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A PROPOSED COURSE FOR AVIONICS TECHNICIANS.(U)

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December 1976

A Proposed Course for Avionics Technicians

Richard E. Duren

A Project AIR FORCE report
prepared for the
United States Air Force

Rand
SANTA MONICA, CA. 90406

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One of a series of three reports examining personnel and training support for advanced avionics systems, this report describes an initial training course which would better prepare airmen to maintain avionics equipment on the flight line. The course is significantly different from the current training course. It is given by and at a Field Training Detachment at the air base to which an airman is assigned; training is on the specific avionics equipment to be maintained; only material relevant to actual tasks is given; and the importance of a "block diagram" understanding of the avionics system (as opposed to a basic electronics understanding) is emphasized. (JDD)

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PREFACE

This study was requested by the Tactical Air Command with the aim of finding solutions to problems that it was having with advanced avionics systems. Rand responded by initiating research in two areas. The Project AIR FORCE (formerly Project RAND) Logistics Program undertook studies in the area of avionics hardware/software reliability. The Project AIR FORCE Manpower, Personnel and Training Program undertook a broad inquiry into personnel and training support. This report is the result of the latter effort. It was produced as part of the "Personnel and Training Support for New Avionics Systems" study.

The report describes an initial training course which, based on detailed analysis of the job of maintaining integrated avionics and the author's own experience as an engineer on the Mark II avionics system, would better prepare airmen to maintain avionics equipment on the flight line. It is one of a series of Rand reports examining personnel and training support for advanced avionics systems. Others in the series are:

R-1894-AF, *The Relevance of Training for the Maintenance of Advanced Avionics*, Polly Carpenter-Huffman and Bernard Rostker.

R-2017-AF, *Analysis of the Content of Advanced Avionics Maintenance Jobs*, Polly Carpenter-Huffman, John Neufer, and Bernard Rostker.

SUMMARY

This report describes an initial training course which would, in the author's view, better prepare airmen to perform flight-line maintenance on the F-111D avionics system than does current initial training. The approach used may be applicable to the F-15, F-16, and other F-111 models. General features of the course were developed through direct observation of job performance, interviews, observation of formal training, discussion of flight-line maintenance with technically qualified personnel, and the author's specific Mark II background.

The proposed course would be given by a Field Training Detachment (FTD) at the particular air base to which an airman is assigned. Beginning stages of the course would emphasize the overall nature of the job, with the remainder of the course generally providing a mixture of background and specific task knowledge.

After learning about the job, students would study a modest amount of basic electronics and be introduced to the avionics hardware. The task of removal and installation of Line Replaceable Units (LRUs) would then be taught. Students would also study the mission of the weapon system, which would naturally introduce the topics of navigation and weapon delivery. After learning navigation and weapon delivery principles, the role of the avionics equipment in the mission, and how these roles fit together, students would learn how to perform the operational checkout tasks. Students would then be provided a block diagram understanding of each avionics subsystem, introduced to the Tech Orders, and assigned to the job for some specified time. The stage would then be set for the teaching of troubleshooting, which would cover all the standard troubleshooting tools, as well as any special techniques deemed appropriate. Final stages would be almost exactly like the actual flight-line job, with students working under supervision.

The course described in this report is significantly different from the current training course. It is given totally by a FTD, uses the specific avionics equipment to be maintained almost from the beginning, contains only material relevant to actual tasks performed on the

job, emphasizes the roles of the equipment and how the roles fit together, recognizes the importance of a block diagram understanding of the avionics system (as opposed to a basic electronics understanding of the avionics system), and attempts to teach students about the job and how to perform it. Based on these differences, the proposed course would provide better preparation for the job than does the current training course.

ACKNOWLEDGMENTS

The author is indebted to Rand colleagues Bernard Rostker and Polly Carpenter-Huffman for their assistance and wishes to extend a very special thanks to Polly Carpenter-Huffman for her contribution during the preparation of this report.

He would also like to thank Lieutenant Colonel John Schira (Headquarters, Tactical Air Command) and Staff Sergeant Fred Benjamin (27th Avionics Maintenance Squadron, Cannon Air Force Base) for their review of a working copy of this report and for their very important contributions to the research.

CONTENTS

I. INTRODUCTION

This study was initiated in response to a Tactical Air Command request for a "disinterested agency" study of problems the Air Force was having supporting the Mark II avionics system in the F-111D aircraft.* Previous work at Rand has concluded that: (1) personnel support problems exist for all advanced avionics systems, (2) flight-line maintenance of advanced avionics is both complex and unlike maintenance of older systems, and (3) portions of the current training for flight-line maintenance personnel are inadequately related to the job. In particular, a significant fraction of the electronic fundamentals appeared to be irrelevent to job performance.

The purpose of this report is to describe an initial training course that would better prepare airmen to perform flight-line maintenance on the bomb/navigation portion of the Mark II avionics system. The course would be given totally at the air base where the men are assigned, would make full use of available equipment, would be related to the avionics system the airmen will be maintaining, and would attempt to teach students how to actually perform the job.

The next section of this report provides general background information, and Sec. III presents the structure of the proposed initial course. The reader should remember that the course described is only an initial course, and additional training would most certainly be made available to those who reenlist.

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*Letter and attachment from Colonel V. R. Hollandsworth, Director of Maintenance Engineering, Headquarters, Tactical Air Command, 5 November 1973.

II. BACKGROUND

The F-111D avionics system is an excellent example of a complex and highly integrated avionics system. Avionics systems can be thought of as being composed of sensors, computational units (analog or digital computers), functional control units, and displays.

Because of advances in computer technology, bomb/navigation avionics systems have progressed from "redundant" systems that employ separate sensors, computers, and display units for each system to "integrated" systems. The first, and simplest form of integration consisted of combining all computational capability in a single executive computer. More powerful digital computers were a means with which to simultaneously provide functional interfaces between subsystems and navigation and weapons delivery computations. The Mark II avionics system in the F-111D is the most complex avionics system in the Air Force's current inventory and uses a central converter-multiplexer to provide the necessary interface between two digital computers and other parts of the avionics system. Because of the complexity of this system and the high cost of diagnosing faulty units on the flight line, it was designed with built-in test equipment (BITE) which was expected to detect and isolate malfunctioning units 95 percent of the time without the use of external Aerospace Ground Equipment (AGE).

The avionics package was to be supported by three levels of maintenance: (1) organizational, (2) intermediate, and (3) depot. Organizational maintenance is performed at the flight line on an aircraft and, usually, consists of isolating a malfunction to a defective Line Replaceable Unit (LRU) and replacing that unit with an operable unit of the same type. Intermediate maintenance consists of restoring a defective LRU to an operable state and is performed at the field shop on the operating base with the aid of test stations. Test stations monitor test points within the internal circuitry of an LRU and compare measured values with what are thought to be acceptable values. Ideally, this process isolates a malfunction to the appropriate Shop Replaceable Unit (SRU), usually a printed circuit board. Some test stations are controlled manually whereas others are computer controlled. Depot maintenance is concerned with the repair of malfunctioning SRUs.

In order to support this maintenance concept, the Air Force has separated flight-line and field shop responsibilities. Flight-line maintenance occupations are divided into three Air Force Specialty Codes (AFSCs): 326X2A (the AFSC of primary interest in this report), 326X2B, and 326X2C. Those having a 326X2A AFSC are responsible for the inertial navigation system, fire control systems, digital computers, and multisensor displays. Those having a 326X2B or 326X2C AFSC are responsible for the flight control and integrated/mechanical instruments, or communication, navigation, and electronic countermeasures (ECM) systems, respectively. The "X" in the above AFSCs represents skill level; in general, an airman progresses from the "1" or helper level, to the "3" or apprentice level, through the "5" or specialist level, to the "7" or technician level. For example, an airman having a 32632B AFSC is responsible for maintaining the flight control and integrated/mechanical instruments and possesses an apprentice skill level.

Simply stated, the job performed by those in the 326X2A career field is to restore the bomb/navigation portion of the avionics system to an operable state (most often by removal and installation of LRUs). A majority of the jobs involve determining which LRU is defective and solving the aircraft bomb/navigation avionics problem by replacing that LRU with an operational LRU of the same type. The process of determining which LRU is defective is often called "fault isolation" and is a most challenging part of the job. Other repairs might involve fixing a faulty wire, connector, or pin; however, these repairs usually are made after it has been determined that the system is probably free of defective LRUs, with additional troubleshooting then leading to the discovery of a broken wire, connector, or pin. Sometimes it is even necessary to prove that repairs are not required.

Flight-line troubleshooting was orginally supposed to consist simply of observing Failure Status lamps on the Avionics Test Panel (ATP) in the cockpit and reading a printout from the Maintenance Control Unit (MCU), an LRU in the avionics system; however, subsequent operational use showed the ATP and MCU to be inadequate, as was confirmed by the

Fault Isolation Verification Program conducted by the Convair Aerospace Division of General Dynamics.[1] Failure of the ATP and MCU to provide adequate fault isolation capability, coupled with the highly complex and integrated nature of the avionics system, resulted in far more maintenance hours than originally contemplated along with an increased rate of hardware deterioration.

To help alleviate this situation, alternate troubleshooting methods have been developed. One very important and useful troubleshooting technique is "computer-addressing," which was first introduced at Cannon AFB and subsequently became an accepted technique.* Further, Tech Orders are being continuously improved and there is an increased reliance on Tech-Order-directed troubleshooting.

To prepare him for the flight-line maintenance job and for career advancement, an airman assigned to the 326X2A AFSC is currently sent to Lowry Technical School for formal "two-level" training. Two-level training (phase I of the initial training) presently includes basic electronics, principles of modulation and analog systems, digital computer principles, general radar principles, general navigation principles, safety and security regulations, use of Tech Orders, and maintennance and inspection forms.

After successfully completing the two-level course, an airman arriving at Cannon AFB receives three-level training (phase II of the initial training) given at the Field Training Detachment (FTD). This training includes functional analysis of systems, system integration, operational checkout, flight-line safety, use of test equipment, removal and replacement of LRUs, some troubleshooting, and use of Tech Orders and checklists throughout the course. Much (if not all) of this training is relevant to job performance, and those portions should be included in the course described in this report.

Tactical Air Command and Air Training Command recognize the importance of training for flight-line maintenance; further, they recognize that many of the skills and much of the knowledge required for the

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*This technique uses computers to investigate the status of the avionics system.

flight-line maintenance job are specific to the Mark II avionics system. This is evidenced by the TAC-conducted Task Oriented Training (TOT) program at Cannon AFB, the purpose of which was to provide TAC with more practical maintenance training. It is also evidenced by the fact that Air Training Command has moved the second phase (phase II) of initial training to the FTD at Cannon AFB; this provides students a greater opportunity to learn the particular avionics system they will be maintaining.

But initial training of those who will be maintaining the bomb/navigation portion of the Mark II avionics system still has shortcomings in preparing airmen to perform flight-line maintenance. The first phase (phase I) of the initial training, i.e., the phase given at Lowry AFB, is too abstract in that material is not tied to the avionics system the airmen will be maintaining; further, there is superfluous material. In general, it appears that there is not enough effort spent teaching the specific avionics system of interest as an integrated whole in either phase I or II of the current training.

III. PROPOSED INITIAL TRAINING

A detailed concept for an initial course to train airmen for flight-line maintenance of the bomb/navigation avionics system in the F-111D is presented in this section. The concept assumes trainees are going to have the same responsibilities as those currently performing flight-line maintenance. The course of study considers that desirable training should teach what is required to perform the job and should have the following features:*

1. (a) Introduce students to Tech Orders.
   (b) Provide the capability to understand Tech Orders.
   (c) Provide the capability to carry out Tech-Order-directed tasks.
2. Provide an understanding of the role of the equipment in the weapon system's mission.
3. Concentrate on the avionics system the airmen will be maintaining.
4. Provide a "block-diagram understanding" of the avionics system along with the location of the blocks (LRU locations).†

Furthermore, initial training would be accomplished entirely by the FTD on the particular air base to which airmen are assigned, i.e., airmen would report directly to the base after completion of basic military

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*These features are based on the author's direct observation of job performance at Cannon and Nellis Air Force Bases, interviews with people performing the job, with expert job performers, with FTD and technical school instructors, observation of formal technical training at Lowry Air Force Base, study of existing two-level training materials, discussion of flight-line training with other technically qualified personnel, and personal knowledge of the Mark II system.

†Appendix A defines a block diagram, provides a block diagram of a typical radar, illustrates that the function of an electronic apparatus can be understood without a detailed basic electronics understanding of the apparatus, and discusses a block diagram as it relates to the knowledge apparently possessed by the best job performers.

training because of the availability of the actual equipment that an airman will be maintaining as well as of instructors who know the nature of the maintenance job and the pertinent avionics system in detail.

The basic structure of the proposed course of study is illustrated by looking at the sequence of training events. When a new class arrives, it would first learn general safety procedures to be applied around aircraft and powered AGE, and be taken on a tour. The airmen would observe maintenance personnel performing the job they will be trained to perform; further, this tour should leave little doubt in their minds about the general nature of the job. In addition, they would be shown supply points and the test stations in the intermediate shop; the purpose of the supply points and test stations as they relate to the job would be explained by the instructors. The tour might also include the maintenance control complex, quality control area, and Tech Order library, with the instructor explaining their relationship to the job. Students should be impressed with two things: (1) the avionics system they will be maintaining is complex and (2) even though the system is complex, there are airmen, just like themselves, maintaining the system. At this point, they should recognize their need for training and be ready to accept it. Students would then be given a briefing on the job and how it is conducted; this would include an introduction to any forms that they may have to fill out. Students would then be "walked through" a "typical" job so that they can see the various tasks to be performed.

Next, students would study basic electronics for two weeks; this would be a job-relevant version of the material contained in the first four instructional blocks of the present two-level course.* A very natural question arises at this point: Why not teach airmen what they need to know about basic electronics or any other subject while they are actually learning to do the job? Such an approach would provide a derivation of the precise knowledge needed by the airmen and might prove to be the best way to train them; however, more research is

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*Appendix B provides the author's estimate of the time required per subject in the basic electronics portion of this course.

required before the author could describe such a course. A modest amount of basic electronics material is included, primarily so that students will be able to understand the Tech Orders; this could be explained to the students. Also, teaching this material early in the course will better prepare a student to explore the Tech Orders on his own without constant assistance from an instructor. This part of the initial training could probably be somewhat reduced if revised versions of the Tech Orders eliminate a need for this type of background.

After basic electronics, training would differ significantly from present training. An extremely simple diagram of the integrated avionics system would be produced to introduce the equipment and system integration and to provide a point of reference for subsequent training. Figure 1-4 and Fig. 1-5 in T.O. IF-111D-2-5-1 approximate what this diagram might look like, but they are incomplete. Figure 1, showing the serial digital channel system tie-in, is a reproduction of Fig. 1-4. In general, an entry in the diagram could represent a group of LRUs whose collective actions can be readily described and understood as they relate to the weapons system. Quite often such groups of LRUs would form a subsystem of the avionics system, so that some of the entries would certainly be subsystems like the attack radar set, doppler radar set, terrain following radar set, and inertial navigation set. However, due to the highly complex and integrated nature of the system, some entries may not be easy to select. At any rate, an entry on this diagram is called a "subsystem" in this report even though it might turn out to be a single LRU. Students would learn the names of the LRUs composing each subsystem and be shown the equipment both on and off an aircraft. This would be a good time to explain that electronic components inside these LRUs can fail and that a significant requirement of the airmen's job is to perform fault isolation on an aircraft followed by removal of the defective LRU and the installation of a serviceable LRU of the same type. Training would now concentrate on the proper method of removal and installation of LRUs on an aircraft as directed by the Tech Orders. During this part of the training, students would also learn how to repair connectors and to solder; in particular, they would learn how to perform these tasks on the troublesome

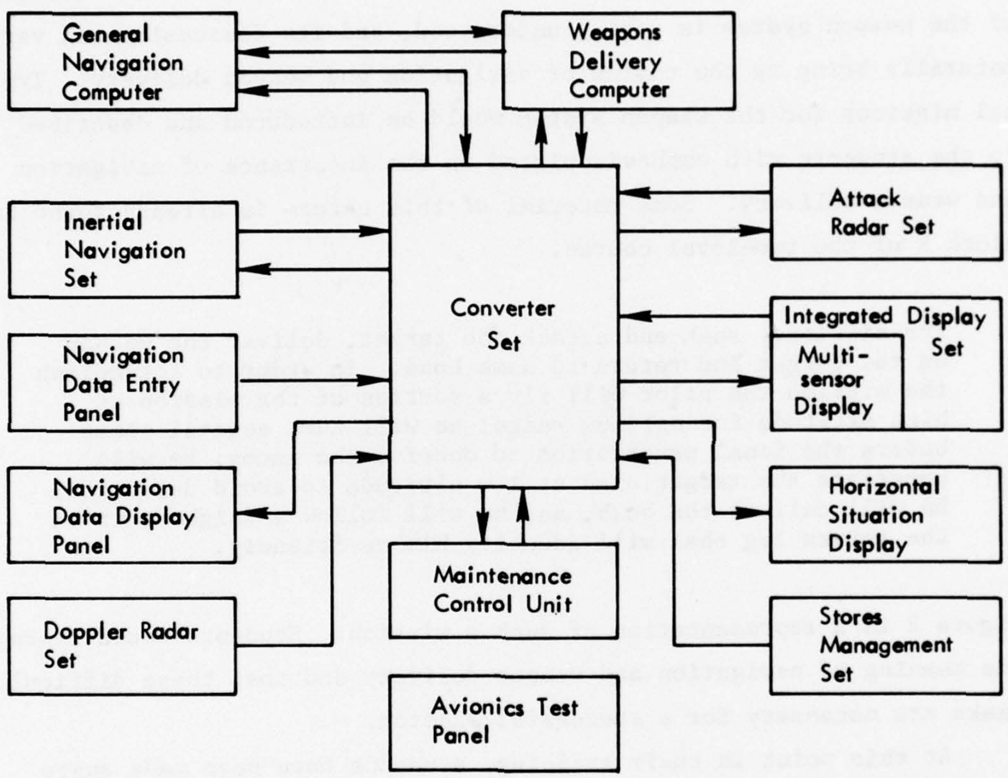

Fig. 1 — Figure 1-4 of T.O. IF-111D-2-5-1

connectors and solder points found in the aircraft. Here is also an opportune time to teach students how to find and read plug and pin numbers.

All the avionics equipment plays some role in the mission of the weapon system, and before proceeding to describe the role of the equipment, students should first learn about the mission; perhaps a motivational film could be shown to the students at this point. The mission of the weapon system is easily understood, and its discussion can very naturally bring up the topics of navigation and weapon delivery. Typical missions for the weapon system would be introduced and described to the students with emphasis placed on the importance of navigation and weapon delivery. Some material of this nature is already found in block X of the two-level course.

> The mission: seek and attack the target, deliver the weapon on the target and return to home base. In order to accomplish the mission the pilot will fly a portion of the mission at high altitude for optimum range; he will turn several times before the final penetration to deceive the enemy; he will penetrate the target area at low altitude to avoid detection, he will deliver the bomb, and he will follow a flight path on the return leg that will identify him as friendly.

Figure 2 is a representation of such a mission. Students would learn the meaning of navigation and weapon delivery and that these difficult tasks are necessary for a successful mission.

At this point in their training, students have been made aware of navigation and weapon delivery, but do not understand navigation principles, weapon delivery principles, or how the subsystems work together when the weapon system is navigating or delivering a weapon. Experience has shown the author that all of these are very important for students to learn.

Attention would now focus on navigation, navigation principles, the role played by each subsystem, and how the avionics system works as an integrated whole in each navigation mode of the weapon system. Pertinent portions of blocks V-X in the present two-level training materials would be utilized here, and the Tech Orders would be introduced

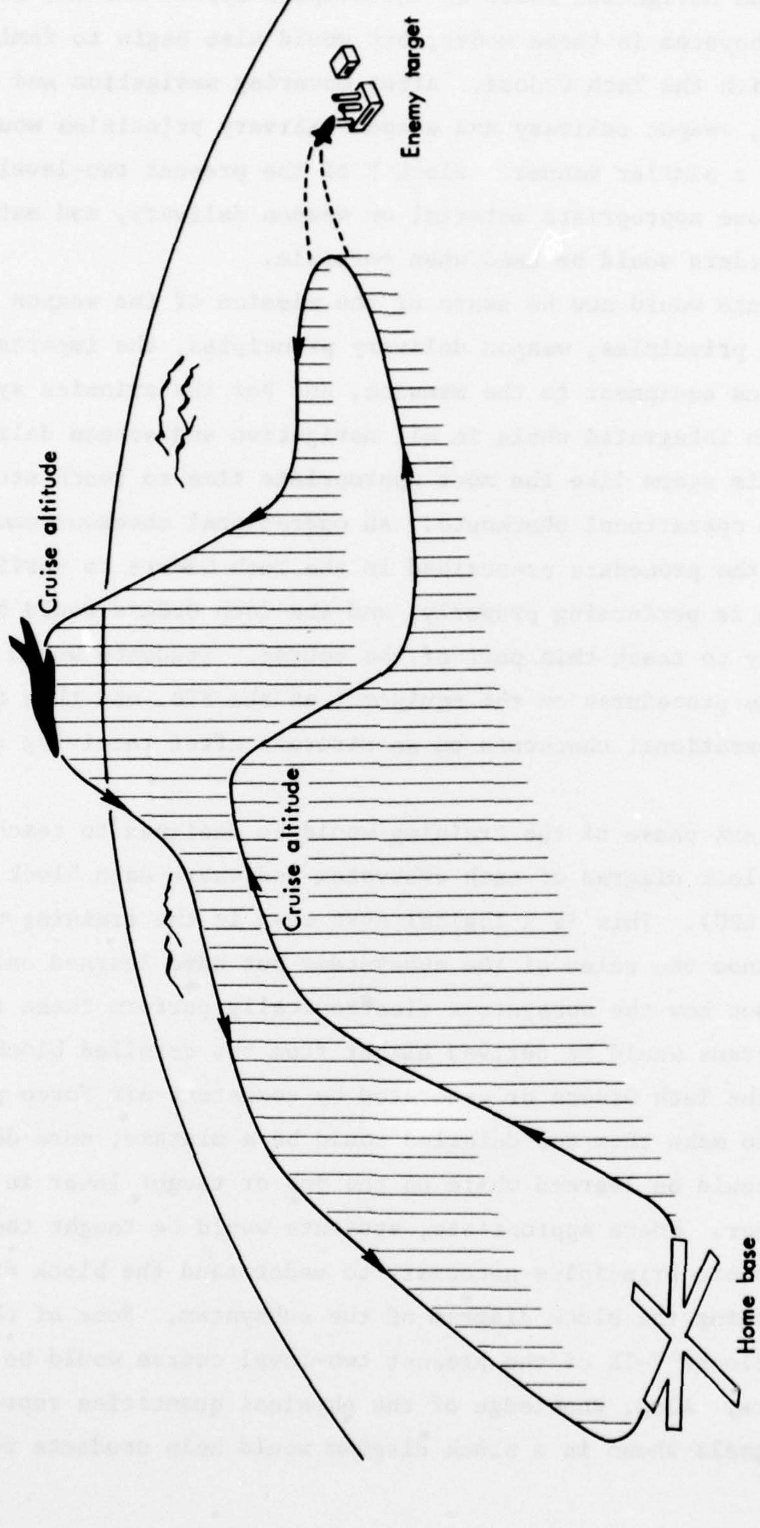

Fig. 2 — A mission profile

directly into the course at this point. This would not only teach the students the navigation modes of the weapons system and the role played by each subsystem in these modes, but would also begin to familiarize students with the Tech Orders. After covering navigation and navigation principles, weapon delivery and weapon delivery principles would be covered in a similar manner. Block X of the present two-level course contains some appropriate material on weapon delivery, and material in the Tech Orders would be used when possible.

Students would now be aware of the mission of the weapon system, navigation principles, weapon delivery principles, the importance of the avionics equipment to the mission, and how the avionics system works as an integrated whole in all navigation and weapon delivery modes. This seems like the most appropriate time to teach students how to perform operational checkouts. An operational checkout amounts to following the procedure prescribed in the Tech Orders to verify that the system is performing properly, and the Tech Orders would be used exclusively to teach this part of the course. Students would first go through the procedures on the equipment at the FTD, and then actually perform operational checkouts on an aircraft after receiving egress training.

The next phase of the training would be designed to teach airmen a simple block diagram of each subsystem and where each block resides (in which LRU). This is a logical next step in the training because students know the roles of the subsystems but have learned only a little about how the subsystems electronically perform these roles. Block diagrams would be derived either from the detailed block diagrams found in the Tech Orders or generated by competent Air Force personnel. Attempts to make them too detailed could be a mistake; more detailed diagrams could be learned while on the job or taught later in an airman's career. Where appropriate, students would be taught the physical and electronic principles necessary to understand the block diagrams while learning the block diagram of the subsystem. Some of the material found in Blocks V-IX of the present two-level course would be appropriate here. Also, knowledge of the physical quantities represented by the signals shown in a block diagram would help students relate the functions performed by blocks in the block diagram to the role of the subsystem in the mission. When possible, appropriate signals would either be picked off AGE connectors or tapped right out of the equipment and displayed to the class (at the FTD); this would help make the block diagram very real and reinforce the students' understanding of the locations of the blocks. Observing the inputs into a particular block as well as the outputs would also help reinforce the students' understanding of the function performed by a particular block.* To the extent possible, the Tech Orders would be exploited, and appropriate sections of them would be part of the course.

The next portion of the training would be designed to further familiarize the class with Tech Orders--their contents, interrelationships among different volumes of the Tech Orders, and when each volume might be required while performing a job. This portion of the training should not be hurried, because the Tech Orders are formidable and are used on the job.

Students would then be given a review of safety procedures, removal and installation of LRUs on an aircraft, reading plug and pin numbers, repairing connectors, soldering, and operational checkouts.

At this time, students would be assigned to the flight line in order to gain job experience. This experience will reinforce in the students' minds that a *very* significant portion of the job is troubleshooting, thereby setting the stage for their next part of training. After a prescribed amount of time (perhaps 4 to 6 weeks) on the job, students would be taught and would perform troubleshooting procedures, first on the FTD equipment and then on an aircraft. These troubleshooting procedures are in the Tech Orders and include all the troubleshooting tools, i.e., computer-addressing, MCU printout, and avionics test-panel readouts. Where appropriate, the rationale behind a procedure would be explained to the students by use of the previously presented block diagrams or the Tech Orders. Additional troubleshooting techniques and operation of necessary test equipment not already covered

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*The instructors would have the equipment ready for demonstration and the class would not participate in setting up the demonstration.

would also be included; students would learn how to perform wiring (continuity) checks during this part of the training.

The final part of the training would be almost exactly like the job. Students would go to the Avionics Maintenance Squadron and actually perform the job, under supervision, so that job related questions can be properly answered as they arise and students will have more confidence in their own actions when they officially start to work. This final portion of the training will include how to properly fill out all the required forms.

IV. CONCLUSIONS

An initial training course that concentrates on how a particular integrated avionics system works (at the functional level) and how to maintain it has been described. The course differs from current initial training in that it:

- Is given entirely by the FTD at the air base;
- Uses the actual equipment almost from the beginning of the course;
- Contains only material directly relevant to maintenance of the specific avionics system the airmen will be working on;
- Emphasizes the role played by each subsystem and how these roles fit together in the mission of the weapons system;
- Recognizes the importance of a block diagram understanding of the avionics system as opposed to a basic electronics understanding of the avionics system;
- Attempts to teach students about the job and how to perform it.

Based on these differences, this proposed training course would provide a better preparation for the 32632A maintenance job than does the current training course.

Appendix A

BLOCK DIAGRAM UNDERSTANDING OF AN AVIONICS SYSTEM

A block diagram consists of simple rectangles and circles with names or other designations within or adjacent to them to show the general arrangement of apparatus to perform the desired functions.[2] Each block often represents a significant amount of electronic apparatus whose function in a subsystem can be understood without addressing the details of how the apparatus works. Each block performs a function required for the subsystem to play its role in the weapon system. Figure 3 shows a block diagram of a typical radar. Arrowheads on a line indicate the direction of signal flow.

For the purposes of discussion and illumination, consider the mixer shown in Fig. 3; it has two inputs and one output, as shown in greater detail in Fig. 4. One input is a radar echo signal with a frequency f_{RF} and the second input is a local oscillator input whose frequency is f_{LO}. The function of the mixer is to translate the echo signal frequency from its original frequency f_{RF} down to the intermediate frequency f_{IF}.[3] So, the output of the mixer is an echo signal at the intermediate frequency. Intermediate frequencies generally lie between 0.1 to 100 MHz, and shifting the echo signal frequency is desirable because amplification at intermediate frequencies is usually less costly and more stable than at typical transmission frequencies.[4] Functionally, the mixer is easily understood without a detailed understanding of the mixer, as can be demonstrated by an extremely simple example. The schematic diagram of a diode mixer in Fig. 5[5] shows an echo signal (frequency = f_{RF}), local oscillator (frequency = f_{LO}) and output signal (frequency = $f_{IF} = f_{RF} - f_{LO}$). Since it is a schematic of a mixer, it also shows an arrangement of electronic components which produces the transition from f_{RF} to $f_{IF} = f_{RF} - f_{LO}$. Knowledge of basic electronics is required to understand Fig. 5, but the function of the mixer can be comprehended without detailed basic electronics knowledge.

The best job performers appear to have an understanding of (1) where various blocks reside (in which LRU), (2) which blocks (inside

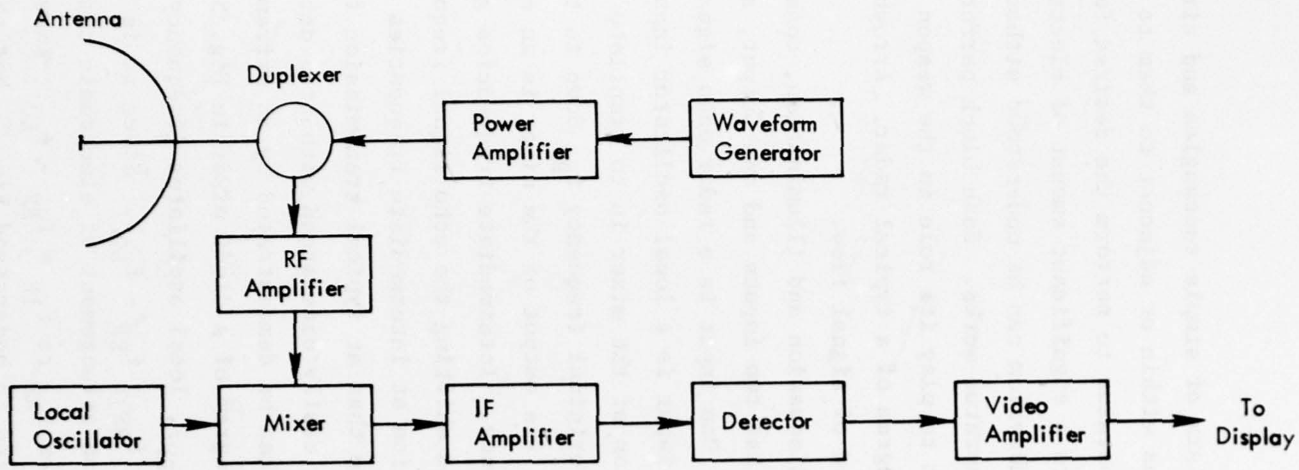

Fig. 3 — Block diagram of a typical radar

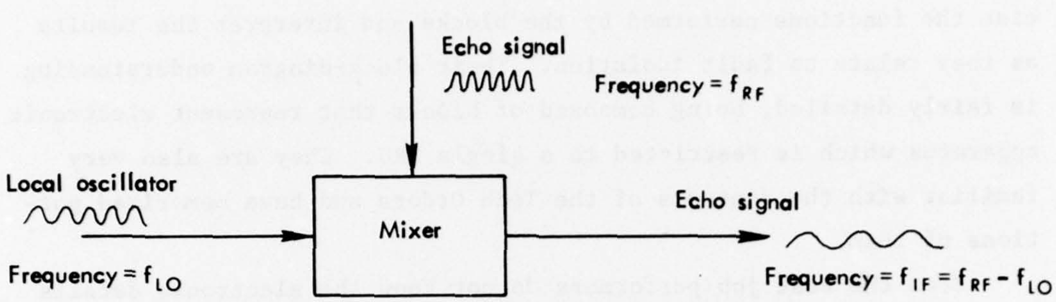

Fig. 4 — Mixer block diagram

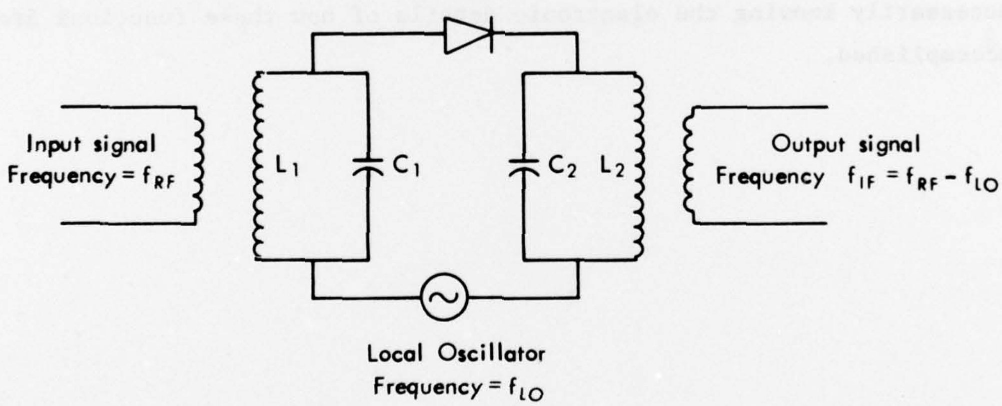

Fig. 5 — Schematic of a diode mixer

an LRU) are used in different modes of operation, (3) the direction of signal flow among these blocks, (4) how the failure of a block to perform its function could affect the weapon system, and (5) how to exercise the functions performed by the blocks and interpret the results as they relate to fault isolation. Their block-diagram understanding is fairly detailed, being composed of blocks that represent electronic apparatus which is restricted to a single LRU. They are also very familiar with the contents of the Tech Orders and have memorized portions of them.

Even the best job performers do not know the electronic details of how every LRU accomplishes its role. There are simply too many LRUs and they are too complicated for the airmen to learn all these details while performing their regular jobs. The point here is that an individual can perform well on the job if he can determine that the electronic functions being performed within an LRU are not adequate for proper system operation, and he appears to be able to do this without necessarily knowing the electronic details of how these functions are accomplished.

Appendix B

REVIEW OF BASIC ELECTRONICS MATERIALS

Course material currently used to train airmen to perform the duties of an Integrated Avionics Systems Specialist, AFSC 32622A, includes basic electronic fundamentals, principles of modulation and analog systems, computer principles, general radar and navigation system principles, and a general introduction to the 326X2A career field. This material would be of interest to anyone who wants to learn about electronics and electronic systems.

The table displays the Block of Instruction, subjects covered, and the time now allocated per subject. Also shown are the author's estimates of the time needed to cover the job-relevant material contained in each basic electronic subject in Blocks I through IV. They are based on personal experience, discussions with members of Rand's Engineering staff, conversations with other engineers, discussions with Air Force personnel, and a review of the two-level material; the author's total time estimate for basic electronics sums to 59.5 hours. Since there are 30 hours per week spent in class, the job-relevant material in these four blocks should be able to be taught in about two weeks; presently 162 hours (5.4 weeks) are spent covering this material.

Independent estimates of the time necessary to cover the job-relevant material in each subject were supplied by other Rand researchers; they are also shown in the table. Their estimate for each subject was based on informal discussions with expert Air Force personnel and technical representatives and, over the first four blocks, sum to 40 hours (1.3 weeks), which is much closer to the author's estimate than it is to the total time allocation for basic electronics in the current course.

Blocks V-X include material on modulation and analog systems, computer principles, and general radar and navigation system principles. Most of this material would be learned in the course described in the main text but it would be learned while students are working with their particular avionics system. This would clearly make that material more meaningful to them.

TWO-LEVEL COURSE MATERIAL

Block Number	Title and Subject	Present Time Allocated (hr)	Estimates Supplied by Other Rand Researchers[a]	Author's Recommendation
I.	Introduction to Electronics			
	Orientation	2	2	2
	Integrated Avionics System Career Field	1	0	1
	Communications Security	2.5	2.5[b]	2.5
	Safety and First Aid	1	2	1
	Structure of Matter	0.5	1.5	0
	Theory of Electron Flow	1	1	.5
	Powers of Ten and Metric Conversion	4	0	.5
	Resistance and the PSM-6 Ohmeter	4	8	2
	DC, Ohms Law, and Power Law	6	0	1
	Series Circuit Analysis	8		2
	Parallel Circuit Analysis	8	8	2
	Series-Parallel Circuit Analysis	8		2
	Voltage and Current Dividers	2	0	0
	Troubleshooting Fundamentals	2	0	0
II.	AC Generation, Reactance, and Test Equipment Operation			
	Magnetism and Magnetic Devices	4	2[c]	2
	Principles of Alternating Current and Its Generation	5	0	2
	DC Motors	1.5	4	1.5
	AC Motors	1.5		1.5
	Transformers	2	1	1
	Saturable Reactors and Magnetic Amplifiers	2	0	0
	Vacuum Tube Voltmeter Operation	4	0	2
	Oscilloscope Operation	4	0	4
	Reactance and Reactive Circuits	8	0	4
	Resonance	8	0	4
III.	Solid State Theory (Part I)			
	Physics of Electricity	1	0	0
	Solid State Theory	15	0	2
	Rectifiers	3	1	3
	Filters	3	1	3
	Transistor Theory	8	2	3
	Basic Amplifier Configurations	6	2	6
	Audio Amplifiers	4	0	2
IV.	Solid State Theory (Part II)			
	Regulated Power Supplies and Zener Diodes	7	2	1
	Unijunction Transistors	4	0	0
	Field Effect Transistors (JFET)	3	0	0
	Field Effect Transistors (MOSFET)	3	0	0
	Transients and Time Constants	5	0	0
	Basic Oscillator Principles	6	0	1
	Integration	2	0	0
	Differentiation	2	0	0
		162	40	59.5
V.	Principles of Modulation and Analog Systems			
	Heterodyning	4		
	Amplitude and Frequency Modulation	4		
	Demodulation and Detection	4		
	Chopper Circuits	1		
	Introduction to Integrated Circuits	1		
	Operational Amplifiers	3		
	Servo Control Systems	13		
	Analog Computers	4		

(continued)

Block Number	Title and Subject	Present Time Allocated (hr)	Estimates Supplied by Other Rand Researchers[a]	Author's Recommendation
VI.	Introduction to Digital Computer Techniques			
	Digital Computers	1		
	Number Systems	7		
	Logic Circuits and Truth Tables	8		
	Boolean Algebra	6		
	Timing and Shaping Circuits	14		
VII.	Digital Computer Units and Systems			
	Adders, Complementors, and Comparators	8		
	Registers	8		
	Decoders and Encoders	8		
	Counters	4		
	Programming the Computer	4		
	Computer Components	4		
VIII.	Basic Radar Principles			
	Principles of Radar	7		
	Synchronization Devices	1		
	Antennas	5		
	Transmitters	11		
	Receivers	5		
	Radar Displays	5		
IX.	Principles of Navigation			
	Introduction to Navigation	2		
	Earth and its Coordinates	6		
	Maps and Charts	8		
	Dead Reckoning	8		
	Lines of Position, Bearings and Fixes	8		
	Celestial Concepts	4		
X.	General Airborne Navigation Systems			
	Airborne Avionic Navigation Systems	7.5		
	Inertial Navigation Systems	11.5		
	Optical Sight Systems and Weapon Delivery	17		
XI.	Introduction to the Integrated Avionics Systems Career Field			
	Course Critique	2		
	AF Publications and Supply Discipline	12		
	Maintenance Management	14		
	Integrated Systems Familiarization	5		
	Solder/Solderless Connector Repair Kit/Tools	6		
	Corrosion Control	1		

[a]Based on informal discussions with expert personnel and technical representatives.

[b]No estimate was available on this subject and the author inserted his estimate here.

[c]Electromagnetism and Relays are presently covered under this subject heading.

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