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PROCEEDINGS: LOWER COST ECM CONFERENCE HELD ON 4-6 FEBRUARY 197--ETC(U)
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AFAL-TR-75-222

PROCEEDINGS: LOWER COST ECM CONFERENCE

Sponsored by:

AFAL, ASD and AFRDR
at Dayton, Ohio
February 4-6, 1975

TECHNICAL REPORT AFAL-TR-75-222
JANUARY 1976

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This technical report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFAL-TR-75-222	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PROCEEDINGS: LOWER COST ECM CONFERENCE Held on 4-6 February 1975 at Dayton Ohio.		5. TYPE OF REPORT & PERIOD COVERED Final Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s) F33615-73-C-4112
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Avionics Laboratory Air Force Systems Command Wright-Patterson Air Force Base, Ohio 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 691X01/03
11. CONTROLLING OFFICE NAME AND ADDRESS Calspan Corp. Buffalo, NY		12. REPORT DATE January 1976
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 144p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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

The Lower Cost ECM Conference was organized by AFAL in response to a request from AFRDR to identify recommended research and development actions that would lead to lower cost modern ECM equipment. Conference objectives were: (1) isolate ECM cost drivers, and (2) provide a set of preliminary recommendations and action items which, if implemented, would help to reduce ECM acquisition costs. To meet these objectives, leaders in the ECM field,

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20. ABSTRACT (Cont.)

both from industry and the Air Force, were assembled in Dayton, Ohio for a three-day Lower Cost ECM Conference. This report summarizes their findings.

In addition to presenting the moderator's reports from each of the ten conference panels, the report includes the recommendations of the executive steering committee. This committee was convened after the conclusion of the conference. Lists of conference members and executive steering committee members are included in the appendices.

FOREWORD

This report contains the principal findings of the Lower Cost ECM Conference sponsored by Hq USAF, Director of Reconnaissance and Electronic Warfare and hosted by the Air Force Avionics Laboratory. The meeting was held on February 4, 5, 6, 1975 at the Dayton Convention Center, Dayton, Ohio, and brought together one hundred and sixty-seven recognized leaders in the ECM field from industry and government representing more than fifty-two industrial firms and all the military services.

Ten panels were established prior to the conference, each having a specific charter and each having prepared questions to address. Panel members were required to develop as large a data base as possible in preparation. The ten panels were:

- Transmit Tubes
- Receivers
- Antennas
- Microwave Components
- Power Supplies
- Solid State Power Amplifiers
- Logic Systems
- Aircraft Integration
- Systems Design
- Infrared Systems

Prior to the conference, an Executive Steering Committee was established composed of senior Air Force people. This group reviewed the results of the conference and formulated a priority list of recommendations. This report contains those recommendations.

Conference chairman was Mr. George Nicholas, Air Force Avionics Laboratory, and Conference organizer was Mr. Floyd Pirie, Air Force Avionics Laboratory. Calspan Corporation supported the conference throughout under contract F33615-73-C-4112. Special credits go to Messrs. L.L. Gilbert, A.J. Dearlove, T.H. Mellenger, and D.R. Bitikofer.

Publication of this report does not constitute Air Force endorsement of the findings and conclusions. It is published for the exchange and stimulation of ideas.

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Section I
INTRODUCTION AND SUMMARY

1. INTRODUCTION

In today's environment, the Department of Defense finds itself confronted with a two-pronged dilemma. On the one hand, the cost of supplying men and equipment to our armed forces is rapidly increasing, and, on the other hand, DOD budget requests are subjected to increasingly closer scrutiny. This dilemma becomes particularly acute for the Air Force in the area of ECM. To counter emerging threats requires increasingly sophisticated equipment, but, since we currently are not actively engaged in a war, the need for such equipment is often questioned. To begin to resolve this problem, the Air Force Avionics Laboratory has undertaken a task to isolate the ECM cost drivers and to formulate specific cost saving recommendations.

More specifically, the objective of this study was to generate a set of recommendations which, when implemented by the Air Force, would lower ECM acquisition costs. To achieve this objective required a four-step process: (1) specify and collect required data, (2) isolate cost drivers (technical and nontechnical), (3) derive a set of performance vs cost relationships, and (4) estimate the cost savings in ECM procurement associated with technology improvements and generate specific recommended actions.

Data collection and specification is in itself a formidable undertaking. The reluctance of contractors and Air Force program offices to disclose data, the differences in accounting systems, the poor quality and reliability of some record keeping, all combine to make data collection extremely difficult.

To simplify the data collection process, the Air Force Avionics Laboratory organized a three-day Lower Cost ECM Conference (February 4, 5, 6, 1975) which brought together the leaders in the ECM field from both industry and government. The primary purpose of the conference was to identify cost drivers at the system, subsystem, and component level. In addition, a set of action items which would be of value to the Air Force were identified. In general, specific cost data were not provided at the conference, but the sources and points of contact to obtain specific data were identified. The conference, by bringing together so many representatives of the ECM community, has laid the groundwork for a continuing and meaningful dialogue between the Air Force and industry which should result in lowering future ECM costs.

The conference was held at the Dayton Convention Center utilizing ten conference rooms for panel sessions and the auditorium for joint sessions. Ten panels had been established prior to the conference, each composed of people from government and industry having known expertise in areas that are of prime importance in lowering costs. Each panel had a specific purview, and each utilized prepared questions as a guide for discussions. Panel members had been requested to develop as large a data base as possible before coming to the conference. Each panel met for three days, and then each Panel Moderator provided a summary of key findings to the Executive Steering Committee and all the panel members in a joint session. See Appendix C for the agenda. The conference was keynoted by M/G Lovic P. Hodnette, Director, Reconnaissance and Electronic Warfare, USAF. General Hodnette outlined the critical nature of escalating costs of avionics and the crucial role of the conference in identifying recommended actions. The ten panels were:

Transmit Tubes
Receivers
Antennas, Radomes and Transmission Lines
Microwave Components
Power Supplies
Solid State Power Amplifiers
Logic Systems
Aircraft Integration
System Design
IR Systems

This report is confined exclusively to the findings of the Lower Cost ECM Conference. Continuing efforts to collect data and quantify the potential cost payoff for a few specific Air Force R&D applications are in progress. The major effort in quantifying cost payoffs will occur during FY-76 under a separate analysis program.

The remainder of this section is devoted to summarizing the findings of the Lower Cost ECM Conference. Section II contains the reports from each individual panel. These reports were prepared by or in concurrence with the panel moderators. Section III takes a brief look at Lower Cost ECM from a systems viewpoint. Section IV contains the recommendations of the executive steering committee. Appendix A is a list of conference panel members. Appendix B contains a list of Executive Steering Committee members.

2. SUMMARY

a. General

Since the panels dealt with generic systems, no dollar values were placed on the cost drivers or savings that would accrue from their recommendations. However, in some instances, percentage values were placed on cost items which enabled the panels to highlight areas where the greatest savings could be realized.

Each panel dealt with costs in their specific area without necessarily relating them to the overall fly-away or life cycle costs. The implications of this autonomous approach are that the highest cost drivers may not be specifically identified. For example, an 80% cost savings in one area may only reflect a small fly-away cost savings, whereas a 10% cost savings in another area may reflect a greater fly-away cost savings. To put things in their proper perspective, the results of a previous study* are cited. This study dealt with existing systems and identified costs at the subsystem level.

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*"Summary Report on the Air Force/Industry Electronics Manufacturing Cost Reduction Study," Technical Memorandum AFML-TM-LT-75, 15 July 1974.

Listed below (from that study) are the average subsystem costs for the ALQ-87, -94, -117, and -119.

Item	% of Total System Acquisition Cost
Power Supplies	16.7
Microwave TWT	29.9
Solid State Microwave Components	3.7
RF Components	15.0
Processor/Programmer	13.2
Structure/Chassis	10.5
Systems Integration	11.0

It can be seen from the list that the microwave area (TWTs, RF components) and power supplies (for TWTs) comprise the bulk of the ECM system costs. The Lower Cost ECM Conference had a panel devoted to each of these areas, so that they were thoroughly covered. By referring to the table, the reader can place the panels' recommendations in perspective when attempting to relate cost savings of each panel to overall system acquisition cost savings.

The panels worked autonomously so that their recommendations only reflect upon the cost drivers peculiar to that panel. However, a review of each panel indicates that the same cost drivers are common to many of them. Some of the more common cost drivers identified are:

Threat Definition
Standardization (lack of)
Specifications
Procurement Procedures
Test Equipment

b. Threat Definition

Threat definition is a prime cost driver if the designer has to design to worst-case threat definitions or to a fixed set of performance specifications. The generation of a set of reference scenarios (part of a bid set) is recommended because it allows the designer flexibility in establishing design parameters and weighing the tradeoffs involved. A final ECM system design is then established by the manufacturer rather than the Air Force. This design will then reflect the lowest-cost set of performance parameters which can be selected and still defeat the threats to the level set by the Air Force's analyses. The Air Force maintains control by specifying minimum performance parameters, minimum growth capabilities, and effectiveness levels to be obtained in pertinent scenarios.

c. Standardization

Most of the ECM panels cited standardization as a method for achieving future system cost reductions. Below is a compilation of the standardization recommendations of the various panels.

Lack of standardization is a current problem associated with microwave components. Component package size standards are practically nonexistent, with almost each component "buy" resulting in a package redesign. "Catalog" items are not truly available. It is recommended that standard package sizes be established for use with components. Other areas where standardization should be applied include TWT amplifiers and power supplies, microwave integrated circuits, antennas, microprocessors, and logic design.

It is recommended that AFAL perform a study to determine the cost savings that could be attained in production by standardizing TWTs and a power supply matched to the tube design parameters. Emphasis should be placed on the lower-level TWTs.

It is recommended that AFAL initiate a program to study the suitability of standardizing high-usage RF and microwave circuits and components in integrated configurations. Each ECM system has a multitude of low-level RF and video circuits and components which, if properly integrated into MIC (microwave integrated circuit) modules, could effectively reduce cost, volume, and power as a retrofit to present equipments (when modified for performance improvement). The modules would also form the basis for standardized low-level modules providing such functions as RF amplification, modulation, signal sources, mixers, etc.

Recommendations of the Systems Panel included compiling a catalog of selected industry-developed MIC modules and development of an interim standardized list of MIC modules. Cost savings over previous lump constant and hybrid MIC circuits is unknown but can be high depending on the extent of the standardization.

Standardization would reduce ECM antenna costs by eliminating Non-Recurring Engineering (NRE) and testing costs (which typically average $50,000 per antenna) and by increasing production lot size by decreasing the number of antenna models which have nearly the same performance characteristics. Specific recommendations include:

- ECM antenna frequency band standardization, perhaps an octave with an overlap at band edges.
- Standardization of base sizes and mounting provisions. Provide rationale for use of modifications or additions.
- Catalog previously developed antenna types and specifications to aid in selecting antennas which would not require developmental NRE costs.

In the area of logic design, standardization should be applied to:

- Documentation of operational computer programs
- Software language
- Functional interfaces.

d. <u>Commercial Components</u>

A study of the application of standard commercial components to the military problem is recommended. Areas such as quality control, environmental suitability, and reliability should be considered. Unnecessary cost driving specifications should be modified, and maximum use of commercial hardware should be made. Replacing MIL SPEC parts with commercial parts in those areas where the manufacturer has a demonstrated knowledge and sufficient back-up data could lead to signficant savings.

e. Specifications

In general, the rigid application of MIL SPECS results in over-specification of many parameters and unnecessary cost growth. For example, specific performance requirements can have a very major effect on Travelling Wave Tube (TWT) amplifier cost. Thus, both state-of-the-art performance must be avoided and expensive features must be examined for cost effectivity. This recommendation could be implemented by having the end-user, the system manufacturer, and the tube vendor review performance/cost tradeoffs at the beginning of the system development. Similar tradeoffs should again be made after delivery of the prototypes and prior to start of production.

It is recommended that power supply requirements be reviewed relative to over-specification of TWT requirements, including in some cases, unnecessary protective circuitry. Also, the power supply designer should be allowed to communicate with the TWT designer before the power supply design specifications are finalized.

More attention should be given to preparation of the general requirements portion of the specification, to allow the power supply designer to obtain more of an in-depth appreciation for these requirements and to facilitate an intelligent interpretation of the specification, so that tradeoffs and/or specification additions can be proposed, which will ultimately result in cost savings.

Similarly, antenna vendors should be encouraged to seek relaxation of firm pattern (and VSWR) specs after initial design efforts are completed and before the tedious, costly tweaking of antenna patterns (which would be required to meet the letter of the antenna specifications) is performed.

The system supplier (component buyer), for the sake of a conservative design, very often requires either an unrealistic performance specification or one that is over-specified for the actual system. Closer cooperation and greater communication between system designer and component supplier could lead to lower costs. In particular, many MIL SPECS could be relaxed because a realistic appraisal of the actual operational environment may show that specification relaxation may not result in any loss in operational performance.

Other areas where over-specification results in excessive costs are data requirements and workmanship standards. DD 1423, "Contract Data Requirements" are, in total, a high cost item. A part of initial program effort for each new procurement should be a review of data requirements. Data requirements and data procedures need to be streamlined to make data procurement most cost-effective. Data Cost tradeoffs should be made part of program negotiations.

The workmanship standards of MIL-STD-883 and MIL-38510 are excessive in some areas. An example is the 10% minimum-width tolerance specified for the foil conductors of P.C. cards. When final inspection is visual, conductors are preferably designed some 10 to 20 times the minimum size required for the current to be carried. Specifying a ±10% tolerance forces contractors to implement less than optimum manufacturing methods and makes visual inspection difficult.

f. Procurement Practices

Costs of most major components are very significantly affected by the quantities, lot sizes, and production rates involved with the particular procurement. Learning benefits and preproduction efforts can cause significant reductions in unit costs for high-volume procurements. Where practical, advantages should be taken of this reduced unit cost. Partial advantage may be taken by obtaining reduced costs for special component parts or subassemblies that may be common to different major components or major subassemblies.

Various procurement and schedule considerations are listed below.

- Procurement quantities, lot sizes and production rates should take into account the effect on unit costs.
- Provisions should be made to allow early and continuing interface checks between tubes and system components.
- Required data items should be reviewed relative to their cost effectivity.
- Consideration should be given to supplying specialized test equipment on GFE basis, particularly for low-quantity procurements.

- Where procurement schedules and quantities are uncertain, consideration should be given to funding for stockpiling of long-term delivery items.

The contractors should have the latitude to optimize the schedule for cost. In the past, the procurement cycle has been inefficient in two ways. Research and development programs through preproduction on the first production run have been too accelerated. Production has been too stretched out. Both production and R&D suffer from intermittent funding.

g. Test Requirements and Test Equipment

It was noted in several cases that both qualification and acceptance testing could have been reduced by using greater selectivity in defining the tests rather than applying, in toto, previous test procedures. The recommendations are that:

- Use of similar design (to already qualified units) be employed to the maximum extent possible to reduce the extent of qualification testing (up to 50 percent savings may be possible)
- Greater use of test history be made to reduce the number of acceptance tests required.

For example, it was noted that a required radome reflectance test accounts for 25 to 30 percent of the electrical segment test cost; with normal radome design, this test is passed with a fairly large margin.

RF power testing requires expensive equipment, both to acquire and maintain, and only a limited number of facilities are available, not all with the same capabilities. It is recommended that the Air Force catalog and update a summary of facility capabilities and inform users of the current status of such facilities.

In the area of antenna system pattern testing, it was noted that the Air Force is developing a near-field antenna pattern analyzer which could be made available for industry use in evaluating some aircraft-antenna interface problems. The use of this capability could avoid costs in building system test stations for antenna pattern evaluations. It is recommended that the use of this facility for these types of tests be further studied to determine recommended applications.

Selection of parts (i.e., parts testing) is a major production cost because of the wide variations in parts. More automatic test stations would reduce this cost, but, because of the low volume and uncertainty of procurements, it does not pay for a supplier to invest in this type of equipment. Government funding in automatic test stations may be of value in lowering the cost of ECM equipment.

The usefulness of extended burn-in tests should also be examined to determine their true value. This is of particular concern when the burn-in test requires the commitment of extensive test facilities.

It is also recommended that a service test phase be initiated as part of the R&D cycle. Five to ten prototype systems should be procured during the phase prior to a production commitment. Test units should be installed and used in command aircraft concurrent with extended bench qualification testing. Periodic reports relating to parts failure, equipment configuration changes, and performance testing should be made and consolidated into the R&D loop. While the cost savings associated with this technique were not quantified, it is readily apparent that significant savings would be accrued by enabling early fixes to the equipment configuration early in the equipment life cycle.

Section II

INDIVIDUAL PANEL RECOMMENDATIONS

1. TRANSMIT TUBES

a. Introduction and Summary

It was noted that a previous study* had identified transmitters as a major contributor to the cost of ECM systems. Rapid product obsolescence, insufficient development, and low production volume were highlighted by this previous study as major problems facing the manufacturer of microwave tubes for ECM systems. Also, of the two major transmitter components (transmit tubes and power supplies), tubes account for a nominal 30 percent of the total system cost.

Most of the ECM systems built within the last few years employ TWTs having output power capabilities of several hundred watts CW or 1-2 kW pulsed. Cross-field amplifiers, such as used for ECM systems, provide average output powers that are normally higher than those provided by TWTs. Power oscillators, such as VTMs and MBWOs, are also of interest. Unlike the amplifier devices having a range of an octave or more, these oscillators provide fractional octave bandwidths with power levels of 100-400 watts average.

It is generally recognized that a communication gap exists among the customer, the system manufacturer, and the tube vendor relative to the role played by tubes in the determination of system performance and cost. This communication problem, as well as the more major cost problems relating to tube parameters and features, production costs, and test requirements, were discussed. Also considered were applications effects, such as interface and life cycle requirements.

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*Summary Report on the Air Force/Industry Electronics Manufacturing Cost Reduction Study, Technical Memorandum AFML-TM-LT-75, 15 July 1974.

(1) Initial Cost Factors

The basic factors contributing to initial tube costs were examined in detail. To establish the sensitivity of the tube's electrical performance to costs, a reference tube was defined and the generalized effects on cost were noted as the parameters were varied. It was readily established that tube requirements that approached the state-of-the-art were unusually expensive. Similarly, tube features (including both electrical and mechanical) that added significantly to the costs but were not state-of-the-art were examined in detail.

Examination of production costs revealed that these costs are determined by the combination of initial unit cost, the reduction of this cost that can be accomplished by the learning experience, and the reduction that results from the use of specific tube preproduction efforts. Typical learning rates vary quite widely, as much as 80 to 95 percent, and are dependent on numerous factors. These factors include the total quantity purchased, the lot size, the production rate, and the degree of standardization. Because of the significant differences in internal tube design parameters and fabrication techniques that are used by the various tube manufacturers, the possibilities for standardization are somewhat limited. There are, however, some areas where standardization could be of benefit.

Appropriately invested support funds can be used to alter both the initial unit costs and the shape of the learning curve. These funds can be in the form of advanced development, engineering development, and/or manufacturing methods programs. It was shown that meaningful payoffs could be achieved by such investments.

The usefulness of environmental and other special tests was examined. It was noted that some test duplication is encountered by tube vendors and that some tests are of doubtful value. Some of the data items were also questioned as to their cost effectivity.

(2) Application Considerations

Although life cycle costs were not one of the major considerations addressed by this panel, it was believed to be of sufficient importance to receive some attention. Available application information, as well as additional information requirements which are necessary to compute life cycle costs, were identified. Computer programs are available to allow subsequent calculation of the life cycle costs. Cost tradeoffs could then be made relative to practicability of repair, and, if appropriate, the nature of the maintenance program could be altered. The cost impact of the turnaround time required to return the tubes for repair was also considered.

The desirability of an early interface between the tube and system was examined. It was concluded that, if necessary, the system schedule should be slipped to allow testing with the power supply, modulators, and output RF components. It was also concluded that these components should be made available for tube optimization during the manufacturing sequence.

b. Specific Recommendations

Although the recommendations of this section are directed toward transmit tubes, the effects of other transmitter components should also be considered. As noted above, transmit tube procurements should not require performance that exceeds available device capability. A standardization effort was proposed that would provide the tube capabilities that are needed to meet the mid-term (2-5 years) ECM system needs. The panel also recognized that the major technology advancements that are normally accomplished in a 5 to 10 year time period should also be continued. Various procurement considerations were also regarded as important and are detailed below as part of the recommendations.

(1) Standardization

As noted above, individual development programs, separate from procurement, were proposed to provide the improved system capabilities needed in the 2 to 5 year time period. To allow such programs to be established, it is first necessary to identify families of transmitters which will economically provide the system capabilities of the future. Included in this determination must be the effects of various application requirements such as cost of ownership. This standardization must include both the performance of the transmit tubes and related parts such as RF connectors, high-voltage leads, and high-voltage connectors. The details of appropriate programs must be defined to accomplish all the required developments. Also, preproduction efforts that will reduce the production costs of existing designs must be defined. Although the output transmit tubes are the components of immediate interest in this section, they cannot be considered independently of the driver(s), exciters, associated power supplies, and microwave components such as diode switches, phase shifters, and isolators. All of these components should properly be considered part of the transmitter, and the actual standardization determinations should be made relative to the overall transmitter requirements.

ECM System Requirements: The above standardization efforts must be keyed to future ECM system requirements. This will necessarily include consideration of the required levels of peak, average, and CW RF power. These power levels should be determined on the basis of existing and projected threat capabilities and the power that is needed to provide the desired J/S for appropriate ECM techniques.

Transmit Tube Requirements: Transmit tubes must be defined to provide the projected ECM system requirements. This would include definition of the basic performance required to provide the necessary band coverage. Note that basic performance, and not the details of internal construction, should be standardized. Appropriate external mechanical and electrical features should also be standardized, without penalizing any particular manufacturer. The results of previous Lower Cost ECM efforts can be used to provide the starting point needed to determine what specific developments are required. Both the costs of development efforts required to provide these transmit tube capabilities and the actual tube procurement costs should necessarily be evaluated.

The near- to mid-term recommendations provide for substantially increasing the investment in exploratory and advanced development of microwave tubes for ECM so that the tube state-of-the-art can be pushed ahead of present and future ECM system requirements. Emphasis should be placed on practical, low-cost solutions. A number of relatively small programs in key areas, having funding levels of $100K to $250K such as to provide the desired program efficiency, were recommended.

Typical of the development items recommended by the panel are those listed below.

(a) Improve the tube efficiency by designing improved collectors and circuits.

Objective: To increase efficiency by 5 to 10 percent.

(b) Improve electron gun and focusing, including cathode/grid material program.

Objective: To provide high-mu grid technique capability across the band from 2 to 18 GHz.

(c) Provide improved dual-mode pulse-up.

Objective: To extend pulse-up capability by 1 to 3 dB.

(d) Provide increased tube bandwidth.

Objective: To reduce tube cost by improved bandedge performance and to minimize or eliminate equalizer costs.

(e) Provide improved tube stability.

Objective: To improve yield.

Application Considerations: A necessary consideration in standardizing ECM transmit tubes is the effect of life cycle costs. Investigations of sufficient detail should be made to allow consideration of effects such as reliability, component life, and, if possible, field replacement costs. An obvious example of this type of consideration is a component whose initial cost may be low but which requires frequent replacement, and as a result may be very expensive to own. Other application effects concern the environment external to the transmitter (e.g., RF loads and prime power characteristics).

Preproduction: In addition to the development of basic component capabilities, preproduction efforts, needed to reduce production costs, should be considered. These programs should be timed such that the component capability is established in a timely fashion relative to system procurement schedules. Specific types of programs are detailed below.

- Manufacturing Methods Programs should be initiated which are applicable to classes or families of tubes, supporting, in particular, low-quantity procurements.
- Materials Programs should be funded in the areas of tube materials, components, and fabrication techniques. Many material and component developments would have value to all manufacturers.

(2) Long-Term Advancements (5 to 10 years)

Recommendations for long-term solutions generally provided for increasing the exploratory and advanced development efforts to provide more advanced capabilities. They included the development of capabilities such as 10 dB pulse-up and efficiency improvements beyond the near-term projections.

(3) Procurement Procedures

An immediate time period (0 to 2 years) recommendation, which the panel considered of prime importance, is to institute a program of periodic review of tube/system performance tradeoffs. An examination of the costs of the tube package and testing requirements should also be made.

This recommendation was made because specific performance requirements can have a very major effect on tube cost. It should be implemented by having the end-user, the system manufacturer, and the tube vendor review performance/cost tradeoffs at beginning of the system development. State-of-the-art performance must be avoided and expensive features must be examined for cost effectivity. Similar tradeoffs should again be made after delivery of the prototypes and prior to start of production.

Various procurement and schedule considerations are listed below.

- The effects of procurement quantities, lot sizes, and production rates on unit costs should be considered. Production gaps should be avoided.
- Provisions should be made to allow early and continuing interface checks between tubes and system components.
- Cost effectivity of required data items should be reviewed.
- Consideration should be given to supplying specialized test equipment on GFE basis, particularly for low quantity procurements.
- Where procurement schedules and quantities are uncertain, funding for stockpiling of long-term delivery items should be considered.

(4) Cross-Field Amplifiers

Many of the above recommendations are applicable to both TWTs and CFAs; the following considerations pertain to CFAs only. It was recommended that existing programs to solve CFA electron gun and circuit technology problems be continued. Future R&D programs should be based on the results of these efforts. Investments in delay line technology for existing CFA devices should be undertaken if a satisfactory return on the investments can be established. Determining the feasibility of using low-power ($\approx$40 watts) CFAs for phased-array radar applications, where efficiency and phase linearity are of particular importance, should be considered.

VTM developments that could be considered, if the need can be justified, are an increase in tuning range, an increase of efficiency from 55 to 65 percent, and an increase in frequency range to above 10 GHz. High-power VTMs may require efforts to avoid possible long shelf life problems. Availability, high cost, and long lead time of Alnico magnets is of concern. Work on samarium-cobalt magnet design and application was suggested.

2. RECEIVERS

a. Introduction and Summary

The receiver panel identified cost drivers that are common to all receiver types while acknowledging that several different types of ECM receivers exist. In general, costs of all receiver types are driven by:

- Changing Threat Environment - In this regard, the ECM community is driven by the need to meet the changing threat environment; this environment dictates the system requirement, which, in turn, sets the requirement for the receiver type to be used.

- MIL-SPEC parts - The required use of MIL SPEC parts in areas where the commercial equivalent part will suffice is a significant cost driver in any form of receiver.

- Maturity of Technology - Systems employing receivers not produced in production lots sustain production "bugs" which add significantly to the cost. Many panel members were of the opinion that receiver equipment moves from the R&D stage into the production stage with insufficient production engineering effort.

- Environmental Requirements - Although these requirements drive the cost, no changes could be seen that would reduce cost; it was difficult to correlate percentage of receiver cost with environmental specifications. All sub-panel members tended to agree that the environmental conditions stipulated are necessary, considering the wide deployment of US forces.

- Form Factor - Changes in form factor to accommodate a new installation usually require a complete mechanical redesign, which, from the sub-panel members' experience, is a significant cost.

- Documentation - The documentation required for military receiver procurement is extensive, compared to that required for commercial purchases.

The recommendations of the receiver panel centered on modeling, components, and institutional practices as three areas of potential cost improvements.

(1) Modeling of Receivers

Because of the necessity to maintain various forms of receivers to support diverse ECM applications (including RHAW) and because of the increasingly complex functional requirements of the receiver/processor ensemble, a more quantitative analysis of receiver application during the original engineering development phases was identified as necessary to minimize both original costs and downstream modification costs.

(2) Component Improvement and Cost Reduction

Various RF/IF video components were identified as candidates for improvement, both in technology (performance levels) and repeatability/standardization to reduce selection, alignment, and special order vendor costs.

(3) Institutional Practices

Several significant cost drivers were identified in this area: MIL specifications (over-spec), test and evaluation procedures, the selective use of commercial versus JAN components, and general workmanship requirements.

b. Specific Recommendations

(1) Modeling of Receivers

It was generally agreed that existing applications require support of both crystal video and superheterodyne receiver technologies. Expanding requirements for power management, increased signal densities and types of signals that are encountered requires continuing support of IFM, channelized, and microscan technologies, as well as hybrid configurations of the generic types of receivers. Current approaches tend to concentrate on application of either the "best" or "lowest cost" receiver type or combination, but no common quantitative criteria exist for determining "next best" or "next lowest cost" in terms of defined information throughput of the receivers to permit effective performance/cost sensitivity tradeoffs. This aspect is particularly critical when angle of arrival parameters are involved. It was recognized that, to a great extent, present-day ECM receivers are designed on a worst-case approach and this should be rectified to a statistical approach.

The generation of a reference scenario, combined with a flexible modeling capability based upon statistical techniques for the various forms and specific configurations under analysis, is recommended to effect significant cost savings not only in the original design phase, but to reduce over-specification and design and the final receiver procurement cost.

(2) Receiver Requirements

The panel identified important parameters and provided relative cost figures on several of them to indicate the tradeoffs involved. The important parameters of an ECM receiver were identified as:

- DF Accuracy
- Sensitivity
- Frequency Coverage
- Probability of Intercept
- Error Rate
- Reaction Time

Relative cost figures on some of the parameters are:

DF Accuracy — The cost of a system requiring an angular accuracy of less than 6° is approximately an order of magnitude greater than that requiring a 12° accuracy.

Sensitivity	The cost of a -80 dBm receiver is approximately 3-4 times that of a -40 dBm receiver.
Error Rate	The production cost of a receiver system that can handle 10 simultaneous threats with an error rate of one per unit time is approximately one-third that of a receiver system that can handle 60 simultaneous threats with a negligible error rate.

Receiving and processing the entire threat scenario without error is a costly requirement because it is a worst-case approach. A statistical approach (yet undefined) was considered to be a better approach to processing the threat scenario.

(3) Component Improvement and Cost Reduction

The crystal video receiver cost driver of significance was identified as being the detectors. They require improved interunit performance consistency and improvements in sensitivity and dynamic range.

Superheterodyne receiver cost drivers center around the components related to the tuner (typically, 70 percent of overall receiver costs). Specific components identified were pre/post selectors, voltage-tunable local oscillators, and mixer-preamplifier MIC techniques.

IFM receivers that take the form of frequency or time discriminators for encoding have significant cost elements: RF limiters; polar discriminators, and the general area of logarithmic signal processing components.

Channelized receivers currently suffer from the cost elements of components per channel. Volume demand, based on some standardization criterion, could reduce the cost of this form of receiver by a factor of four in the near future. SAW technology is particularly attractive in this respect and should be emphasized.

Microscan receiver costs are driven by the VCO components, dispersive delay lines, and components required for the preprocessing function.

(4) Test and Evaluation

The level of testing required is not usually specified by government contract except for the final acceptance testing. Intermediate testing on printed circuit boards and the like is specified by the contractor's quality control and production test groups. Subpanel members thought that a reduction in intermediate testing would decrease the yield on final testing and thus increase the cost. An investigation of the necessity for simultaneous environmental testing should be conducted because of the cost involved.

It was estimated that testing may cost as much as 15 percent of a project, but, for the most part, the required government tests are not excessive; however, the documentation and retesting after a minor change are significant cost factors. It was too difficult to define any cost because each company has its own accounting procedures. Selection of parts (i.e., parts testing) is a major production cost because of the wide variability of parts. More automatic test stations would reduce this cost, but because of the low volume and uncertainty of procurements, it does not pay for a supplier to invest in this type of equipment. Government funding in automatic test stations may be of value in lowering the cost of ECM equipments.

(5) Standardization

The workmanship standards of MIL-STD-883 and MIL-38510 are too stringent in some areas. An example is the 10% minimum-width tolerance specified for the foil conductors of P.C. cards. When final inspection is visual, conductors are preferably designed some 10 to 20 times the minimum size required for the current to be carried. Specifying a ±10 percent tolerance forces contractors to implement less than optimum manufacturing methods and makes visual inspection difficult.

Most systems are overspecified, which causes a significant cost growth. Better use of present-day technology is the way to proceed to obtain cost reductions.

Contractors feel that they should be consulted more in the MIL-SPEC formulation and also be allowed to use their judgment in the selection or rejection of parts in production. If allowed to do this, contractors should warranty their equipment.

The ECM receiver panel was of the opinion that a standardized set of receivers to meet the bulk of conventional ECM system needs is not feasible nor would it be cost-effective. The retrofit cost of using a "so-called" standardized receiver in an existing aircraft would be prohibitive. Even if the retrofit problem were ignored, the specification on the form factor and the amount of growth capability that should be included appear to be unresolvable problems.

(6) Aircraft Interface

The following factors were identified as key items involving aircraft interface:

- Form Factors
- EMI
- Physical Environment
- Antenna Location
- Obtaining Accurate Data for Aircraft Installation

The last item above was considered the most significant cost driver because inaccurate data affect all the other factors.

The size of the system determines the method of integration. Large systems benefit from a single integration contractor, while smaller projects and retrofits can be more effectively handled by the supplier.

Past experience indicates that the integration is finalized too early in the system development and insufficient time is allocated to tradeoff studies or that competent receiver designers are not involved in the tradeoff studies.

(7) Research and Development

The panel identified two specific areas in which R&D funds could be used to effect a cost reduction of ECM receivers for present-day system requirements.

- The development of distributed receiver techniques to overcome form factor problems is in order.
- Determination of the degree of commonality among ECM receivers and receiver requirements for the purpose of identifying high-usage items that are amenable to LSI, MIC, or thick-film techniques, which could yield lower system acquisition cost, is in order.

(8) Manufacturing/Procurement

The total ECM equipment market is about $500 million, and it appears that six companies receive 75 percent of that business. It also appears that about six companies do all the ECM receiver business. Therefore, competition does not appear to be excessive. Some panel members believe that using "design-to-price" procurement and requiring the supplier to give at least a 5-year warranty will weed out the marginal suppliers and, in general, result in an improved situation--in terms of lower-cost products. "The design-to-price" concept fosters a harder look at tradeoffs so that the supplier might give the best performance within the dollar constraints. It is recognized that improvements in ECM system procurement methods are in order, but the problem is complex and could not be given sufficient attention due to the short time available. This one question should be the subject of a future conference.

Most ECM receiver suppliers believe that their present manufacturing techniques are consistent with the volume of business that they receive. The ECM industry is not amenable to using the so-called automation techniques, because of the volume involved. Automatic parts-insertion machinery is expensive and can be employed only if a large volume of business is realized.

3. ANTENNAS, RADOMES, AND TRANSMISSION LINES

a. Introduction and Summary

Antennas, radomes, and transmission lines provide the interface between the outside world and the ECM system. Because of their charter, they interact with aircraft integration, system integration, transmitters, and receivers. Efficiency is important because any losses may severely affect system performance.

The panel addressed fixed and steerable antennas, radomes/coatings, transmission lines/connectors/antenna coupling reduction, testing, and technology. In general, cost reductions could be made by standardization of both specifications and hardware, relaxed test requirements (where appropriate), and improved procurement procedures.

b. Specific Recommendations

(1) Standardization

Fixed Antennas: Fixed antennas are conventional types which include blades, slots, spirals, and monopoles fixed to the airframe or pod. Areas of potential cost reduction identified by the panel are:

1. ECM antenna frequency band standardization, perhaps an octave with an overlap at band edges.

2. Standardization of base sizes and mounting provisions. Provide rationale for use of modifications or additions.

3. Catalog previously developed antenna types and specifications to aid in selecting antennas which would not require developmental nonrecurring engineering (NRE) costs.

These areas deal with standardization of "conventional" ECM antennas (frequencies, mechanical mounting, and performance). The potential cost reductions would be due to elimination of NRE and testing, which typically averages about $50,000 per antenna, and increasing production lot size by decreasing the number of antenna models which have nearly the same performance characteristics.

Antenna Coupling Reduction: The achievement of adequately low receive-transmit antenna coupling is a difficult problem, and results of previous development efforts are generally not available. A data bank of existing materials, techniques, and achieved test results of coupling reduction efforts should be developed by the Air Force and made available to contractors. This would avoid much duplication of effort and potentially effect major cost reductions, especially for those coupling problems which require aircraft fuselage treatments. Developmental efforts on lower-frequency broadband and choke designs and on fuselage surface current attentuation technology should be performed.

Radomes and Coatings: There is no centralized source for providing to industry, design and performance information on radome materials and rain erosion coatings. In most cases, each manufacturer must perform similar design and test programs to establish the preliminary design and material(s) selection. It was recommended that AFML take the lead in characterizing materials using radome shape factors, environments, frequencies, etc., and publishing or making available this information to industry as a design guide. In accomplishing this goal, AFML should:

1. Develop, using government and industry inputs, a set of environmental and mechanical/electrical performance requirements to be used for testing of radome materials. This list would include a limited number of radome shape factors to be used during testing.

2. Accumulate available test data for the test configuration specified and perform the tests required for data not available.

Transmission Lines and Connectors: Standardization and improvement of transmission lines and cables was started by the Air Force about 15 years ago (evolving into ASNAE specifications), but there still exists a large variety of cable/connector combinations and there are no qualified sources for semirigid coaxial assemblies. Cable assemblies complying with the ASNAE specifications are quite costly (two to ten times more than "other" cable assemblies), but cable life has been increased substantially. Because of the high cost of replacing aircraft transmission line assemblies, and the aircraft down-time entailed, the standardization on the ASNAE series may well be cost-effective. A study should be performed by the Air Force to substantiate this premise using as input data past history of required cable replacement and current production costs.

It was recommended also that the Air Force fund a specific program to develop and qualify a minimum number of transmission line types required. This would avoid fractured efforts by contractors who are currently required to provide, as part of individual programs, cable assembly development and qualification.

Testing: It was noted in several cases that both qualification and acceptance testing could have been reduced by using greater selectivity in defining the tests rather than applying *in toto* previous test procedures. The recommendations are that:

1. Similar design (to already qualified units) be employed to the maximum extent possible to reduce the extent of qualification testing (up to 50 percent savings may be possible)

2. Greater use of test history be made to reduce the number of acceptance tests required.

For example, it was noted that a required radome reflectance test accounts for 25 to 30 percent of the electrical segment test cost; with normal radome design, this test is passed with a fairly large margin.

RF power testing requires expensive equipment, both to acquire and to maintain, and only a limited number of facilities are available, not all with the same capabilities. It was recommended that the Air Force catalog and update a summary of facility capabilities and inform users of the current status of such facilities.

In the area of antenna system pattern testing, it was noted that the Air Force is developing a near-field antenna pattern analyzer which could be made available for industry use in evaluating some aircraft-antenna interface problems. The use of this capability could avoid costs in building system test stations for antenna pattern evaluations. It was recommended that the use of this facility for these types of tests be further studied to determine recommended applications.

(2) Long-Term Advancements

Technology (Recommended R&D): Areas in which R&D funds could be effectively applied to reduce future ECM antenna system costs are:

- Materials
  - Better radome and rain erosion coatings
  - Lower-loss, reproducible ferrite fabrication techniques
  - Better ceramic fabrication techniques
- Lower-cost, effective materials and techniques for fuselage surface treatment to reduce surface currents
- Integrated/active antennas for lower-frequency, broadband receive applications (size reduction)
- Digital parallel processing techniques (DIPPA) for broadband, lower-frequency DF applications.

It was also concluded that major cost reductions could be made readily by sharing, at working levels, of information and data among vendors and government agencies (i.e., better use of present-day technology), as well as by future technology advances.

(3) Procurement Procedures

Fixed Antennas:

- Lot, rather than time-phased, procurement of antennas to increase the number produced in any one lot.
- Greater flexibility in antenna pattern specifications to avoid "firm" specs where, in most cases, ERP requirements based on threat scenarios, aircraft RCS estimates, and simulation results are not really firm.

The first item above would reduce procurement costs by increasing production lot size (an average 10 percent production cost reduction is obtained by doubling the number produced).

The second item above would be anticipated to yield substantial NRE cost reductions, but very close liaison would be required among the antenna vendor, government procurement agencies, and system analysis/engineering. Specifications of antenna patterns and gain can be ultimately traced to evaluations of averaged aircraft survival probability versus jammer ERP, which generally do not vary significantly with "pattern ripples" or gain variations of 1 or 2 dB. Antenna vendors should be encouraged to seek relaxation of firm pattern (and VSWR) specifications after initial design efforts are completed and before the tedious costly tweaking of antenna patterns is performed, which would be required to meet the letter of the antenna specifications.

Transmission Lines and Connectors: The reason for the relatively high cost of cable assemblies was stated by vendors as the low production quantity. It was noted that cable assembly cost has been maintained constant in the presence of inflation because of the increased production due to recent Navy use of the ASNAE series cables. (The Navy specification is a somewhat modified version of the Air Force specification, but the same cable qualifies for both.) It was also noted that 90 percent of the cable assemblies produced are for retrofit use. Cost reductions could possibly be obtained by wider usage of the ASNAE series cables (for other services), and a study of the total acquisition and repair costs of RF systems may justify this wider usage.

4. MICROWAVE COMPONENTS

a. Introduction and Summary

Evaluation of microwave components relative to possible cost drivers and to determination of recommendations that could be used to reduce these costs, indicated the desirability of establishing two major subgroups of (1) VCOs and (2) control and passive microwave elements. These evaluations are reported separately below.

b. Specific Recommendations

(1) VCO Subgroup Recommendations

Generally, it was concluded that no particular technological area could be identified as a cost driver. The VCO, in contrast to the typical microwave component, is primarily a subsystem in the early stages of development and incurs costs accordingly. Specific performance parameters, etc., apparently are not paramount in terms of cost drivers. The current state of VCO development is such that institutional costs do not contribute significantly to VCO costs.

R&D Recommendations

These recommendations are concerned with Government support of semiconductor technology advancements and with failure rate reductions.

Silicon and GaAs Varactors: The state-of-the-art of both silicon and GaAs varactor development lags current system requirements by a wide margin, especially in the areas related to frequency stability (long and short term) and reproducibility. Air Force programs now in the earliest stages are vitally needed and should be extended to cover GaAs devices and manufacturing control.

Microwave Transistors: Microwave transistors have typically been packaged to satisfy the needs of RF amplifiers. Unfortunately, the device is then not optimized for oscillator application. To compound this situation, two of the key transistor vendors have recently become marginal suppliers and may not be long-term suppliers at all. Bipolar and FET oscillator transistors need to be developed, and a reliable source of these devices must be established.

Gunn Diodes: Gunn diodes have escaped virtually all attempts at characterization and are seldom reproducible. Characterization techniques must be developed and made common in the industry before the full potential of these sources can be utilized. Likewise, manufacturing technology for Gunns must be developed.

Reliability: Early field failure rates for VCOs (1-1/2 to 2 years ago) were remarkable -- seldom have so many failures been seen. But, whereas 20 to 25 percent was common on these early devices, 5 percent is more common now. Further reductions in this rate can and must be achieved. The panel therefore recommended that an end-item burn-in be imposed on all VCOs and that other quality assurance provisions be enforced by supplier and user alike.

Procurement Procedures

It was noted that a critical cost driver is due to one particular component procurement procedure. The imposition of JANTA-type screening requirements on microwave semiconductors is extremely expensive when the semiconductor costs are a major material expense in the end-item. Cost is escalated drastically by the screening. Sufficient data are now available to show that the intent of JTX screening can be achieved through a limited test program. It was estimated that a 96-percent-effective screening can be achieved for a cost escalation of 10 to 12 percent, compared with the 25 or more percent cost escalation caused by JTX requirements. Therefore, a strong recommendation was made that the screening requirements imposed upon active microwave devices be revised.

(2) Control Subgroup Recommendations

This subgroup was concerned with all microwave components, other than VCOs, that are employed in an ECM system. In contrast to the VCO Group, the devices examined are relatively mature; hence, specific cost drivers can be detailed.

R&D Recommendations

Stripline: Most current microwave components utilize stripline circuitry. The basic board employed, a Teflon-fiberglass material, varies in both thickness and dielectric properties. As a consequence, end-item yield can be quite low, particularly for large-scale integration of components. In essence, the effects of circuit board variations can only be determined by end-item performance (after total fabrication). The following recommendations pertain to stripline configurations.

An investigation should be initiated for a new circuit board material. The ideal material should be uniform, homogeneous and isotropic, and capable of being processed without special problems. Also, it should be machineable, drillable, punchable, and impervious to the chemicals normally associated with printed circuit board fabrication. Cladding methods should be such that the use of films or adhesives is avoided, since these materials alter the properties when the dielectric is used in very thin sections. Material thickness range should be from 0.004 in. to 0.250 in. and should have the following electrical and mechanical properties:

Dielectric Constant	Any value from 2 to 4, as long as it is uniform, repeatable and predictable to ±0.01
Loss Tangent	0.0003, Maximum
Useful Temperature Range	-80°F to +500°F
Tensile Strength	20,000 psi
Flexual Strength	15,000 psi
Impact Resistance	15 foot-pounds/inch
Thermal Conductivity	$\approx 10 \times 10^{-4}$ calories/seconds/ $cm^2/°C/cm$
Coefficient of Thermal Expansion	$\approx 2 \times 10^{-5}/°C$
Water Absorption	Zero

An investigation should be initiated to determine methods of improving quality control of current circuit board material.

A program should be initiated to develop accurate means of measureing stripline circuit board parameters during the production process.

PIN Diodes: As currently supplied by the semiconductor houses, PIN diodes are not characterized in the microwave region by the manufacturer. Consequently, circuits can be diode-specific. As with the stripline board, diode performance is currently obtained only after insertion into the component and subjected to full overall test. Therefore, it was recommended that a program be initiated to develop production methods for RF characterization of PIN diodes.

It was recommended that a manufacturing methods program be initiated to improve chip mounting techniques. Current methods are costly and are not truly satisfactory from a manufacturing basis.

A program should be initiated to improve diode reliability.

Packaging: Current component costs could be reduced by increased levels of integration. However, little knowledge is available regarding the most economic level, given the variabilities of raw materials, connectors, launchers, and other production costs. Most system houses, moreover, are reluctant to employ single components much above the single function level of integration. It was recommended that a study be initiated to establish the most economic level of integration.

A major contributor to component cost can be associated with interconnects between components and stripline-launchers used to couple from connector to circuit stripline. Additional development was urged for obtaining better and lower cost stripline launchers and interconnects.

Sealing of components still remains an economic problem, for both the overall package and the interconnects. A program should be initiated to improve current packaging techniques.

Component package size is practically nonexistent, with almost each component "buy" resulting in a package redesign. "Catalog" items are not truly available. It was recommended that standard package sizes be established for use with components.

Procurement Procedures

Discontinuous and Short Run Production: The nature of the ECM "buy" is such that short and discontinuous production runs are encountered. There is a start-up or nonrecurring expense incurred with each "buy," driving piece price higher than normally would be encountered in a conventional market. Although acknowledged as a cost driver, the panel felt that this is the nature of the business.

Nonstandardization of Products: A system supplier (and component buyer) very often requires component form-factor and/or operating characteristics to conform to system concept. Greater design effort and the acquiescence of the system supplier to accept standard packages could reduce some of these costs.

Specifications: A system supplier (component buyer), for the sake of a conservative design decision, very often requires either an unrealistic performance specification or one that is over-specified for the actual system. Closer cooperation and greater communication between system designer and component supplier could lead to lower costs. In particular, many MIL-SPECS may be relaxed because even a realistic appraisal of the actual operational environment may show that specification relaxation may not result in any loss in operational performance.

Development Cycle: A system supplier (component buyer) does not recognize the true cycle of component development. However, competition among component manufacturers leads to acceptance of short development times, with the attendant costs associated with schedule delays, etc.

5. POWER SUPPLIES

a. Introduction and Summary

It was established that power supplies do constitute a substantial portion of the size, weight, and cost of any ECM system. Therefore, it was concluded that more than the present limited attention should be given to their design. Also, because these supplies seem to inevitably be one of the last items considered in the ECM package, there is a need for optimum coordination to accommodate the short development time and to allow for the complex interface with the other portions of the system.

Cursory examinations were made of several power supply parameters and features to determine their effect on costs. As a general rule, a 3 dB increase in output power results in approximately 33 percent increase in cost for the same tube type, whereas voltage has only a slight effect on cost. Modulators can add significant costs, with floating deck configurations costing as much as 4:1 more than transformer types. However, transformer-type modulators have significant recovery problems. Dual-mode modulator design costs can be quite high.

Some parameters do not adversely affect costs, provided particular levels of performance are not exceeded. Examples are efficiencies of not greater than 90 percent and regulation to not less than 1 percent.

Whereas high-reliability parts may add 20 to 40 percent to parts costs, the true reliability may not necessarily be improved. In some critical areas, these parts may not be the optimum choice. There was some belief that, although high reliability parts were a production cost driver, they may pay for themselves if life cycle costs are considered.

The effect on cost of reduced weight and size is noticeable only when comparable technologies are considered. Reductions achieved by the use of different technologies do not have significant effects on cost. The choice of cooling type does significantly affect costs. A cold plate configuration is preferred to that of direct air cooling.

Protection circuits have a significant effect on cost and reduce the supply reliability. An apparent need relative to these circuits is to more precisely determine requirements and specifications. Although helix protection circuits are a fundamental requirement, the need for other protection circuits may be questionable. The average effect of these circuits on unit production costs is approximately 10 percent with over/under-voltage protection circuits adding costs of as much as 15 percent.

b. Specific Recommendations

(1) Mid-Term R&D

Potting Materials Standards: It was recommended that the Air Force develop standards for high voltage potting materials so that material purchased in different batches will have reliable and predictable characteristics. Potting materials which are used in all nonliquid-cooled power supplies to insulate the high voltage are one of the major contributing factors to power supply cost.

Seals for Fluid-Encapsulated Power Supplies: It was recommended that the Air Force develop new feed-through seals and standards for these seals to minimize the coolant leakage problem.

High-Voltage-Supply Encapsulating Schemes: The Air Force should consider any research and development programs which would lead to major breakthroughs in high-voltage-supply encapsulating schemes.

High-Voltage Wire: It was recommended that the Air Force develop new high-voltage wire and new standards for high voltage wire. The two most commonly used high-voltage-wire insulators existent in TWT power supply design today are silicone rubber and teflon; both present significant problems.

High-Voltage Connectors: It was recommended that the Air Force develop new high-voltage connectors and standards for high-voltage connectors. High-voltage connector problems continue to plague ECM systems, particularly at high altitude.

High-Voltage Switching Devices: The Air Force should develop new high-voltage-switching devices such as transistors, triodes, and fast, stable photocouplers. Standards for high-voltage-switching transistors which encompass the proper parameters should be developed. Most of the high-voltage-switching transistors in use today come either directly or indirectly from the TV and automotive industries and are not directly applicable to ECM systems.

IC Switching Regulator Controls: The Air Force should consider developing a family of standard integrated circuit switching regulator control circuits. The current market for power supplies of this type is too small to induce company-sponsored development at this time; a standard line of integrated circuit pulse-width switching regulator control circuits could reduce the size, weight, and cost of power supplies.

New Standards for Aircraft Secondary Electrical Power (MIL-STD-704): It was recommended that the Air Force reconsider the electrical power requirements for new aircraft and that either 3 kHz to 4 kHz high-frequency power at 115/208V, three phase, or alternatively, 200V DC, be considered. Many studies in the past have established the desirability of high-frequency power;

the majority concluded that a frequency in the 3-kHz range was optimum. This would allow for an optimum input transformer having many advantages in terms of reliability, simplicity, and line isolation. This transformer would be within acceptable size and weight constraints and would be optimized relative to its effect on the overall aircraft electrical power system, including the weight and efficiency of the generator. An interesting alternative is the use of 200V DC, which would allow the alternator-rectifier a wide range of shaft speeds and still result in a small power supply through the use of a DC-to-AC converter operating in the 10- to 30-kHz range.

Along with the line frequency, the line transients specified in MIL-STD-704 should be reexamined.

Computer-Aided Design: It was recommended that computer-aided design programs be developed for given designs to assist in design optimization and size, weight, and cost estimating. The panel unanimously agreed that computer-aided design itself could not solve the state-of-the-art effort required in most present-day ECM high-voltage power supplies. It was believed that existing programs which show size and weight trade comparisons between chopper frequency and other parameters could be extended to provide cost estimating procedures for a given circuit design. As new components which advance the present state-of-the-art are developed, computer-aided design may be able to play a more significant role in optimization of actual circuit design parameters.

(2) Procurement Procedures

It was recommended that power supply requirements be reviewed relative to over-specification of TWT requirements, including, in some cases, unnecessary protective circuitry. Also, the power supply designer should be required to communicate with the TWT designer before the power supply design specifications are finalized.

More attention should be given to preparation of the general requirements portion of the specification, to allow the power supply designer to obtain more of an in-depth appreciation for these requirements and to facilitate an intelligent interpretation of the specification, so that tradeoffs and/or specification additions can be proposed, which will ultimately result in cost savings.

6. SOLID-STATE AMPLIFIERS

a. Introduction and Summary

As with the other major components employed in ECM systems, the high cost of employing solid-state amplifiers is due to both procurement procedures and technical limitations. Since solid-state amplifier devices are generally not well-defined, there is a tendency to use them in state-of-the-art configurations. Thus, the general comments of Section I relative to the need for orderly research and development efforts are also applicable here. Previously described procurement procedures for these state-of-the-art devices are also applicable in this case.

b. Specific Recommendations

(1) Standardization, Mid-Term R&D

As noted previously, critical components such as solid-state amplifiers should be developed on separate development programs to provide the improved system capabilities needed in the 2 to 5 year time period. To allow such programs to be established, it is first necessary to identify solid-state amplifiers which will be required by ECM systems of the future. This standardization should include both the basic RF performance and the various interfaces such as prime power, connectors, and cooling provisions. RF performance should be considered with characteristics such as bandwidth, gain, output RF power, efficiency, and noise figure. It was recommended that the following efforts be pursued as part of a solid-state amplifier standardization effort.

1. Initiate R&D transistor programs to advance the development of power transistors for frequencies from 50 MHz to 2.5 GHz:

   a. To improve the reproducibility of important characteristics.

   b. To generate a family of standard transistors and to thoroughly characterize each of the standard transistors.

2. Initiate R&D transistor programs to develop standard octave-bandwidth, high-power transistors for frequencies higher than 2.5 GHz.*

3. Upon completion of program no. 1, initiate R&D transistor amplifier programs to improve design characterization and standardization of amplifiers. Computer-aided design techniques should be employed.

4. Upon completion of program no. 2, initiate R&D transistor amplifier programs to build standard transistor amplifier modules for the higher frequencies required for ECM application. Standard amplifier modules should be developed for intermediate amplifier stages, whereas final power amplifier stages should be developed to meet requirements of a particular ECM system.

5. Initiate an R&D program to reduce insertion losses of microwave components employed with amplifiers, including filters, combiners, directional couplers, hybrids, isolators, etc.

6. It was recommended that the transistor amplifier developer should not be the same company that develops and manufactures the transistors used in the amplifiers.

(2) Long-Term R&D

It was recommended that long-term developments of broadband devices using devices other than transistors, especially Impatt diode amplifiers, receive continued support in R&D phases in order to fully develop their potential capabilities. However, such amplifier developments must be consistent with the need for eventually providing high-power, efficient outputs across ECM-type bandwidths. Because these are two terminal devices, they may eventually be more cost-effective than the three terminal classes of devices.

*The steering committee recommended that this not be done. See Section IV.

(3) Procurement Procedures

As with the other major components which may be employed in near-state-of-the-art configurations, solid-state amplifier procurement procedures should be governed by the considerations outlined in Section I. This would apply particularly to the short term, where state-of-the-art requirements should be avoided if costs and deliveries are to be optimized.

7. LOGIC SYSTEMS

a. Introduction and Summary

The logic systems panel consisted of a diverse group of government and industry people. In general, the diverse opinions concerning techniques for reducing ECM costs were probably due to the following:

1. Logic systems within ECM systems cover many applications, and the digital technology used is the only common denominator for these applications.
2. The majority of the ECM manufacturers believe that their competitive edge is maintained by their digital processing technology and, therefore, are unwilling to speak of specifics.
3. The only common ground these manufacturers hold is that the Air Force's own organization and purchasing practices are causing the rise in costs of ECM logic systems.

There was unanimity, however, in the view that savings were urgently needed and that there were areas in which realistic savings were, indeed, achievable. It was the moderator's view that the impact of logic design upon total system cost is particularly profound in that, through effective power management (a logic design function), the total system hardware can be significantly affected. That is, ECM performance can be markedly improved (in terms of higher specular, temporal, and modulation efficiency) for a given receiver/transmitter configuration. Conversely, the number of transmitters/power supplies needed to jam a given threat environment could be reduced through effective management. Therefore, it was the opinion of the panel that heavy emphasis upon effective power management techniques can significantly reduce system acquisition costs.

Commonality and standardization were discussed at length. It was the moderator's view (not universally shared) that, from an operational and technical viewpoint, standard ECM systems that could be modularly sized to the environment are possible. However, from a practical business viewpoint, it is probably not practically implementable.

The general divergence of thought led to a consensus technique for finalizing the views of the panel. A slate of recommendations was prepared. Each was voted on by the group as to content and wording. The accompanying recommendations are the consensus of the group as to means of reducing ECM costs in the logic design area.

In conclusion, the logic design panel considered the requirement for realistic specifications for both systems and components to be the major cost driver among those presented. Secondly, they considered the interplay between acquisition cost and life cycle cost to be fundamentally important to cost savings. They also recommended a continuation of Air Force-sponsored studies of this nature in terms of regular meetings of small working groups. This will assure that the attack on the cost problem is officially and formally pressed.

b. Specific Recommendations

(1) Hardware

Commercial Components: A study of the application of standard commercial components to the military problem was recommended. Areas such as quality control, environmental suitability, and reliability should be considered. Unneeded cost driving specifications should be modified, and maximum use of commercial hardware should be made.

Large Scale Integration (LSI): Foster the technology in LSI which would be specialized for ECM manufacturers. Examples of components which would be useful in ECM equipments and which are not available now are:

- Fast LSI compare between limits
- The large functional building blocks
- Content-addressable memories

Microprocessors: The development of small, high-speed microprocessors should be fostered and supported. Modularization was recommended, and standardization in basic arithmetic and logic units seems to be possible and desirable.

(2) Design

Digital Circuitry: Designs should be directed towards sensibly maximizing the use of digital circuitry as a cost saving device. The center of the system, the computer, is digital, and it was recommended that the preprocessor and the techniques generator, and even the transmitter at the output, use digital circuitry.

Functional Modularity: The use of functional modularity in preprocessing and techniques generation was recommended. It would provide for some standarization in hardware, in system design, and in sizing the equipment to the problem. It would also reduce the system impact due to changes of expansion.

Performance Specifications: A study should be undertaken to determine realistic system requirements as a function of vehicle and engagement area. It was further recommended that performance specifications be written in terms of specific scenarios as opposed to worst-case parameter requirements. This would afford the designer greater flexibility in configuring an adequate and lower cost system.

(3) Standardization

Documentation: Documentation delivered with operational computer programs should be standardized.

Language: The standardization of language should be studied.

Algorithms: Standardization of algorithms, except in limited cases, does not appear practical without standardized hardware. However, documentation and dissemination of algorithms is recommended.

<u>Functional Interfaces</u>: Attempts should be made to standardize functional interfaces within the logic system.

<u>General</u>: A study should be started and definitive work published on the possibilities and limitations of deinterleaving, parameter derivation, and ECM techniques. This would avoid needless repetition of studies and possible false starts in hardware development.

(4) Software

<u>Higher Order Languages (HOL)</u>: The use of higher order languages that are commercially supported was recommended. The savings in initial design and in support would be significant. However, the unit equipment costs may be somewhat higher due to the relative inefficiency of the HOL. It was emphasized that the savings in HOL will only be realized with the use of mature compilers and translators.

<u>Software Packages</u>: The panel recommended that the contractor provide distinct software packages to accomplish the following:

- Effective bench test and validation of receiver/transmitter subsystems
- Initial flight test evaluation of the system
- Operational mission requirements

Sufficient schedule flexibility should be permitted for conducting the evolutionary levels of testing to confirm operational software.

(5) Life Cycle Costs

The panel acknowledged that a conflict exists between acquisition costs and life cycle costs and recommended a continued study of the problem to allow industry and the Air Force to define total system cost and weight the elements properly.

(6) Advanced Development

Introduction: Reprogrammable multiple pulse train trackers, multiple pulse train deinterleavers and bulk-data memory comparators are specific areas that relate to immediate and pending logic problems. Hardware/LSI (Large Scale Integration) developments in these areas will have broad ECM system application potential, will contribute to reducing overall system costs and increased system flexibility, and at the same time will lead to establishing universal low cost ECM system logic building blocks.

Pulse Train Tracker Module: Present and future power management type ECM systems utilize PRI pulse train trackers. This capability is in essence reinvented with each new system start. The development of a versatile logic tracker module would lead to logic module standardization and provide cost saving benefits. The flexible tracker module should: be reprogrammable; be computer/microprocessor-interface-compatible; be capable of handling stagger-type pulse trains; provide data smoothing for jitter-type pulse trains; perform PRI interval and phase corrections; and provide synchronous timing pulses to ECM technique generators. The payoff would be significant cost savings resulting from minimizing redundant hardware on a per-signal basis and modular commonalities. The tracker module would be capable of tracking at least 16 signals simultaneoulsy.

Pulse Train Deinterleaver Module: A companion to the PRI tracker is the pulse train deinterleaver module. This flexible module should provide the capability for real-time deinterleaving of composite video pulse trains and should be interface-compatible with crystal video, superheterodyne, and channelized receivers. This interface flexibility would permit the module to have broad ECM application potential and provide significant cost savings as a basic ECM logic building block. This module should be reprogrammable, capable of identifying a pulse train as either a new signal or a stagger subset of a currently acquired signal, and capable of acquiring both frequency hopping and jitter type signals. This module should be interface-compatible with the PRI tracker for pulse train handoff and update. Microprocessor/computer interface compatibility should be provided to enable priority structuring and updating of active threat file.

Bulk Memory/Data Comparator Module: ECM data processing throughput rates for current and projected signal environments are significantly increasing. Current software/computer approaches and implementation techniques are approaching throughput saturation. The choices available as a solution to this problem are either faster clock rate processing or parallel hardware processing. The former approach would necessitate evolving to higher speed computer/processing equipment with associated higher power, cooling, and cost problems. The latter approach would increase hardware costs significantly. In the area of logic/processing, this increase in cost may not necessarily be the case due to state-of-the-art LSI integrated circuit technology.

Parallel/bulk memory data comparators directly impact costs, data processing rate and throughput capacity. Current modules such as CAM (Content Addressable Memory) type memories have an eight-word by four-bit storage and comparator capability. State-of-the-art IC (Integrated Circuit) technology makes it potentially feasible to extend this parallel bulk memory comparator capability. A high-bit-density module would contribute to significantly increasing data processing throughput capability without paying the penalty and cost of higher-speed/power-type logic technology.

8. AIRCRAFT INTEGRATION

a. Introduction and Summary

The Aircraft Integration Panel considered a number of important factors relating to ECM costs. Among the key factors considered were:

- Antenna/aircraft interface (including radomes)
- ECM equipment interfaces (connectors, cables, transmission lines)
- Environmental Control Unit (ECU) interfaces
- ECM/prime power interfaces
- ECM/Electromagnetic Interference Compatibility (EMIC) impacts

Cost drivers were considered from both the user and supplier point of view. Problems related to two types of installations (modifications to existing vehicles and designs of new systems) were considered. It was evident that the earlier planning for aircraft integration and installation could be performed, the greater the cost reductions would be in this area. Add-on installations by their very nature tend to be costly because of restrictions either on aircraft or ECM equipment modifications, or the complications of EMI/EMC problems.

The findings of the Integration Panel applied across the board to avionics in general and emphasized standardization and near-term improvements.

b. Cost Drivers

Since add-on installations tend to be more costly than new installations, the panel identified typical cost drivers in the aircraft installation/integration associated specifically with a B-52 and indicated that the figures would also be reasonable for an F-4 modification. The following five major cost drivers and their associated factors were identified:

Cost Drivers	Percent of Total Installation/Integration Costs
1. Antenna/airframe interface including radomes and transmission lines	40
a. Antenna pattern/isolation measurements	
b. Structural modification	
2. ECM/EMIC impacts	20
a. Radar Warning Receivers	
- Equipment Susceptibility	
- Use of adaptive thresholding and noise cancelling schemes	
- Inherent rejection of undesired signals by precision RWR signal processing	

Cost Drivers	Percent of Total Installation/Integration Costs
b. Active ECM	
- Suitable provisions for blanking, lookthrough, etc., incorporated into ECM equipments during design phase	
- Standardized blanking interfaces	
- Use of physically similar pods to reduce flight certification costs	
3. ECM equipment adaptors, cables, harnesses, racks	20
a. Equipment adaptors and mounting racks	
- Equipment size	
- Environmental requirements	
b. Cabling and harnesses	
- Major cost impact: high-frequency coaxial cables	
4. ECM/prime power interface	
a. Compatibility with existing aircraft power sources	10
5. ECM/ECU interface--using ram air	10
a. Required temperature levels and equipment heat dissipation	
b. Compatibility with existing ECU package	

c. Specific Recommendations

The recommendations identified areas or technology requiring R&D which would impact acquisition costs. Again, because many of the aircraft installation/integration problems are associated with modifications or "add-ons" to existing systems, many of them are directed towards those types of systems and, by their nature, do not represent "new technology starts." The recommendations, in some instances, are similar to those of the other panels, but they are specifically identified because of their cost impact on aircraft integration.

(1) Hardware

Transmission Lines: Development of improved cable and RF transmission line systems is required.

- A need for an integrated development approach among the EW system supplier, cable/transmission line supplier, and system integrator
- Funds should be allotted specifically for improved cable and transmission lines with emphasis on lower loss cables and connectors and wideband characteristics with consistent phase characteristics
- Competition should be fostered to develop more sources for complete transmission line/cable assemblies
- A need to develop EW equipment design techniques which would eliminate the need for flexible waveguides

Power Supplies: Develop high-frequency, solid-state prime power supplies, for new installations only, which would reduce the weight and lower the cost to both aircraft and EW equipment.

Cooling/Sealing: Liquid cooling systems are preferred because they are more cost effective in high-density heat loads, and an integrated cooling system design approach should be considered early in the system design. In conjunction with liquid cooling, improved seal design techniques are required to reduce maintainability problems.

(2) Environmental

Nuclear: Nuclear hardening requirements for EW equipment should be evaluated to determine if any unique requirements exist, and any available expertise should be disseminated to the EW community.

Specification: Missionized environmental test specification development should be explored, since cost reductions may occur by deleting nonessentials in MIL-E-5400.

Temperature: Temperature cycling and temperature extremes should be minimized so that component requirements can be relaxed and wider use of commercial components be made.

(3) Systems

Multiplexing (MUX): Multiplexing techniques for high-signal-density application are desirable and should be carefully considered in the design of an EW installation because MUX would reduce quantities of transmission lines, reduce EMI/EMC problems, and provide S/V payoffs. However, a tradeoff study should be performed prior to incorporating a MUX system to determine cost/performance gains.

Integrated Packaging: A study is required of ways to reduce or eliminate duplication of packaging and environmental control components. A key consideration of this study should be the maintainability impact of such criteria.

(4) Standardization

Integration Contractor: If a separate integration contractor approach is used, then a single program manager for the aircraft installation/integration who has authority/responsibility to control overall EW equipment/aircraft integration should be used; he may also be the prime contractor.

Data: The contractor data format should be used as much as possible and the number of data items and data approval items required should be reduced. Also, the number of data submissions required should be reduced through the expanded use of the data accession list.

GFE: The use of GFE or the imposition of standardization requirements must carefully consider the impact on the total system acquisition cost and the logistic pipeline.

DAIS: The digital avionics information system should consider the cost impacts of the EW function early in the design phase because of the unique characteristics of EW systems and the dynamic nature of the threat; more cost payoff may accrue from digital processing outside the DAIS framework.

AGE SPO: The establishment of an AGE special projects office similar to the life support or simulator SPOs should be considered to determine the balance between the flight line AGE and BITE (Built In Test Equipment) and also to minimize the proliferation of AGE.

Test: The merits of a centralized EW integration test facility (including a full-scale anechoic chamber) should be studied.

Aircraft Signatures: Control of radar cross section, infrared, etc., should be required in new aircraft and external stores design.

EW Installations: The preferred approach to aircraft EW system design is internal installation with adequate growth provision (by modulator add-ons) to reduce the impact on installation cost and aircraft performance.

MESA: The multifunction elemental system approach should be considered because it may reduce redundancy of the total avionics package and provide cost savings because of commonality.

Thermal/Mechanical Design: The EW equipment suppliers should exploit the existing knowledge in thermal and related mechanical design techniques and develop a handbook (similar to the SAE Aerospace Thermodynamics Manual) for use by EW manufacturers.

9. SYSTEM DESIGN

a. Introduction and Summary

Recommendations were formulated relative to component development, standardization, system requirements, and institutional procedures. Components recommended for further development were MICs, SAW devices, and TWTs. Improvements in bandwidth, average power, pulse-up, and efficiency of TWT amplifiers were included. Standardization recommendations were directed toward TWT amplifiers, microprocessors, and software. System-oriented considerations included the determination of effects of reduced RCS, the determination of on-aircraft antenna patterns, and the basic format of future system configurations.

b. Specific Recommendations

(1) Mid-Term R&D Standardization

Microwave Integrated Circuits (MIC)

It was recommended that AFAL initiate a program to study the suitability of standardizing high usage RF and microwave circuits and components in integrated configurations. Each ECM system has a multitude of low-level RF and video circuits and components which, if properly integrated into MIC modules, could effectively reduce cost, volume, and power as a retrofit to present equipments (when modified for performance improvement). The modules would also form the basis for standardized low-level modules providing such functions as RF amplification, modulation, signal sources, mixers, etc.

An additional task recommendation was to compile a catalog of selected industry-developed MIC modules to develop an interim standardized list of MIC modules. Cost savings over previous lump constant and hybrid MIC circuits is unknown but can be high, depending on the extent of the standardization.

Surface Acoustic Wave (SAW) Devices

It was recommended that AFAL initiate an evaluation of surface acoustic wave (SAW) devices relative to ECM system needs. These devices offer the possibility of significant cost and size savings in a number of applications. Where appropriate, recommendations should be made for specific SAW device developments to meet ECM system requirements. Possible applications and estimated cost savings of SAW devices to ECM include:

- Channel filters for receivers (est. 35% savings on receiver costs)
- Dispersive delay line receivers
- Delay lines for repeaters

- Frequency synthesizers
- IF filters
- Pseudo-real-time correlation

The study should include considerations for reducing and/or developing system techniques for circumventing undesirable characteristics of SAW devices such as:

- Triple transit effects
- Direct feedthrough
- Bulk-wave propagation
- Quarter-wave transducer effects
- Bidirectional insertion loss
- Impedance mismatch

TWT Amplifier Improvements

Bandwidth: Multi-octave TWT technology may be needed. Applicable equipments are low-cost, lightweight systems where the price goals do not permit use of normal octave band TWTs. This tube would be employed to meet ECM requirements where the threat is of a low priority in one octave, and all high priority ECM signals can be countered by a single tube. Ideally, the tube would have a form factor such as to fit in the applicable existing equipment. Dual-octave coverage is a design objective. This tube, utilizing the existing equipment power supply, may result in a net 10% savings in system costs, even when extending the tube cost by a factor of two. Before pursuing development of a multi-octave TWT, the appropriate studies should be conducted to better quantify the savings associated with such a device.

Pulse-Up Duty Cycle: It was recommended that effort be given to the development of a TWT with an extended duty cycle (10%) and an increased pulse-up capability (to 3 dB). The tube would have application for the F-15 ICS, B-1, and Multews. Specific technology needs are:

a. Improvement of multi-collector configuration

b. Efficiency

c. Means for higher dissipation to improve the tube duty cycle characteristics

The cost improvement program could result in an approximate 10% saving.

Frequency Synthesizers

It was recommended that AFAL initiate a study to investigate the cost advantage of a frequency synthesizer for ECM. These devices produce a stable source of microwave oscillations at a commanded frequency within 100 nanoseconds of receiving a digital command. As such, the frequency synthesizer has the capability to perform ECM techniques for pulse, pulse doppler, and CW signal generation, and it can be a source of BIT (Built-In Test) simulation. The study should include a determination of how the frequency synthesizer can best perform these functions and the system interfaces involved in these applications. The study should also consider the cost effectiveness of a frequency synthesizer as compared to other methods of performing the stated ECM functions for ECM systems of several degrees of complexity. Assuming favorable cost effectiveness, it was recommended that a brassboard development be initiated to demonstrate the frequency synthesizer performance for use in systems employing advanced ECM architecture.

c. Standardization

(1) Standardized TWT and Power Supply

It was recommended that AFAL perform a study to determine the cost savings that could be attained in production by standardizing TWTs and a power supply matched to the tube design parameters. Emphasis should be placed on the lower-level TWTs.

(2) Microprocessor Standardization

The potential cost savings that may be realized by standardization and other technological advances in the RF chain could quite easily be consumed in the development of microprocessors that are required to cope with more exotic and denser threat environments. Recently, microprocessors have been proposed as central elements to perform the following EW/ECM system functions:

- Demultiplexing dense environment data rates
- Signal sorting and threat recognition
- Antenna control (steering, DF calculations)
- Adaptive receiver control
- ECM techniques generation
- Displays and intersystem communications
- BITE with significantly reduced AGE requirements

Currently, many different structures exist. This hardware architecture could be standardized to prevent cost growth. Studies should be initiated now to investigate the feasibility of such standardization, at least to address the near-term mod-kit solutions that will be required through 1980.

The Air Force should take advantage of the "standard" microprocessor family currently going into commercial/industrial production to realize a considerable cost savings potential.

(3) Software Standardization Study Subset (Near and Long Term)

- Optimize particular ECM suite functions (i.e., enhance signal correlation and linearize VCO operation) by utilizing hybrid firmware, software tools, and components.
- Sectionalize the software in current systems to speed operations (i.e., PRI/pulse sorting, frequency determination, etc.) and to enhance software applicability to specific EW missions in adaptive EW systems as well as dedicated EW systems.
- Utilize core-oriented instruction sets currently dedicated for system control, where these instruction sets can enhance signal processing and jammer control. This application infers foreground/background software operations. Also, the relief of executive routings should be accomplished by firmware.

- Utilize distributed processing techniques in updating current software to be more responsive to the EW system requirements, which include:
  - Sequencing software tasks
  - Dedicated software tasks
  - Software distributed among interconnected processors to accomplish decentralized distributed computing.
- Permit a standard allocation of procedural software for future system inequities (hardware workarounds).
- Integrate algorithms and new system control functions via software into existing systems to extend applications and life cycle.
- Conduct BIT functions by software/firmware on an automatic timely basis.

d. System Requirements

(1) Advanced ECM System Architecture Study

It was recommended that a study be initiated to evolve the characteristics of a future (1980) low cost ECM system. The study should consider existing technology, namely, the utilization of distributed microprocessors, a data bus, software, and BIT modules. The system should permit the addition of growth functions while still retaining the basic architecture. Specific functions of the generic system should include: emitter listing, threat warning, complete jammer control, signal correlation and signal enhancement, and ESM functions.

The study should define the basic architecture for a low cost system operating in the 1980 environment. BIT should be incorporated, negating significantly the requirement for AGE.

(2) RCSR Cost Impact Study

The committee emphasized the importance of radar cross section reduction (RCSR) as a cost driver. Before RCSR can be given up as a practical cost driver, the true integration costs to design it into new (B-2, F-19) and existing (F-16) airframes should be determined through a RCSR cost impact study. A continuing study was recommended, emphasizing preintegration meetings between the ECM and aircraft integration contractor and the cognizant SPO.

(3) On-Aircraft Antenna Pattern Measurement

The panel recommended that the Air Force consider providing a full-scale electromagnetic mock-up facility for each new aircraft which is expected to require ECM equipment installation. The mock-ups would be used to measure on-aircraft antenna patterns for use in analysis and simulation tests, to determine optimum antenna locations, and to evaluate the effects that external stores and variable-geometry airframe structures have on radiation patterns. Such measurements have already been made on mock-ups of the B-52 for Linebacker II, on the F-4, and are already planned for the F-111. This same facility could include capability for full-scale electromagnetic compatibility tests in a (secure) anechoic chamber.

e. Institutional Recommendations

(1) Scenario Data

It was recommended that ECM manufacturers be provided with threat scenario data very early in their program, even at the RFP stage. The data would be used to help improve the effectiveness of the design and could assist in reducing costs. A flexible but standard scenario(s) would minimize the need for a total scenario analysis with each new contract.

(2) Aircraft Integration

Early participation of the ECM manufacturer in the airframe/equipment integration should be a matter of USAF policy. Close contact between the manufacturers' design engineers and the problem/environment of the proposed ECM equipment location should materially reduce costs by avoiding costly misunderstandings.

(3) Cost Analysis Prior to Production

At the CDR and/or at the conclusion of flight testing, the Air Force and the contractor should conduct a value analysis to trade cost versus performance with a view toward obtaining the most cost-effective performance. Candidate tradeoff parameters could be simplification, power output, frequency coverage, antenna pattern as a function of single-shot probability of kill, and cost. Consideration should be given toward providing the using Command with performance versus cost sensitivity data during the requirement formulation process so that the requirement is more responsive to cost. The using Command should also be made aware of and urged to participate in cost performance trades during the equipment development acquisition process.

(4) Recommendation for Service Test Phase as Part of R&D Phase

The Panel recommended that a service test phase be initiated as part of the R&D cycle. Five to ten prototype systems would be procured during the phase prior to a production commitment. Test units would be installed in using Command aircraft concurrent with extended bench qualification testing. Periodic reports relating to parts failure, equipment configuration changes, and performance testing would be made and consolidated in the R&D fixed loop. The cost savings cannot be quantified, however. It is readily apparent that significant savings would be accrued by enabling early fixes to the equipment configuration early in the equipment life cycle.

(5) Data Item Recommendation

DD 1423, "Contract Data Requirements" are, in total, a high cost item. A part of initial program effort for each new procurement should be a review of data requirements. Data requirements and data procedures need to be streamlined to make data procurement most cost-effective. Data cost tradeoffs should be made part of program negotiations.

10. IR SYSTEMS

a. Introduction and Summary

The task of the infrared panel was somewhat more difficult than that of other panels because the IR EW field stands at a much earlier point in its evolutionary development relative to the whole of EW technology. Consequently, the requisite experience base is much smaller. While on the one hand, the immaturity of the IR EW field represents a drawback, in another sense, it represents an opportunity to profit and learn from the mistakes and experience of the more advanced aspects of EW technology. The challenge over the next decade will be to recognize and differentiate between those problems which can be solved by analogy to the EW field as a whole and those for which the IR community must provide its own cost effective solutions.

The initial discussions focused upon organization and ground rules for the meeting. The panel limited itself to passive and active IR EW systems operating in the nominal spectral bands 1.8 to 2.7 μm and 3.0 to 5.3 μm. They considered five generic types of systems, using data from specific case histories where available. These are:

- Scanning Passive Warning Receivers (e.g., AAR-34)
- Fixed Field of View Warning Receivers
- Flash Lamp Jammers
- Incandescent Solid Jammers
- Laser Jammers

The panel attempted to restrict itself to a discussion of acquisition costs, although some points related to life cycle cost did arise. Also, no attempt was made to belabor the institutional problems because it was decided that this would be too time-consuming and redundant with findings of other panels. However, it was recognized that the institutional problems must be addressed if cost reductions are to be effected, and a list of recommendations in this regard is provided. One of the most important results of this initial conference was considered to be the laying of a foundation for future low cost conferences considering IR EW systems. It is therefore necessary to note a number of specific areas in which the conference was implicitly or explicitly limited by the ground rules or the panel membership. These are as follows:

- Unclassified Conference
- No Consideration of Performance
- No Consideration of Life Cycle Costs
- Single Panel of Systems Personnel
- Limited to Five Generic Systems

Given the time and background of the panel members, it is unlikely that more could have been accomplished by widening the scope. The reasons for limiting the scope are reasonable for an initial thrust. Nevertheless, it is necessary to review the impact of these limitations of scope with the intent that future undertakings of this nature might be more specific and profitable.

Taking each of the above points in turn, the unclassified conference seemed to be a most serious limitation, for it immediately excluded discussion of performance parameters of IR EW systems and specifically excluded certain whole classes of IR EW systems (e.g., OCM, OPTINT, etc.). It was therefore recommended that future conferences be classified.

It was freely acknowledged that the relatively modest procurement lots in IR EW have been the result of factors other than cost. Consequently, more IR EW systems would not be produced even if the cost were substantially reduced. Performance is still the controlling factor. A more comprehensive discussion of this problem would be a natural outgrowth of a classified conference and may be peculiar to IR EW equipments. However, it was felt to be a part of a more general problem existent in the EW field.

At some point in the evolution of low cost EW endeavors, it is necessary to introduce the question of ultimate performance criteria and the implication for system parameters. What are they? How are they defined, measured, simulated and/or determined from operational data? Statements such as, "The systems must both work and be cost effective . . ." do not come to grips with the essence of the cost problem. Performance must be somehow quantified in terms like mission survivability and this, in turn, related to parameters such as probability of detection, ranges and angles of coverage, jamming-to-signal ratio, etc. When this is accomplished, it is then seen that "it works" is only a qualitative number. Cheaper systems will be seen to work less well than more expensive systems, other things being equal. The burden for reducing costs by making these tradeoffs in performance will eventually fall upon hardware contractors. The problem of defining the measures of effectiveness and developing a methodology for doing tradeoffs is primarily an institutional problem.

Life cycle costs were not considered and probably could not be considered reasonably by this panel at this time. The quantities of production and numbers of equipment are too low, and the industry and government attendees, by virtue of past experience, were biased to R&D and production as opposed to maintenance and logistics. Life cycle costs for IR EW equipments are expected to present special problems and substantial costs and should therefore be considered in the future. One example which was cited shows the importance of life cycle costs: The maintenance costs for the cooling system for the AAR-34 have thus far been comparable to the entire R&D effort for threat detectors (all contractors) or to the acquisition cost of 600 units. The exact dollar estimate of these costs could not be confirmed, but even if they were somewhat exaggerated, they emphasize the importance of life cycle costs.

Other panels were organized according to systems and components. In a sense, the IR panel was represented only at the system level. While it was conceded that it would have been premature at this time to break down the panel by subsystem elements such as detectors, sources, optics, cooling, etc., this should be done at future meetings. Eventually, it will be necessary to provide more in-depth data on IR component costs. Since the IR part of the EW field does not currently constitute a large enough fraction of the EW cost to warrant 5 to 10 separate panels, an alternate method for obtaining more in-depth coverage should be sought. It is noted that the IR community has a number of forums for providing additional depth on the cost problem. For example, it may be of value to have a specialty subgroup of IRIS or the laser conference devoted to cost reduction. Another possibility would be to have the various working groups of IRIS put cost considerations on the agenda of their meetings.

The five generic systems considered by the panel did not completely represent IR EW. For example, decoys and suppression were important omitted subjects. Furthermore, there are other IR EW systems such as OCM, Laser Countermeasures and OPTINT which were not represented. It was therefore recommended that a broader representation of infrared and electro-optical EW systems be considered in the future.

b. Current System Costs

The following table gives the estimated cost distribution for the two generic types of IRCM equipment which have had limited production.

COST DISTRIBUTION FOR IRCM SYSTEMS

	Passive (AAR-34)*	Active (ALQ-123)** (AAQ-4/8)***
Components and Basic Research	1%	5%
Feasibility Studies	2%	22%
Design (Through EDM)	10%	18%
Test and Evaluation	2%	5%
Manufacturing	85%	50%
	600 units	100/100 units

*Does not include R&D costs of similar competing threat warning systems.

**The active column is based upon the ALQ-123, where two systems competed through the STM level.

***The AAQ-4/8 is thought to have a similar distribution, but first-hand data were not available for this particular system.

The quantity of IRCM systems is large enough to provide reliable cost guidelines, but only for two systems, that is, the AAR-34 and the Arc Lamp Jammers. With regard to the fixed-field-of-view threat detectors, the incandescent source jammers, and the laser source jammers, not enough systems have been produced to provide reliable guidelines.

c. Cost Drivers

The panel identified cost drivers associated with IR systems and noted that, in the past, cost was completely dominated by performance factors. However, a design-to-price concept would allow the contractor to perform the tradeoff in performance by providing ranges for the critical parameters and allow him to optimize the delivery schedule for cost reduction.

Suppression and signature reduction have a substantial impact on IRCM performance requirements and, consequently, upon IRCM costs. Conceptually, cost and performance tradeoffs between suppression and other forms of IRCM are possible.*

High temperatures and attendant cooling problems are the major cost drivers arising from environmental constraints. Window materials with low emissivity and methods of window cooling are considered to be derivatives of this environmental problem. It is expected that the problem will become increasingly important in the future as systems are required to look forward. For future IRCM systems, laser cooling is also expected to be a cost driver. In general, the IR panel was not critical of military environmental performance specifications. These consensus was that, in general, they are reasonable and well thought out. It was noted that, in some cases, the vibration specifications were not stringent enough for the specific installations of IR systems. This later point is probably a reflection of the two specific systems (ALQ-123 in a pod and AAR-34 on top of the vertical stabilizer) with which the panel was most familiar.

Aircraft installation and interface problems are a major cost driver, but are considered to be outside the scope of the IR panel. However, a previous EO panel** found that current baseline EO system installation costs are 17 percent of the other acquisition costs, and they projected that, while this

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*ASE Measure of Effectiveness (MOE), Test Requirements (TR) System Requirements (SR) and Associated Analysis: Interim Technical Report, IR Countermeasures (U), 30 September 1974, Calspan for AVSCOM under MIPR A5873-F-74-1010, Contract F33615-73-C-4112 (SECRET).

**Air Force/Industry Electronics Cost Reduction Conference: Electro-Optics Panel, March 24-29, 1974, St. Petersburg, Fla. (preliminary copy published by Fairchild Space and Defense Systems, Syosset, LI, E. G. Muehleck, Chairman).

absolute amount would decrease, the relative costs of installation would rise to 25 percent. A recommendation for earlier identification of the location and interface problems was made. The panel did not feel that an integration contractor is needed or that cost savings could be made by using an integration contractor.

Major cost devices are listed in order of importance by functional areas for passive and active systems in the following table.

IR SYSTEM COST DRIVERS

Active	Passive
1. Stabilization	1. Stabilization and Tracking
2. Sources	2. Signal Processing and Electronics
3. Power Supplies and Energy Storage	3. Optics Design Fabrication Materials
4. Optics Design Fabrication Materials	4. Detector Arrays and Cooling
5. Cooling	5. Cooling (other and unique)

d. Specific Recommendations

Data Access: The panel felt that they did not have adequate access to data. Four specific problem areas were cited:

- Interservice fragmentation of intelligence data
- Increased use of L-documents for everything of value
- Long time lags in data reduction for DOD tests
- Too much secrecy with regard to DOD planning

Number of Competitors: The number of competitors is about the right level in the IR EW field and also in various special areas of the field. However, it was recommended that the competition be continued through the preproduction or service test model level; this would reduce acquisition costs.

Simulation Facilities: Generally, the simulators currently used are considered adequate for active jammers to verify basic feasibility. However, they may be inadequate for obtaining accurate data for cost reduction, which implies cutting performance margins rather closely. For passive systems, none of the simulators was considered adequate. The general inadequacy lies in the simulation of the background, but the panel did not recommend any solutions to the problem. They felt that the problem of simulators and their impact on cost reduction was sufficiently complex to merit a separate study and recommended that such a study be undertaken.

System Integration: Cost savings are possible through greater integration with microwave sensors and with on-board processing and displays.

Research and Development: Both new technology and better use of existing technology are needed to obtain cost reductions in IR EW. Table 1 gives specific areas for which the application of current R&D funds is recommended for the purpose of reducing manufacturing costs in the future. It was generally felt that, while adequate consideration and funding is given to new technology in the initial thrust, the funding is dropped too soon after feasibility is proven or a working model is developed. Frequently, a serious gap develops because critical components do not meet size, weight, and environmental performance criteria and this, in turn, increases the cost of later stages of system development. In this sense, it was felt that the emphasis should be upon development of existing technology.

Scheduling: The contractors should have the latitude to optimize the schedule for cost. In the past, the procurement cycle has been inefficient in two ways. Research and development programs through preproduction on the first production run have been too accelerated. Production has been too stretched out. Both production and R&D suffer from intermittent funding.

Measures of Effectiveness: Measures of effectiveness or bounds on performance which allow cost reduction tradeoffs should be provided.

Cost Figures: Approximate cost figures of both the R&D and production levels that are acceptable for a given problem should be provided.

TABLE 1. AREAS WHERE R&D EXPENDITURES CAN REDUCE ACQUISITION COSTS OF IR SYSTEMS

PASSIVE SYSTEMS	ACTIVE SYSTEMS		
	FLASH LAMP	INCANDESCENT SOLID	LASER
1. R&D FOR STANDARDIZED AND MODULARIZED DETECTOR ARRAYS.	1. R&D FOR PRODUCTION ENGINEERING IS 50% OF 100 UNIT ACQUISITION COST. BETTER PRODUCTION PROTOTYPES OR LARGER QUANTITIES WOULD REDUCE PER-UNIT COSTS.	1. R&D IN MECHANICAL MODULATOR (25%).	1. R&D TO INCREASE LASER EFFICIENCY AND IMPROVE FORM FACTORS.
2. COMMONALITY AND STANDARDIZATION OF LOGIC. USE OF ON-BOARD EQUIPMENT MEETING IR NEEDS.	2. R&D FOR CHEAPER PROTECTIVE WINDOW (2%).	2. R&D IN SOURCE MATERIALS.	2. INCREASED POWER AND WAVELENGTH OPTIONS.
3. R&D FOR COMMONALITY OR STANDARDIZED CRYOGENIC UNITS (SIGNIFICANT IN BOTH ACQUISITION AND LIFE CYCLE COST).	3. CONTINUED R&D COMPETITION THROUGH PREPRODUCTION (50%).	3. R&D IN WINDOW MATERIALS (20%).	3. WINDOWS AND COATINGS.
4. TRI-SERVICE AGREEMENT ON DISPLAY AND ANGULAR ACCURACY REQUIREMENTS.		4. CONTINUED R&D COMPETITION THROUGH PREPRODUCTION.	4. STANDARDIZED POINTING AND TRACKING.
5. CONTINUED R&D COMPETITION THROUGH PREPRODUCTION.			5. SOLID-STATE MODULATORS AND BEAM DETECTORS.
			6. CONTINUED R&D COMPETITION.

Section III

SUMMARY OF OVERALL SYSTEM RECOMMENDATIONS

This section elaborates on some of the technologies presented in Section II, discusses alternative technological approaches, and groups together some of the individual panel recommendations to point out possible cost-effective tradeoffs.

1. SYSTEMS DESIGN

The Receiver and Systems Design Panels both recommended the study of Surface Acoustic Wave (SAW) devices. Presented below are the recommendations of the Systems Design Panel concerning advanced development of SAW devices.

SAW devices have many EW applications (e.g., filters, repeater delay lines, oscillators, dispersive receivers); however, they are relatively new and need refinement to exploit their full utility. When used as filters in channelized receivers, they can improve performance and are smaller and cheaper than conventional filters, the cost and size of which have been primarily responsible for the limited use of the otherwise attractive channelized receivers. Since SAW devices are manufactured using photolithographic techniques, high production/high reproducibility is possible. Considering the number of filters used in a channelized receiver, this factor is important.

Cost reductions can also be confidently predicted when SAW devices are used to replace conventional delay lines. While USAF does not possess large numbers of delay line repeater systems, a SAW delay line can be used in this conventional role to effect large volume savings which are also reflected in lower costs. Improvements such as reduced insertion loss could effect even greater savings by eliminating a TWT in the recirculating loop. Also, and perhaps just as important, the SAW delay line can be employed in a repeating noise jammer in much the same way as it is used in a repeater system.

Numerous other EW applications for SAW devices are appearing frequently (e.g., dispersive delay line receivers and secure data links for mini-RPVs).

Some goals toward developing SAW technology are listed below. Note that, while specific numbers are given as goals, and some have been realized in the laboratory, achieving these values in production will result in the greatest cost saving. Also, it should be noted that the values represent an overall "requirement," and certain applications can be satisfied with lower performance.

Filters

- Noise figure: < 12 dB
- Sidelobes: 55 to 60 dB
- Insertion loss: ~ 6 dB

Delay Lines

- Extend frequency to 3 GHz
- Insertion loss: ~ 10 dB
- Triple transit suppression: 55 to 60 dB

Oscillators

- Extend high frequency to 800 MHz - 1 GHz
- Improve short- and long-term stability for quartz and other different temperature-stable materials

Dispersive Delay Lines

- Increase bandwidth
- Lower pulse compression ratios
- Improve time-bandwidth products

2. ANTENNA SYSTEMS

Phased arrays are being increasingly considered and employed for ECM systems. These arrays are relatively small (15 to 20 elements) compared with radar phased arrays, which may employ a few thousand elements. ECM phased array technology is separated into two main classes: scanned-beam and multiple-beam techniques.

a. Scanned-Beam Techniques

Scanned-beam arrays presently use ferrite phase shifters because of their high-power-handling capability. The relative cost breakdown for the phased array is given below:

Major Component	% Cost
Polarizer	14
Array Elements	7
Phase Shifters	30
Drivers	20
Power Divider	14
Input Switch (to switch among arrays for 360° coverage)	15

With regard to ferrite phase shifters, a need was indicated for improved manufacturing techniques of low-loss ferrite toroids. At present, toroids cost \$50 to \$200 apiece (a function of frequency and quantity). Also, more ferrite vendors are needed to help in driving cost down. Costs of \$10 to \$40 per toroid were indicated as reasonable goals.

Phase shifter drivers should also be developed to reduce cost, and a recommendation for LSI device development was made. At present, driver costs are \$75 to \$150 per unit; \$25 per unit was deemed a reasonable cost goal.

b. Multiple-Beam Techniques

In multiple-beam arrays developed for ECM systems, a TWT amplifier is associated with each element; therefore, the transmitter power output stage is combined with the array. The relative cost breakdown for multiple-beam arrays is:

Major Component	% Cost
Polarizer	11
Array Elements	22
Multiple-Beam Network (lens)	33
Input SPNT Switch	33

The costs of TWTAs for use in the array are:

Power Output	Cost
20-25 watt	$500 (15,000-unit purchase)
40 watt	$780 (15,000-unit purchase)

At present, low-volume cost of a TWTA is about $3,000.

Note that the price of the input SPNT switch is about one-third that of the array, based on the present cost of $50 to $100 each. Additional design and development of SPNT switches was recommended to reduce the cost of multiple-beam techniques.

The selection of a phased-array technique, scanned- or multiple-beam, is somewhat system-dependent. However, for those systems where either technique is suitable, cost tradeoffs between the two should be made.

3. TRANSMITTER GROUP

The transmitter group includes all components in the RF chain, other than those used in reception. Components concerned are transmit tubes and drivers and associated high-voltage supplies, exciters, switches, and RF plumbing. These components must be compatible in respect to power handling, frequency coverage, and VSWR. To establish such an overall capability, transmitter requirements should be based on postulated future system needs.

Component compatibility also requires consideration of interface hardware (i.e., RF connectors, RF cables, high-voltage wire, and high-voltage connectors).

a. Solid-State Devices

Active and control types of solid-state components are discussed below; those recommended for development are tabulated in Table 2. Most ECM requirements dictate a broadband configuration for solid-state amplifiers. The most common exceptions to this requirement are the narrow-band, solid-state amplifiers used with expendables, which will not be considered here.

Solid-state amplifiers may be considered for both transmitter and driver applications. However, broadband devices having sufficient bandwidth for transmitter applications are generally limited to frequencies below 2.5 GHz. Above this frequency, broadband, solid-state amplifiers are limited to power levels which are only suitable for driver requirements. Such broadband drivers can be provided to 4.0 GHz using bipolar transistors, and, at marginal power levels, above 4.0 GHz using FET transistors. Because solid-state drivers, unlike TWT drivers, do not require high-voltage supplies, they should, in time, offer significant cost savings. However, these devices are presently near state-of-the-art, and an improved capability for producing such amplifiers is necessary to realize this cost saving.

TABLE 2. ACTIVE AND CONTROL TYPES OF SOLID-STATE COMPONENTS RECOMMENDED FOR DEVELOPMENT

HIGH VOLTAGE SWITCHING TRANSISTORS

MICROWAVE TRANSISTORS

- **AMPLIFIERS**
  - **HIGH POWER (UP TO 2.5 GHz)**
  - **DRIVER POWER LEVELS (UP TO 4 GHz)**
- **OSCILLATORS (VFO APPLICATIONS UP TO 4 GHz)**

IMPATT DEVICES

BROADBAND DRIVERS ONLY, ONE-HALF WATT, ABOVE 4 GHz

GUNN DIODES

OSCILLATORS ABOVE 4 GHz

POWER SUPPLY REGULATOR CONTROL ICs (PULSEWIDTH TYPE)

VARACTORS (SILICON AND GaAs) (VFO APPLICATIONS)

In particular, further characterization and development of the active devices used in these amplifiers are necessary to fully realize their potential in reducing ECM system costs. Also, as noted in Section II.4, two of the key transistor vendors are becoming marginal suppliers. Thus, to realize the full cost-saving potential of using such an important class of component, it is necessary to develop both the components and source(s) which can be considered reliable.

The bandwidths of bulk-effect devices such as Impatts, although moderate, still do not fulfill system requirements. In addition, the available circuits do not presently exploit the bandwidth potential of existing devices. Therefore, near-term developments of such amplifiers do not appear to offer meaningful cost savings.

Broadband variable frequency oscillators (VFOs), which are used as exciters for many ECM system RF chains, typically employ transistors as their active elements below 4.0 GHz and Gunn diodes at higher frequencies.

Successful cost reduction efforts for VFOs will be strongly dependent on appropriate development and characterization of both transistor and Gunn diode devices. As noted above, establishment of reliable sources is very important. As noted in Section II.4, development of silicon and GaAs varactors must be continued if recent system requirements are to be met.

Solid-state microwave control and transistor switches are the passive devices of most interest. High-power, solid-state diode switches are particularly important, considering the various antenna configurations and/or antenna feed systems to be implemented. Switch capabilities need to be maintained at a level compatible with the transmit tube power capability.

Transistor switch devices are basic to the highly efficient circuits being used in up-to-date power supplies. As noted in Section II.5.b.(1), characterization and control of appropriate parameters of these switching transistors are necessary to provide the performance necessary to meet low cost objectives.

b. Power Supply-TWT Interface

System-imposed TWT gating requirements have a significant effect on both the TWT and its power supply. A major consideration involves the decision to provide the TWT with either a grid, an anode, or some variation of these. A grid allows tube control with the least amount of voltage swing, but has major impact on tube cost and degrades the beam optics. Such modulator considerations are of particular importance when it is necessary to bias the tube to minimize output noise and/or to conserve prime power. To achieve cutoff bias when using an anode, the voltage swing required for turn-on is too high to permit achievement of the minimum delay switching times required by some systems. If only CW to pulse-up switching is required, then minimum switching speeds can be achieved with an anode. Under such conditions, the non-cutoff limitation can be compensated for by programming the RF input to the transmit TWT.

Anode control presents another problem during turn-on, if no provision is made for supplying the large modulator voltage required for beam turn-off. Under such turn-on conditions, the helix current is momentarily large; if the helix power supply is incapable of supplying this current, the tube will be destroyed.

Generally, helix regulation of ±1 percent is relatively easy to achieve without unusual costs, whereas tighter regulation increases costs. However, such regulation may be necessary to obtain band-edge performance with a marginal TWT. Tighter regulation may also be necessary to meet stringent phase requirements imposed by antenna arrays.

A floating deck type of modulator can provide the ultimate in electrical performance but significantly increases modulator costs. Generally, the transformer-coupled configuration is simpler and less costly. However, the floating deck configuration allows achievement of minimum rise and fall times for both short and long transmit pulses. If regulation and/or precision control of tube bias are required, use of the floating deck configuration is obligatory.

c. Band Coverage

A fundamental system consideration concerns determination of the number of transmit tubes required to provide both the required band coverage and the power density needed by the particular ECM programs. This decision is affected by the threat density that is to be accommodated and the number of threats that are to be countered by simultaneous, overlapping RF transmissions.

The ECM program characteristics that affect power tube selection can be divided into two major categories, based on the transmit duty cycle: noise jammers, which require high-duty-cycle transmitters; and repeater programs, which require low-duty-cycle transmitters. Some applications require that both types of programs be implemented simultaneously.

Simultaneous transmissions can be provided either by separate transmitter tubes or by one transmitter tube with appropriate additional capabilities. This generally requires an increase in the tube's instantaneous power capability so that its total output power capability is greater than the sum of the power needed to counter each threat. Consideration must be given to the loss of power resulting in part from the generation of IM products. These IM products may also degrade the effectiveness of the ECM programs being implemented. Similarly, consideration must be given to the effects of suppression between some combinations of signals.

The requirements noted above for increased power may be fulfilled either by CW tubes of sufficient power or by dual-mode tubes. Dual-mode tubes are designed to allow pulse-up during only a portion of the operate cycle to meet the increased power requirements. This allows the tube's beam power to be at a reduced level during the remainder of the cycle, resulting in a lower drain on the power supply. The duty cycle capability of this pulse-up feature varies greatly among the various types of dual-mode tubes. Pulse-up capabilities of tubes in production are generally limited to 2 to 3 dB, whereas higher pulse-up ratios are presently limited to laboratory tubes. These higher pulse-up capabilities should be considered, if appropriate, for systems whose implementation will start in the next 2 to 3 year period. Note that, unlike some dual-mode tubes of the past, present-day tubes of this type generally are implemented in a manner that will not significantly degrade efficiency.

Design procedures have recently become available which have allowed the optimization of broadbanding techniques. These new designs have been successfully incorporated into laboratory tubes, and a bandwidth capability of more than an octave is now considered to be readily achievable. As in the case of the dual-mode tube capability, these expanded-bandwidth tubes can be considered for use in systems whose implementation will start within the next 2 to 3 years. However, as the bandwidth is expanded, the need to deliver increased amounts of simultaneous power to more threats is also increased.

Other tube capabilities that should be considered include paralleling of tubes to achieve an increase in power. It has been shown that this approach does not require critical matching of components. Also, techniques are being developed for applying the combined outputs of two tubes to a single antenna. Standard couplers can be used to combine the outputs from two tubes for application to multiple antennas.

d. Tube Family Standardization

The above discussions on solid-state devices, power supply-TWT interface, and band coverage provide some of the hardware and system background needed to determine the structure of the RF chain. Additionally, the requirements imposed by system cost, weight, and size should also be considered in the decision process. Of particular interest is the possibility that a smaller number of transmit TWTs can be used to cover the required bandwidth. This possibility is important because additional power can often be obtained from a single tube with significantly less than a proportional increase in cost.

However, such increased band coverage by a single subsystem may impose some difficulties on the transmit antenna and the RF plumbing interconnecting the transmitter and the antennas. A cost tradeoff based on projected system requirements is needed to determine the number of channels, the bandwidth of each channel, and the power outputs from each. Similarly, any component developments that are necessary to provide the desired system structures should be determined.

4. AIRCRAFT INTEGRATION

Certain design decisions and tradeoffs which deal with aircraft integration also have major design impacts upon the overall ECM system. These technical areas, which were discussed in Section II.8, include aircraft signature control, ECM pods vs on-board equipment, air vs liquid cooling, nuclear hardening requirements, creation of benign operating environments to facilitate use of commercial components, and the use of techniques such as multiplexing (MUX), Digital Avionics Information System (DIAS), Multi-function Elemental Systems Approach (MESA), and integrated packaging.

Two of these technical areas (aircraft signature control and ECM pods vs on-board equipment) warrant additional discussion which is beyond the scope of the aircraft integration panel recommendations.

a. Aircraft Signature Control

Control of radar cross section and infrared signature should be required in new aircraft and external stores design. There is a basic overall cost and performance tradeoff between alternative approaches of reduction of radar cross section via basic design and use of radar-signal-absorbent materials vs the higher-ECM-radiated-power requirements for an unmodified airframe. Airframe redesign and the use of radar-signal-absorbent materials may increase the airframe cost and may slightly degrade the aerodynamic performance, but will mean that the output power required from the ECM equipment to protect the aircraft will be reduced. The reduction in radiated power requirements means a smaller, lighter, less expensive ECM suite and a reduction in electrical power requirements, resulting in a decrease in aircraft gross weight, an increase in available thrust, and an increase in aircraft performance.

b. EW Installation - Pod vs Internal

The preferred approach to aircraft EW system design (from an aerodynamic performance standpoint) is internal installation with adequate growth provision (by modular add-ons) to reduce the impact on installations cost and aircraft performance. The aircraft integration panel indicated that future aircraft would have sufficient planned capacity for ECM growth, in response to new or modified threats, so that patch ECM fixes are not anticipated.

Past history, however, belies this assumed capacity and it is contended that planned pod-mounted ECM equipment for certain types of new aircraft has several advantages, namely:

- centralized ECM equipments
- minimization of black boxes and cables in the aircraft
- simpler aircraft/ECM interface
- easier modification to ECM system
- less inter-aircraft interference

Section IV
RECOMMENDATIONS OF STEERING COMMITTEE

The Lower Cost ECM Conference steering committee, after reviewing the panel reports, isolated those recommendations they felt were most important. This section summarizes the output of this panel. The recommendations are divided into two categories: technical and institutional.

1. SUMMARY OF TECHNICAL RECOMMENDATIONS

a. Transmit Tubes

1. Conduct a detailed (one contract) intensive study of the following six areas of development. The study should find the potential payoff (ROI or $) if money is spent in each of the areas. This should be followed immediately by a consolidated development program.
   - Improved collectors - to increase efficiency
   - Improved electron-gun and focusing
   - New cathode/grid material
   - Improved dual-mode pulse-up capability
   - Increased bandwidth - to improve band edge performance
   - Improve tube stability - to improve yield
2. Expand ASD's program on depressed collectors, to double efficiency from 20% to 40%.
3. Study paralleling TWTs to trade bandwidth against the number of tubes and associated plumbing.

b. <u>Receivers</u>

1. To reduce costs of crystal video receivers, start with detectors.

2. To reduce costs of IFM receivers, start with RF limiters and polar discriminators.

3. To reduce costs of channelized receivers, develop SAW technology.

4. To reduce costs of microscan receivers, start with VCOs and dispersive delay lines.

5. To allow cost/performance requirements studies, develop detailed digital models of receivers.

c. <u>Antennas, Radomes, and Transmission Lines</u>

1. Logistics Command will study and report to the committee as to whether the following would result in a significant cost reduction. If so, it is a Materials Laboratory task to consider materials improvements that would lead to lower costs. In particular:

   - Radome and rain erosion coatings
   - Lower loss, reproducible ferrite fabrication techniques
   - Ceramic fabrication techniques

d. <u>Microwave Components</u>

1. Significantly reduce cost of rejects and designs by developing a new stripline board material.

   - A new board material is required
   - Improved quality control of boards
   - Board parameters must be measured <u>during</u> production

e. Power Supplies

1. Perform the following tasks in a comprehensive program with an industrial firm knowledgeable in materials and techniques for handling high voltage.

   - Develop standards for high-voltage potting materials so that uniformity from batch to batch with reliable, predictable characteristics may be purchased.
   - Develop new feed-through seals and standards for these seals which minimize the coolant leakage problem.
   - Consider research and development program which would lead to major breakthroughs in high-voltage-encapsulating schemes.
   - Develop new high-voltage wire and new standards for high-voltage wire.
   - Develop new high-voltage connectors and standards for high-voltage connectors.

2. Consider electrical power requirements for new aircraft and either 3 kHz or 4 kHz high-frequency power at 115V/208V, three phase. Major considerations are EMI, shielding, motor speed, bearings. (Note MA-1 has 1800-Hz power supply.) Incorporate the power supply in an isolated system, e.g., a pod, expendable drone, etc.

3. Study 200V DC distribution system with DC-DC converters in each ECM set.

4. Examine the effects of EMP and specify nuclear survivability design data.

f. Solid-State Power Amplifiers

1. Cease funding of any developments of standard active high-power transistors for frequencies above 2.5 GHz.

2. Cease funding of any GaAs or Impatt devices for ECM, except as a low-power driver.

3. Continue funding to AFAL/TE to do the following:

   - Advance the development of power transistors (50 MHz to 2.5 GHz)
     - To improve reproducibility
     - Generate a family of standard transistors
   - Once appropriate transistors exist (first two recommendations), design standardized amplifiers.
   - Reduce insertion loss of microwave components employed with amplifiers.

g. Logic Systems

1. Study and publish a paper on the possibility and limitations of standardized deinterleaving, parameter derivation, ECM technique generation, FFT, coordinate transformation. The purpose is mainly to isolate areas where standardization would have a high payoff.

2. Develop standardized interfaces, so that microprocessors or LSI can be interchangeable.

3. Develop small, high-speed modularized microprocessors.

4. Study to determine appropriate LSI building blocks for unique ECM functions which are common among many ECM equipments.

5. Continue efforts to have standardized software languages.

h. Aircraft Integration

1. Build an anechoic chamber for aircraft, with emphasis on EMI. This testing is too expensive to do in an airborne situation.

2. Build an antenna pattern measurement facility (open air, upside-down aircraft).

3. Group A costs often exceed Group B costs. To minimize these costs, the first step is to develop techniques for improved cable and RF transmission line systems.
   - Integrated development approach
   - Foster competition

4. Signature control (RCS, IR, etc.) should be a requirement in new aircraft and external stores design. Consider trades such as EW vs Mach No., conformal weapons and pods, etc.

i. System Design

1. Compile a catalog of selected industry-developed MIC modules and develop a standard line of MIC modules.

2. Use "LSI" on MIC to eliminate connectors and minimize bulk.

3. Study the feasibility and applications of a frequency synthesizer--particularly to eliminate VCOs.

4. Do not develop multi-octave TWT until it is analyzed in a trade-off study against multiple narrow-band tube options.

2. SUMMARY OF INSTITUTIONAL RECOMMENDATIONS

a. Transmit Tubes

1. Do something to avoid specifying performance beyond the SOA, and beyond the knee of the survivability vs power curve. Actions before, during, and after CDR were suggested.
   - Train program managers.
   - Flexibility to relax specs after the contract is signed.
   - Use incentive (performance) to improve to SOA.

2. Be sure that cost savings, not technology expansion, is the goal of any development. Otherwise, someone will now specify the newly attainable performance, and costs will go up.

3. Develop standard families of tubes, connectors, and leads, particularly drivers and power amplifiers (tri-service). Each year, advance the standard to be current.

b. Receivers

1. Standardize a receiver of each type. (There is a subissue of whether to start from scratch or build on an existing equipment.) One reason for doing this is to standardize parts.

2. MIL-SPECS should be flexibly applied on a case-by-case basis. Encourage companies to comment on the MIL-SPEC before signing each contract.

3. Try to streamline qualification of parts, especially ICs. They are now becoming available much faster than they are being qualified.

4. Apply design-to-price.

5. Find a feasible way to use warranties.

   - MIL-SPECS keep getting more stringent (to protect the government), so costs go up.
   - Study ways of enforcing warranties.
   - If there are warranties, commercial parts could be substituted for MIL-SPEC parts.

6. Consider substituting commercial parts for MIL-SPEC parts.

c. Antennas, Radomes, and Transmission Lines

1. Define who should standardize and be responsible for standardization (AFSC?). This applies to all areas--not just this panel.

d. Microwave Components

1. AFAL/TE has a workshop on the items listed below. It should receive the necessary support and continue until it results in a Military Standard.

   - Standardize the definitions of VCO performance parameters.
   - Standardize the tuning voltage interface between VCO and system.

2. Eliminate discontinuous short-run production. Again, standardized interfaces will help achieve this goal.

e. Power Supplies

1. Have the TWT vendor supply the power supply as an integral part of the tube to minimize interface problems.

f. Aircraft Integration

1. The earlier the planning for integration/installation, the greater the savings. The anechoic chamber and pattern range are needed to facilitate this planning.

g. System Design

1. A service test phase should be initiated as part of the R&D cycle.

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Appendix A
PANEL MEMBERS

TRANSMIT TUBES PANEL

B. Pallokoff (Moderator)	Teledyne MEC
D. Laycock	ASD/ENASD
R. Cataldo	Watkins-Johnson Co.
J. Thompson	Westinghouse Electric Corp.
R. Espinosa	Northrop Corp.
J. Burgess	Varian Associates
T. Madden	AFAL
E. Illokken	Hughes Aircraft Co.
S. Durkin	Naval Research Laboratories
R. Wills	Naval Electronics Laboratory Center
D. Bitikofer	Calspan Corp.
O. Doehler	Warnecke Electron Tubes Inc.
W. Friz	AFAL/TEM
A. Raczynski	Microwave Associates
L. Clampitt	Raytheon Co.
L. Yarrington	AFML
W. Linn	Litton Industries Inc.
M. Weinstein	Mictron Inc.

RECEIVERS PANEL

R. Hollis (Moderator)	Watkins-Johnson Co.
D. Newton	Calspan Corp.
M. Whatley	Texas Instruments Inc.
R. Shockley	E-Systems Inc.
D. Lundy	Motorola Inc.
W. Hennings	Dalmo Victor Co.
J. Collard	Varian Associates
C. Brown	Systems Research Laboratories
A. Heckman	AFAL
W. Elliott	Loral Corp.
J. Gala	ASD-F-15
K. Zeiger	Northrop Corp.
J. Adair	AFAL/TEM
N. Spencer	Rockwell International Corp.
D. Kerins	ATI/ITEK
H. Hewitt	Stanford Research Institute
P. Schulz	General Instruments Corp.
A. Parker	AFAL

ANTENNAS, RADOMES, AND TRANSMISSION LINES PANEL

R. Burnett (Moderator)	The Boeing Co.
A. Hale	Goodyear Aerospace Corp.
H. Leach	Adams-Russell Co. Inc.
J. Belcher	American Electronic Labs.
S. Sensiper	Transco Products Inc.
M. Simpson	Sedco Systems Inc.
D. Archer	Raytheon Co.
G. Danford	ASD
S. Andre	Calspan Corp.

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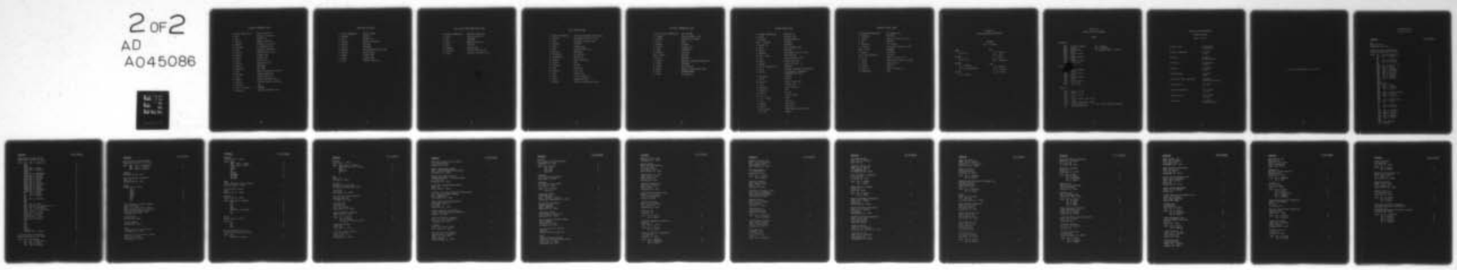

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MICROWAVE COMPONENTS PANEL

J. Saloom (Moderator)	Varian Associates
H. Howe	Microwave Associates
T. Rose	Raytheon Co.
C. Hartwig	Sanders Associates
R. Knowles	Frequency Sources Inc.
K. Schoniger	E W Communications
R. White	Addington Laboratories
E. Kushner	Narda Microwave Corp.
R. Wohlers	Calspan Corp.
R. Yaeger	Teledyne MEC
K. Engle	Motorola Inc.
D. Stelzer	Omni Spectra Inc.
K. Reddig	ASD/ENADA
J. Summerlot	ASD/ENAMD
H. Hunt	Sperry Microwave Electronics
H. Harrison	Aertech Industries
R. Clark	Watkins-Johnson Co.
S. Hopfer	General Microwave Corp.
A. Gorwara	Stanford Research Institute
R. Kemerley	AFAL
Lt Col F. Covington	ASD/RWSV
F. McDonnell	American Electronic Labs

POWER SUPPLIES PANEL

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M. Crane	Raytheon Co.
C. Stewart	Sanders Associates
J. Pavliga	AFAL/AAA
S. Norton	ASD/ENACC
E. Heckman	Westinghouse Electric Corp.
J. Bartels	Northrop Corp.
F. Brandt	Teledyne MEC
R. Nelson	Calspan Corp.
C. Reeve	Watkins-Johnson Co.

SOLID STATE POWER AMPLIFIERS PANEL

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J. Meli	ASD/ENADC
A. Miller	Hughes Aircraft Co.
G. McCoy	AFAL/TEM
E. Schwartz	Calspan Corp.
R. Schneider	Analytic Services Inc.
K. Farber	American Electronic Labs.

LOGIC SYSTEMS PANEL

L. Algase (Moderator)	Airborne Instrument Laboratories
K. Overman	Westinghouse Electric Corp.
A. Hale	Goodyear Aerospace Corp.
J. Caschera	AFAL/WRP
D. Lange	Calspan Corp.
G. Fath	General Electric Co.
H. McCarter	ASD/ENAID
D. Fitzgerald	Hq AFLC/MMK
O. Lowenschuss	Raytheon Co.
R. Hinchey	Sperry Rand Corp.
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Appendix B

EXECUTIVE STEERING COMMITTEE

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Col B. Nix

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Maj W. Cook

HQ AFSC

Mr. P. Sandler

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ASD

Col A. Monahan

Col B. Dube

Dr C. Miller

Mr. A. Kundrofas

AFAL

Col O. Edwards

Mr. G. Nicholas

Mr. W. Portune

Appendix C

LOWER COST ECM CONFERENCE

AGENDA

February 4

0900	Welcoming Remarks	Dr. W. Eppers
0910	Keynote	Gen. L. Hodnette
0925	Introduction	Mr. George Nicholas, Chairman
0940	Break	
1010	Panels Convene	
1200	Lunch	
1300	Panels Convene	
1430	Break	
1445	Panels Convene	
1630	End of Day	

February 5

[illegible]	Panels Convene	
1000	Break	
1015	Panels Convene	
1200	Lunch	
1300	Panels Convene	
1430	Break	
1445	Panels Convene	
1630	End of Day	
1830	Social Hour	

February 6

0830	Panels Convene	
1000	Break	
1015	Panels Convene	
1230	Lunch	
1330	General Session Mod. Report	
1430	Break	
1445	General Session Mod. Report	
1545	Closing Discussion	Mr. George Nicholas, Chairman
1615	End of Conference	

LOWER COST ECM CONFERENCE

SUMMARY SESSION

Start 1:30 P.M.

Transmit Tubes	B. Pallokoff Teledyne MEC
Microwave Components	J. Saloom Varian
Receivers	R. Hollis Watkins Johnson
IR Devices	R. Cotterman Sylvania
Antennas	R. Burnett Boeing
Power Supplies	T. Porter Keltec
Solid State Power Amplifiers	W. Matthei Microwave Associates
Logic Systems	L. Algase AIL
Aircraft Integration	L/C W. Eaton Hq, AFLC
Systems Design	J. Van Meter Raytheon
Discussion	G. Nicholas General Chairman

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