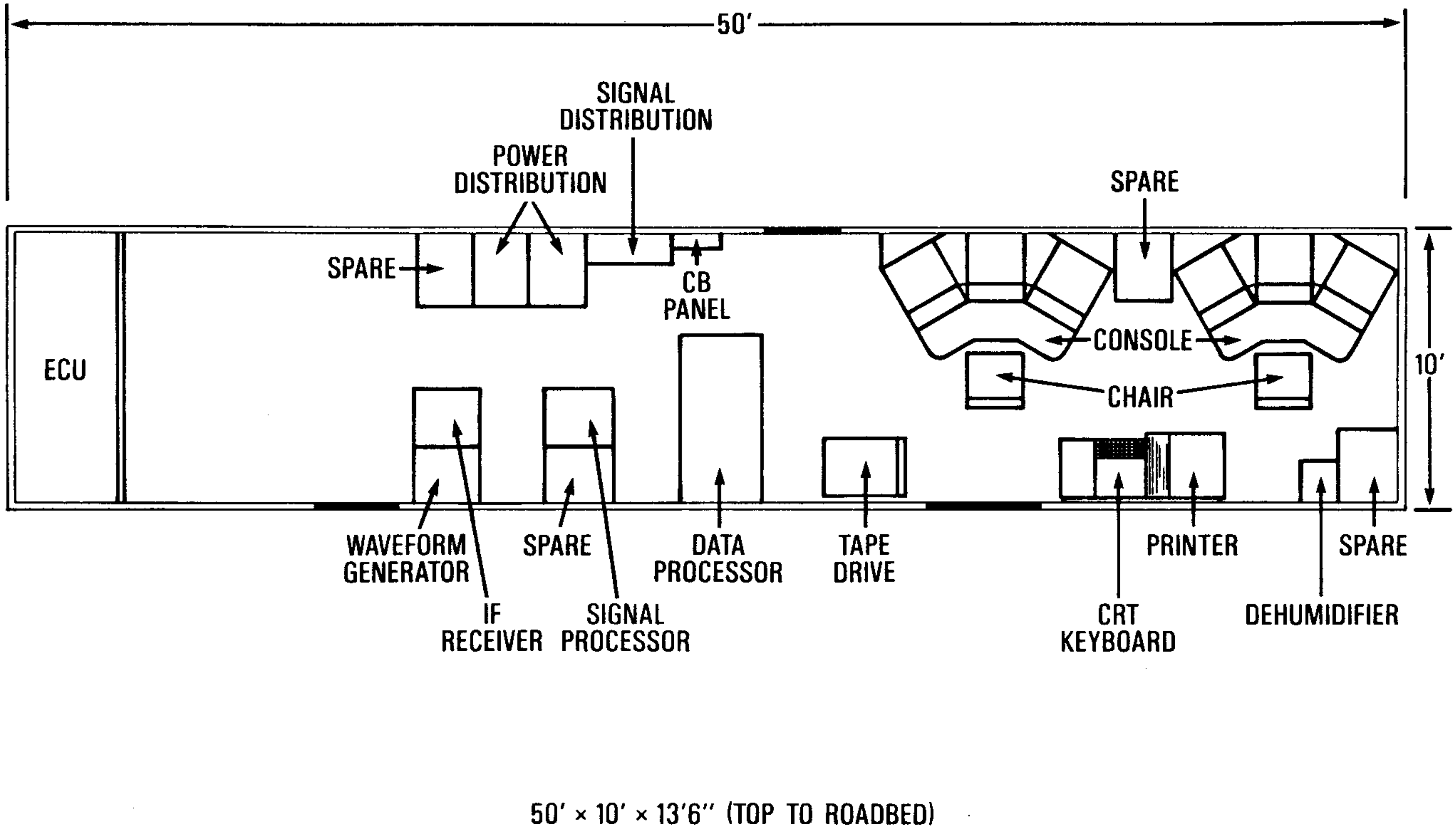


FIGURE 4. INTERIOR LAYOUT, ELECTRONIC EQUIPMENT VAN

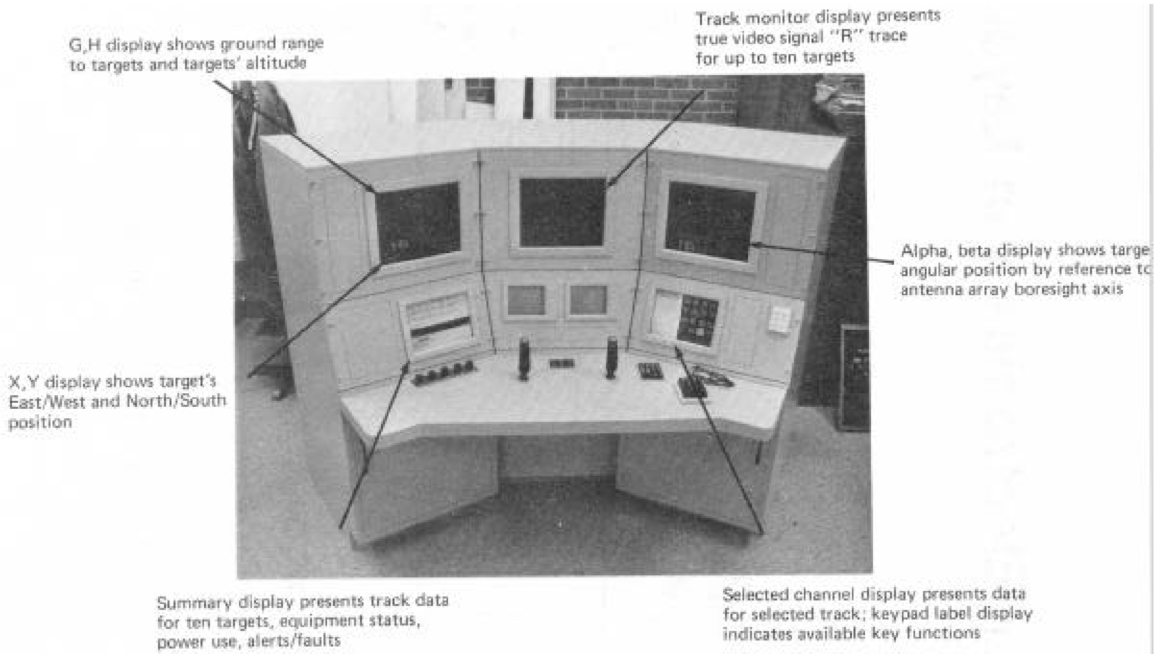


FIGURE 5. IDENTICAL CONTROL/DISPLAY CONSOLES