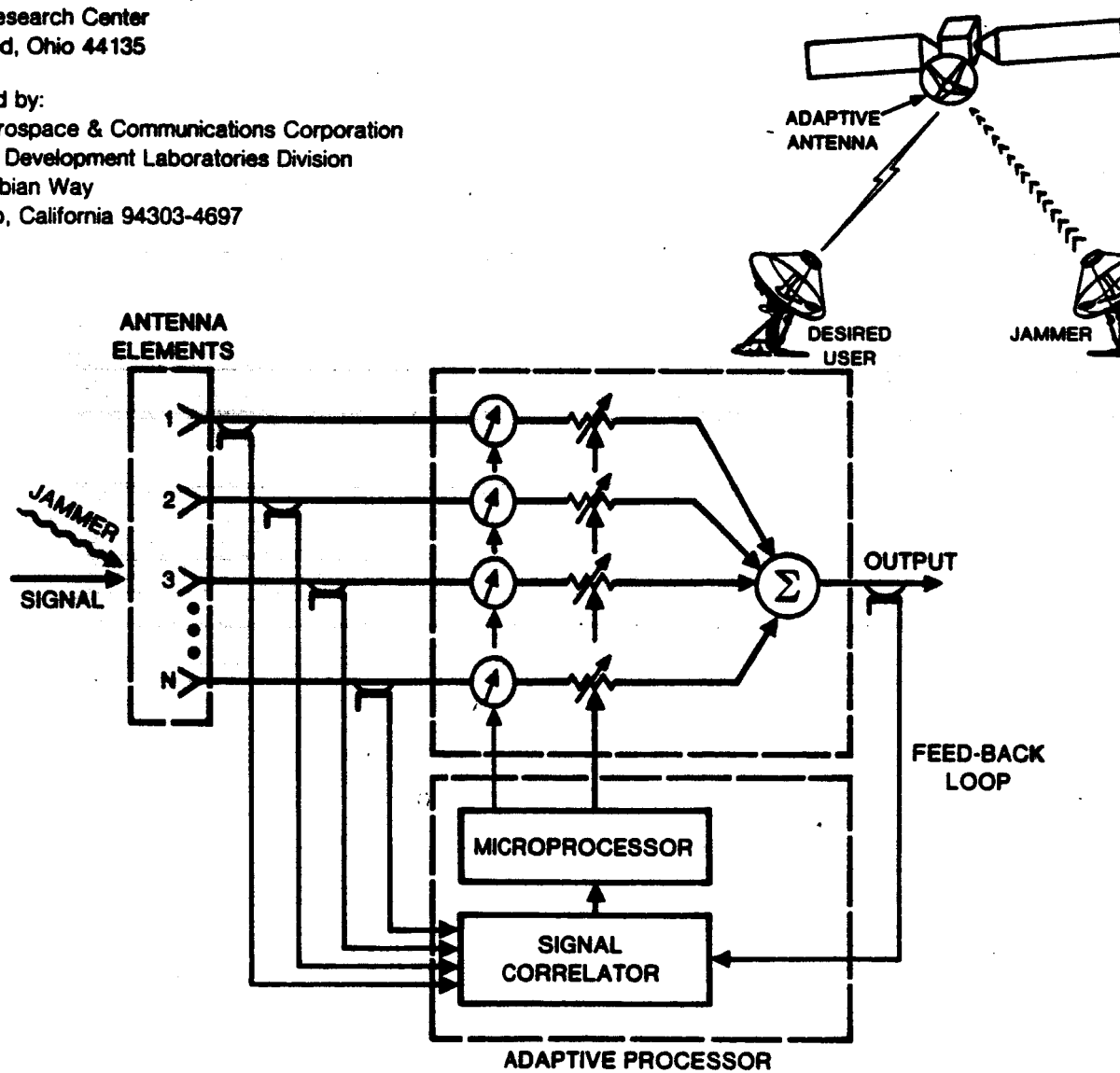


APPLICATION OF ADAPTIVE ANTENNA TECHNIQUES TO FUTURE COMMERCIAL SATELLITE COMMUNICATIONS

CONTRACT NAS3-24892 - EXECUTIVE SUMMARY

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| 16. Abstract The purpose of this contract was to identify the application of adaptive antenna technique in future operational commercial satellite communication systems and to quantify potential benefits. The contract consisted of two major subtasks. Task I, "Assessment of Future Commercial Satellite System Requirements", was generally referred to as the "Adaptive" section. Task II dealt with "Pointing Error Compensation Study for a Multiple Scanning/Fixed Spot Beam Reflector Antenna System" and was referred to as the "reconfigurable" system. Each of these tasks was further subdivided into smaller subtasks. It should also be noted that the reconfigurable system is usually defined as an open-loop system while the adaptive system is a closed-loop system. The differences between the open- and close-loop systems were defined. Both the "adaptive" and "reconfigurable" systems were explained and the potential applications of such systems were presented in the context of commercial communication satellite systems. | | | |
| 17. Key Words (Suggested by Author(s)) Adaptive Land Mobile Antenna Reconfigurable Advanced Communications Close-loop Antenna Technology Satellite Open-loop Antenna Multiple Beam Antenna | | 18. Distribution Statement General Release | |
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EXECUTIVE SUMMARY

1.0 INTRODUCTION

The purpose of this section is to present a summary of the work performed for the Application of the Adaptive Antenna Techniques to Future Commercial Satellite Communications contract. From here on, the contract will be referred to as the AAATFCSC contract for the sake of brevity.

The AAATFCSC contract was performed for the NASA-Lewis Research Center, Cleveland, Ohio. The contract number was NAS3-24892. The program was started on April 21, 1986 and ended on October 20, 1986. The NASA contract monitor for the project was Dr. Richard Lee.

The AAATFCSC contract was implemented by the Space Systems Operation (SSO) within the Western Development Laboratories (WDL) division of Ford Aerospace and Communications Corporation (FACC). Dr. L. Ersoy, a member of the Antenna Engineering Department, within SSO, was the program manager. Dr. E. A. Lee was assigned as the task leader for Task I, Assessment of Future Commercial Satellite System Requirements. Dr. E. W. Matthews was assigned as the task leader for Task II, Pointing Error Compensation Study for a Multiple Scanning/Fixed Spot Beam Reflector Antenna System. The contract brief is presented in Table I.

TABLE I

| | |
|-------------|--|
| CUSTOMER | NASA LEWIS RESEARCH CENTER |
| CONTRACT NO | NAS3-24892 |
| TITLE | APPLICATION OF ADAPTIVE ANTENNA TECHNIQUES TO FUTURE COMMERCIAL SATELLITE COMMUNICATIONS |
| DURATION | APRIL 21,1986 TO OCTOBER 20,1986 |

The purpose of the AAATFCSC contract was to identify the application of adaptive antenna technique in future operational commercial satellite communication systems and to quantify potential benefits. As indicated above, the contract consisted of two major subtasks. Task I, "Assessment of Future Commercial Satellite System Requirements", was generally referred to as the "Adaptive" section. Task II dealt with "Pointing Error Compensation Study

for a Multiple Scanning/Fixed Spot Beam Reflector Antenna System" and was referred to as the "reconfigurable" system . Each of these tasks was further subdivided into smaller subtasks. It should also be noted that the reconfigurable system is usually defined as an open-loop system while the adaptive system is a closed-loop system. However, it is possible to define a closed-loop reconfigurable system as well. Needless to say, the latter system is actually a form of an adaptive one also.

In this summary section, the differences between the adaptive and reconfigurable systems are presented first. A review of the subtasks, and the results and the highlights of the project are subsequently presented in a summary form. A more detailed explanation of the projects findings is given in the accompanying final report.

2.0 ADAPTIVE AND RECONFIGURABLE SYSTEMS

There appear to be two fundamental aspects associated with a communications system. The first is related to the transmission of the signal over a channel connecting the transmitter to the receiver. The second aspect is the signal processing at either end of the communications channel, that is needed to prepare the signal for transmission or to extract desired information at the receiver. In general, neither the transmission channel nor the signal itself is ideal, well defined, or well known; this factor may cause system performance degradation in the absence of proper safeguards. One alternative to improve system performance is to propose an over-designed system, which would perform properly in the worst adverse conditions. Such "over kill", however, would be very expensive. Another alternative is to design an average system for a typical operating environment with the understanding that the system performance may not be acceptable some of the time. A third alternative is to design a "smart system" which can "adapt" itself to changes in the environment. While such an adaptive system could be quite expensive as well, in most cases a reasonable compromise can be found between the system smartness (and the resulting system performance) and the cost factor.

For the purpose of this contract, the adaptive system is assumed to consist of input port(s) and sampling coupler(s), output port(s) and sampling coupler(s), a variable beam forming network (VBFN) for signal processing, and an adaptive processor containing the algorithm that determines the parameters of the VBFN. Such an adaptive system is depicted in Figure 2-1 for the receive antenna application. This system is referred to as a closed-loop system since there exists a feedback loop between the output port of the antenna and the adaptive processor. While higher level closed-loop systems such as a system between the spacecraft and the earth station with a feedback loop were also considered in this project, Figure 2-1 remains the basic adaptive system of interest.

In contrast, a reconfigurable system is assumed to consist of input port(s), output

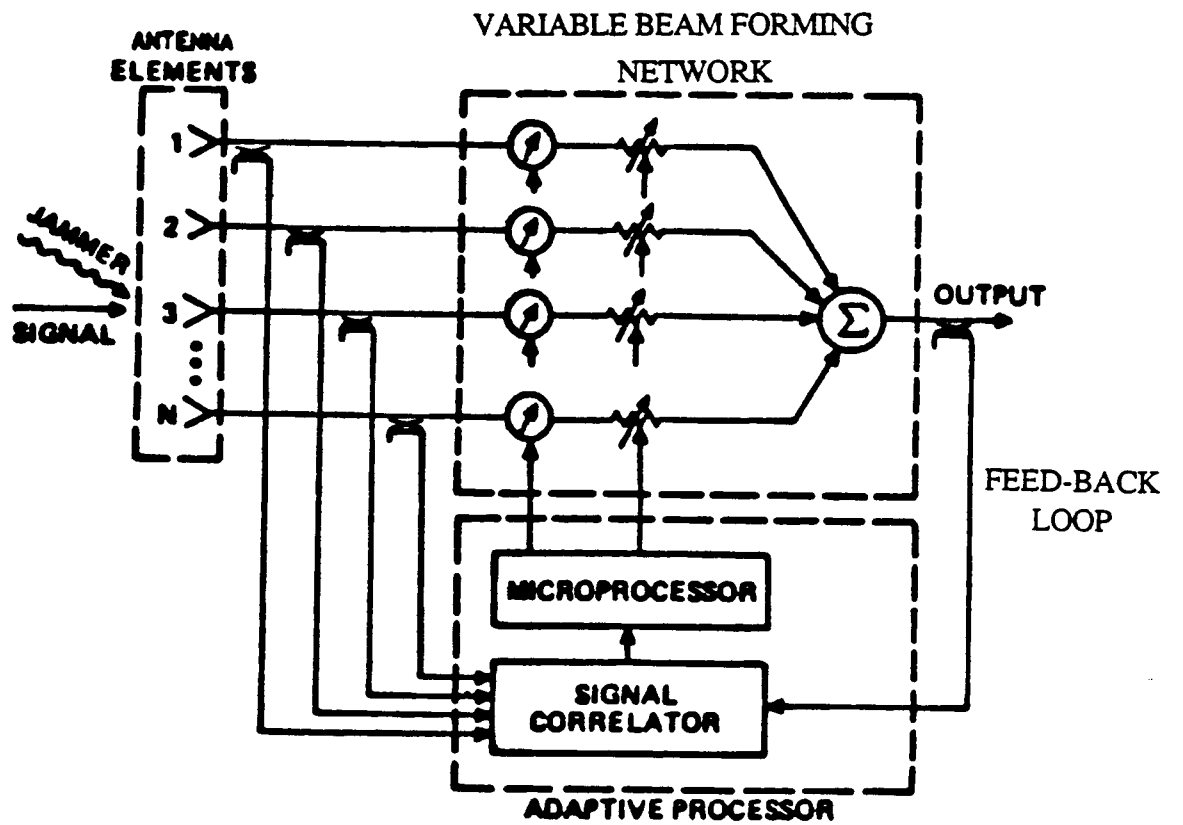


FIG. 2-1. ADAPTIVE SYSTEM FOR A RECEIVE ANTENNA

port(s), a VBFN and a controller unit as shown in Figure 2-2a. The controller unit could be a simple device receiving commands from a ground station or a preprogrammed "clock" with a look-up table containing the desired setting parameters for the VBFN. An open-loop reconfigurable system may utilize a set of sampling couplers at the antenna elements to help determining the VBFN settings. Such a system is illustrated in Figure 2-2b. On the other hand, a closed-loop reconfigurable system consists of a basic reconfigurable system with a feedback loop between the VBFN output and the controller unit as depicted in Figure 2-2c. The absence of the sampling couplers at the antenna elements is compensated for by systematically perturbing the parameters of the VBFN and observing the change at the output port of the system. The ways to determine the VBFN's parameters for open and closed-loop reconfigurable systems are discussed in the final report. As can be seen from Figures 2-1 and 2-2, the reconfigurable system is a less complicated and therefore a more cost effective version of an adaptive system.

3.0 COMMERCIAL COMMUNICATIONS SYSTEMS

Three commercial communication systems have been considered in the AAATFCSC contract. These are the scanning/fixed spot beams, multiple shaped beams and land-mobile system concepts.

The scanning/fixed spot beam antenna concept forms the basis of the Advanced Communications Technology Satellite (ACTS) system, and was developed on Contracts NAS3-22498 and -22499. The concept consists of a multi-horn feed array illuminating a dual reflector antenna configuration. Individual horns produce spot beams at different positions, depending upon horn location. Low sidelobe spot beams are produced by exciting a seven-horn cluster with the proper amplitude and phases. The coverage area is subdivided into 6 regions with one scanning spot beam per region as depicted in Figure 3-1. In addition to the scanning spot beams, there are 18 fixed spot beams distributed throughout the coverage area. The fixed beams and the scanning beams in a given region are isolated from each other by frequency diversity. The scanning beams in adjacent regions are isolated from each other by polarization reversal. The beams are assumed to be linearly polarized. It should be clear from the above explanation that each scanning beam utilizes all the frequency channels available to the scanning beams, but provides a TDMA type of service within its designated region.

In contrast, the beams in a land-mobile system provide simultaneous service to the entire coverage area. There are enough pencil beams to blanket the area under consideration. While this system provides a very high gain, one cannot utilize all the available frequency channels for all the beams as frequency diversity is needed for isolation purposes among the adjacent pencil beams. In this type of system there are sacrifices in the number of available channels in favor of continuous coverage with high gain over the entire coverage region. Atypical land-mobile

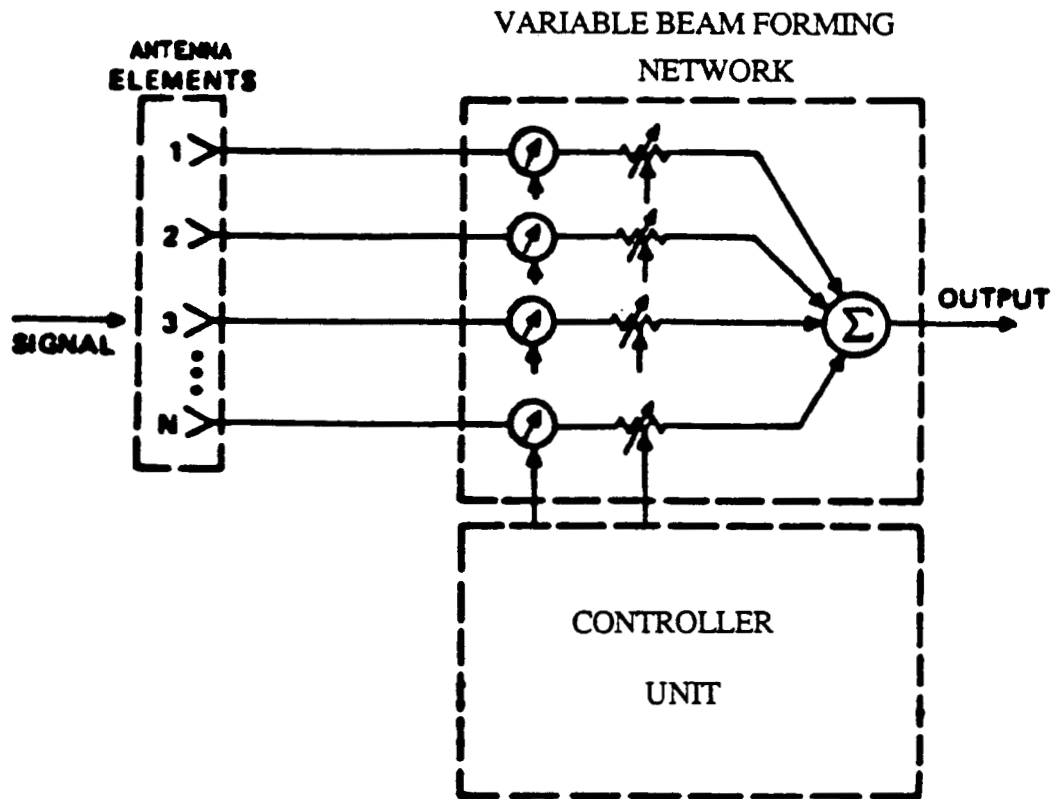


FIG. 2-2a. BASIC RECONFIGURABLE SYSTEM FOR A RECEIVE ANTENNA

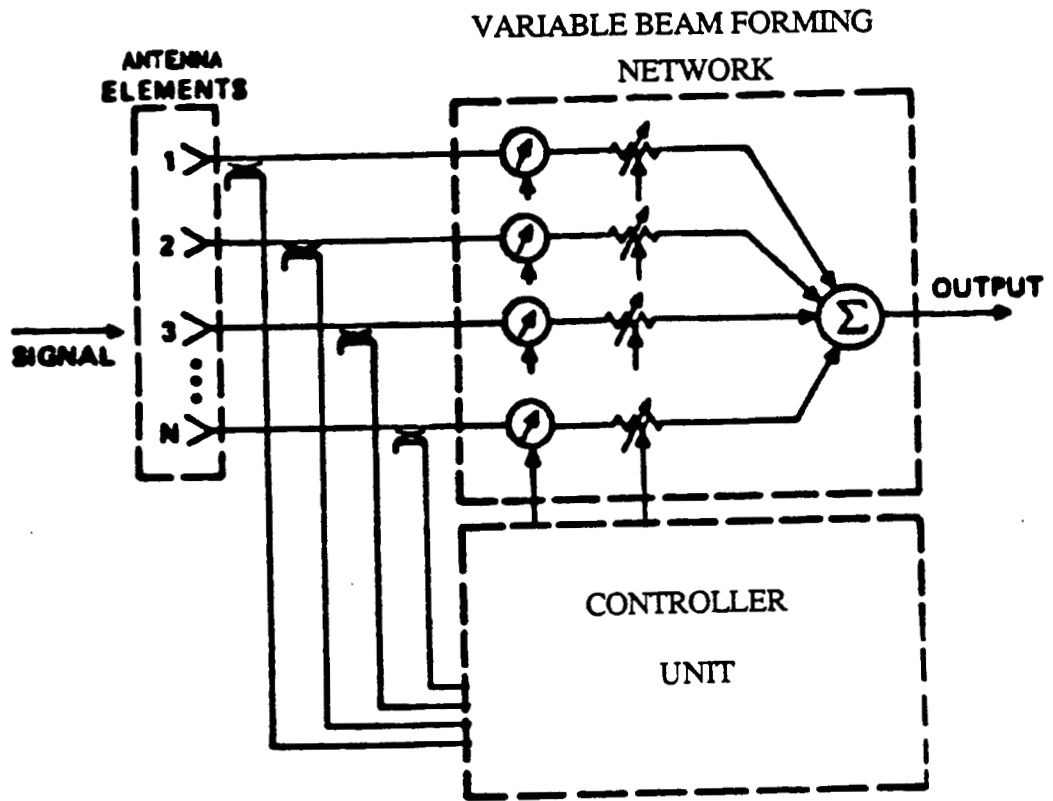


FIG. 2-2b. OPEN-LOOP RECONFIGURABLE SYSTEM FOR RECEIVE ANTENNA

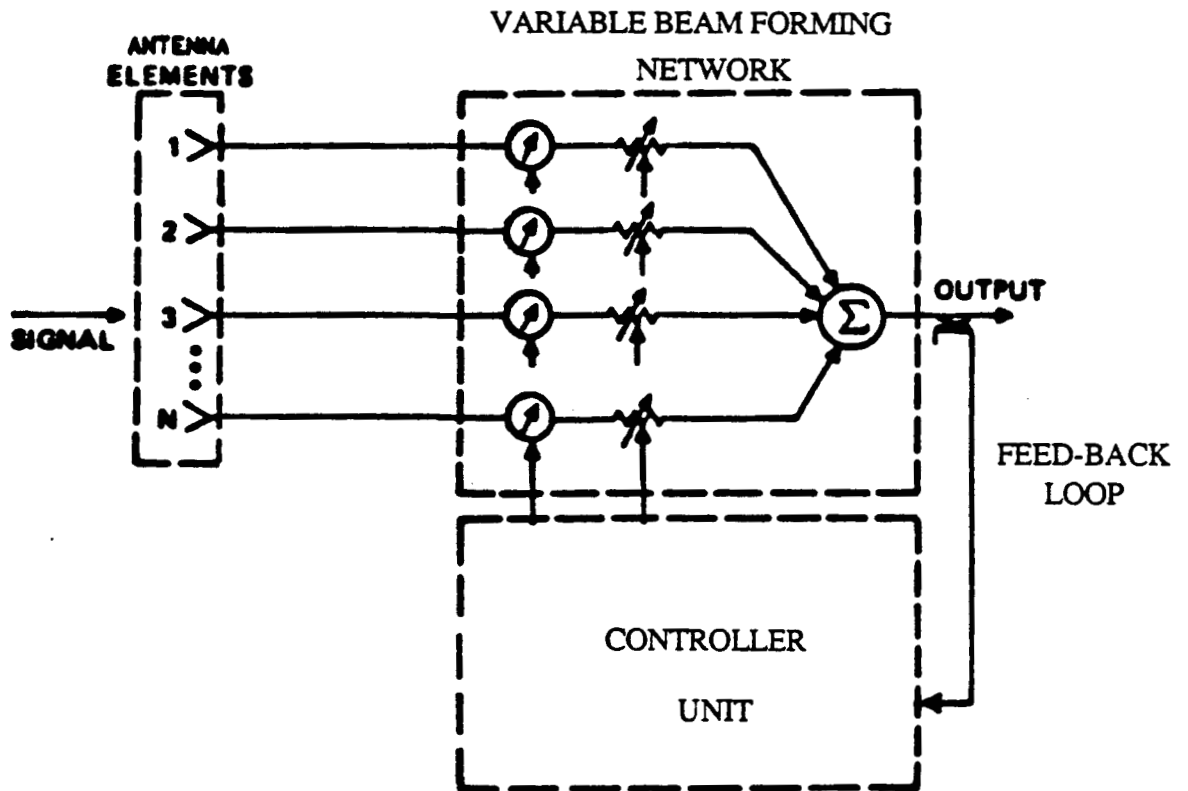


FIG. 2-2c. CLOSED-LOOP RECONFIGURABLE SYSTEM FOR RECEIVE ANTENNA

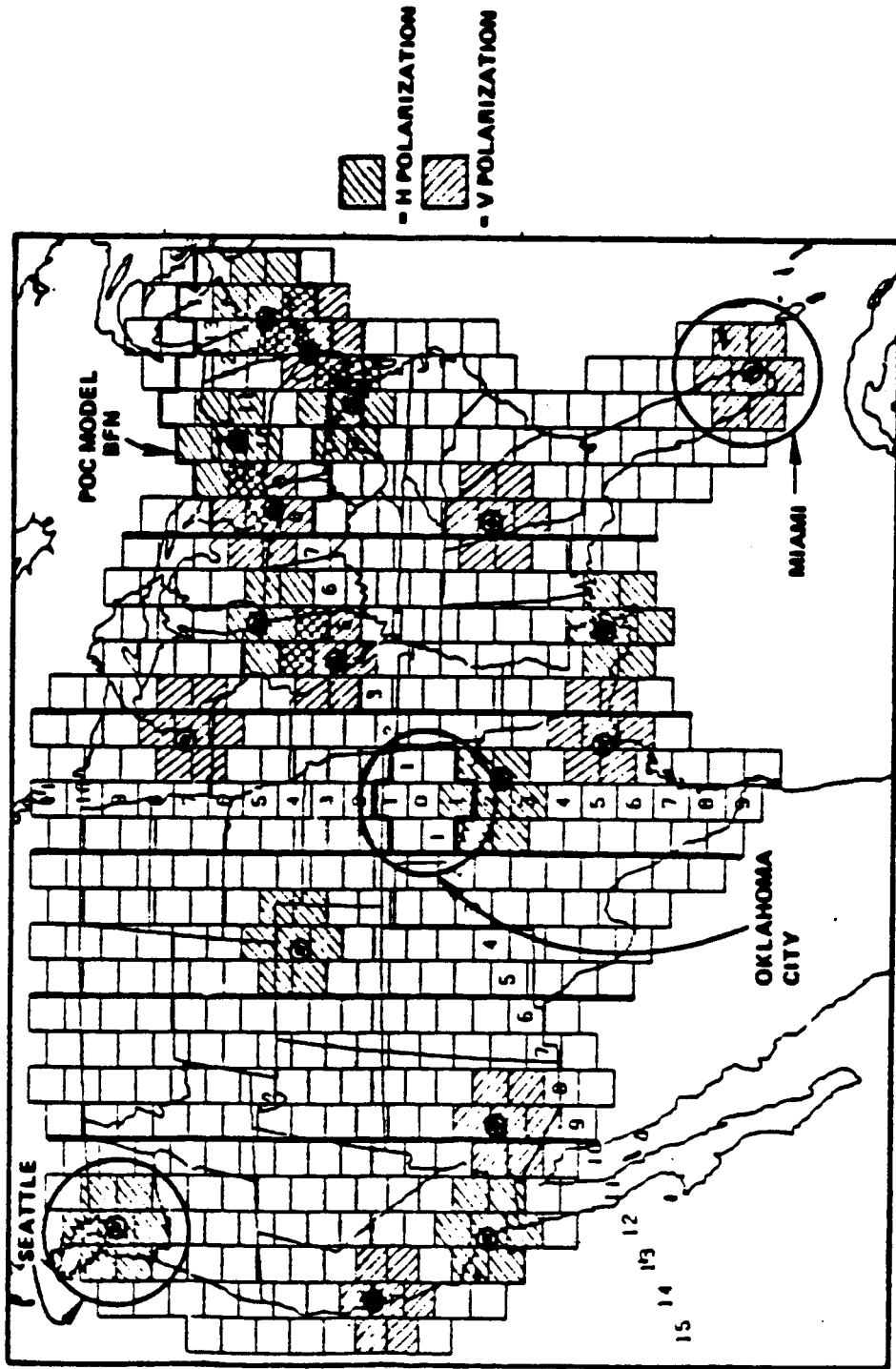


FIG. 3-1. TYPICAL ACTS MULTIBEAM COVERAGE SCENARIO

system is depicted in Figure 3-2.

The multiple shaped beam antenna system also provides continuous coverage over a given region, but all channels are available for use. This is accomplished at the expense of antenna gain. The feed horns in a cluster are combined in a beam forming network (BFN) to generate a single shaped beam. Each beam utilizes the entire frequency band. A typical multiple shaped beam antenna system is depicted in Figure 3-3.

It is determined that adaptive concepts can be used with all three communications systems. The reasoning behind this determination is that an adaptive system requires that a given beam should be generated by a number of feed elements. In all three systems above, this requirement is met. While it is true that in the case of the scanning/fixed spot beam antenna concept and the land-mobile system only few horn elements (about 7) are used to generate each beam, there are adjacent elements available to be used if needed. Furthermore, in many cases, even a seven feed cluster is sufficient for an adaptive antenna application, so long as the number of "jammers" is less than the horn elements and the user(s) and jammer(s) are sufficiently separated from each other. In a commercial application, it was assumed that there would be a few unintentional "jammers".

One common characteristic of all three systems is that they are all reflector antennas. In a reflector antenna, the pattern shape is controlled by varying both the amplitude and the relative phase between the feed elements. Hence, even if there are only a few elements in a cluster, there should still be enough parameters available per feed to control the pattern shaping, leading again to the conclusion that the adaptive concepts could be used in all three communications systems.

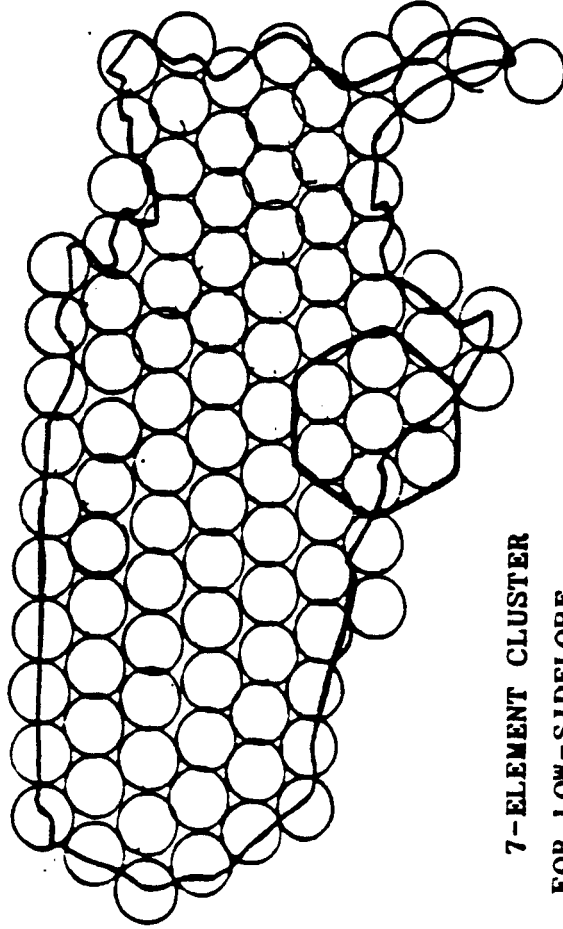
Furthermore, multiple beam antennas with switches to change cluster configurations and an ACTS system with scanning beams are presently available systems with, if not adaptive, at least reconfigurable antennas. Hence, these systems could be converted into fully adaptive antennas with relative ease.

Finally, there are enough applications (as presented below) suitable for an adaptive system operating in a commercial environment. This should provide sufficient motivation for the market place to come up with the necessary technological advancements to make adaptive systems practical for commercial applications.

4.0 REVIEW OF SUBTASKS

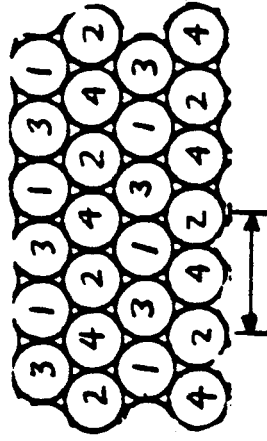
All three commercial communications systems discussed above were investigated in Task I. The scanning/fixed spot beam antenna concept was the subject matter for Task II:

BEAM POSITIONS

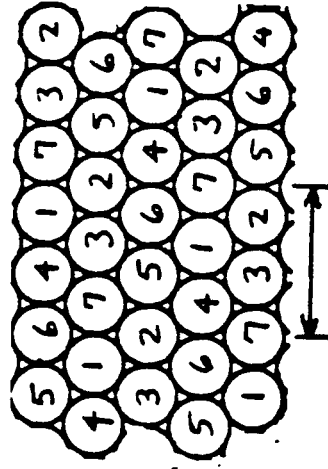


**7-ELEMENT CLUSTER
FOR LOW-SIDELobe
INDIVIDUAL BEAM**

**FREQUENCY ASSIGNMENTS
FOR ISOLATION ENHANCEMENT**



**1-Beamwidth Separation
A. FOUR FREQUENCY SETS**



**2-Beamwidth Separation
B. SEVEN FREQUENCY SETS**

FIG. 3-2. TYPICAL LAND-MOBILE BEAM COVERAGE SCENARIO

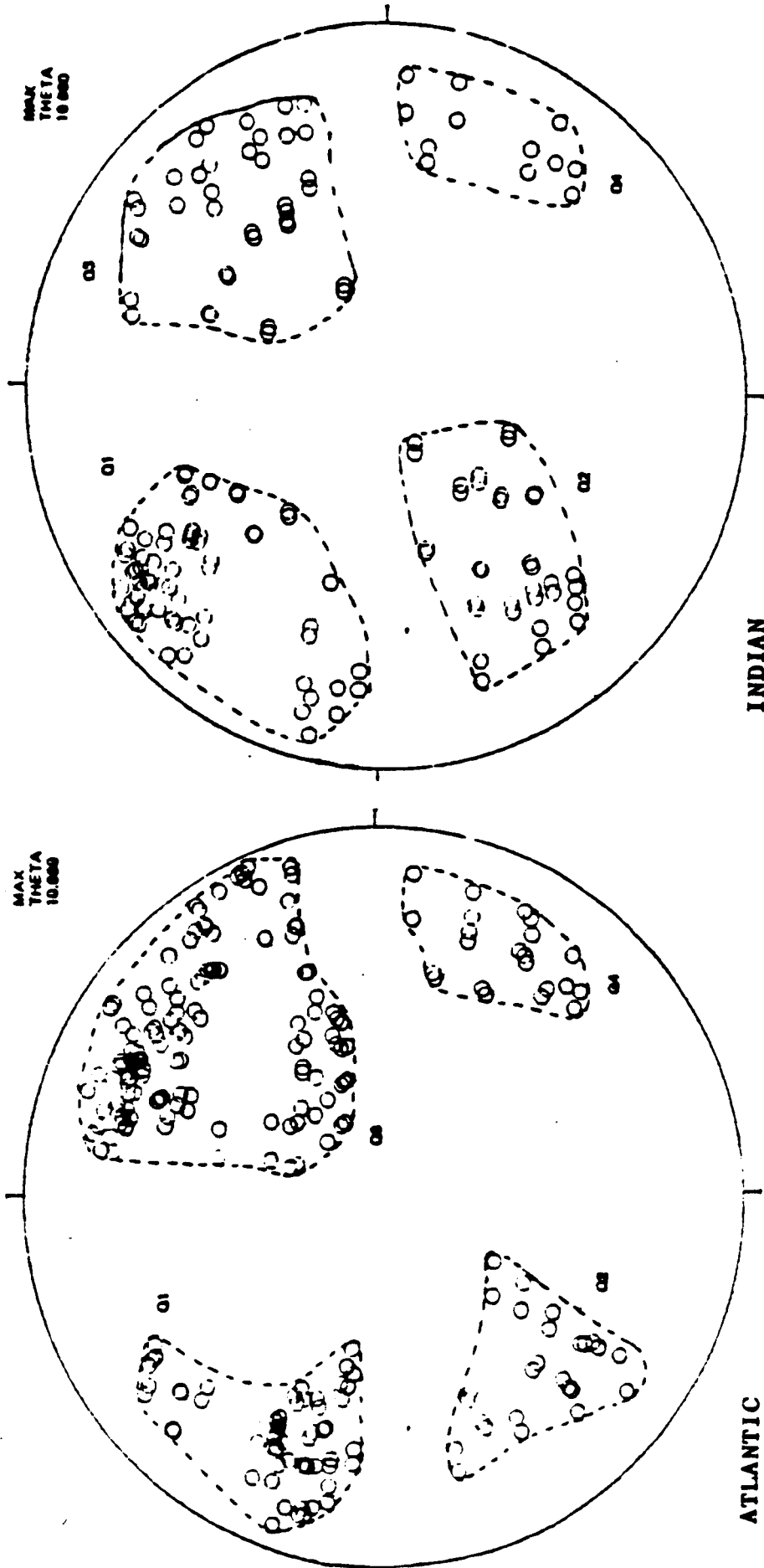


FIG. 3-3. TYPICAL MULTIPLE SHAPED BEAM ANTENNA SCENARIO

Task I) Assessment of Future Commercial Satellite System Requirements

The main task of this section was to identify applications and quantify benefits of adaptive systems for all three commercial communications systems mentioned earlier. Five major applications were identified in this regard.

- Interference control
- Sidelobe control
- Precision beam forming
- In-orbit adjustment and testing of antenna systems
- Compensation for transient propagation effects.

Each of these applications is briefly discussed next

Interference control : Interference, usually referred to as the jammer, is defined as the undesirable signal within the main coverage area of the antenna. In commercial communications systems, the interference is assumed to be unintentional and not rapidly varying with time. The sources of interference could include solar noise, multipath, other satellites or simultaneous ground based transmissions. The task of the adaptive system is to place a null in the direction of the interference without seriously degrading the over all antenna performance. This appears to be the most widely used application of an adaptive system.

Sidelobe Control : In the case of a multiple beam antenna with frequency reuse, it is important to achieve a predesignated isolation level between adjacent coverage areas. The isolation is directly related to the location and level of the sidelobes over the adjacent coverage area. It is much harder to lower all sidelobe levels than to change the locations of sidelobes. With an adaptive system, the locations of sidelobes can be changed depending on the signal traffic. Operationally, sidelobe control is similar to interference control except that for the former, the interfering signal is assumed to be located in the sidelobe region. The task, however, still remains to place a null in the direction of interference.

Precision Beam Forming : In many applications, it is important to generate a shaped beam closely following the boundaries of the coverage regions. This can be accomplished by properly adjusting the weighting coefficients of the BFN. Typically, these adjustments are done on the ground before the satellite is launched into orbit. An adaptive system with a feedback loop between ground and satellite could be used to shape the beam in space. This would not only take into account the actual operating environment of the satellite (thereby permitting more precision beam forming) but also would provide a means to take corrective actions in case of antenna misalignment or reflector surface deformation.

In-Orbit Adjustment and Testing of Antenna Systems : This application deals with

testing and adjusting the BFN. While this could be done with the aid of a signal from the ground, it is not necessarily the only way to accomplish the task. Indeed, a signal generated on board the spacecraft can be injected into the network for diagnostic purposes. Couplers at the antenna elements can be used to detect components with wrong settings or failed components. Corrective measures can be taken using the flexibility of an adaptive antenna system.

Compensation for Transient Propagation Effect : As indicated earlier, one of the fundamental aspects of a communications system is the communications channel and its effect on the signal. The adaptive antennas have been used to "clean" the undesirable effects of the environment on the signal. For satellite application, the major concern is the decrease in the signal strength due to weather related conditions such as rain. An adaptive system could be used to direct some of the energy to the effected area without seriously degrading the overall performance of the antenna system. The system benefit is that the necessity for weather margins could be reduced or eliminated.

The present study indicates that adaptive concepts could be used to implement all five applications listed above in a commercial communications system. The first two applications, interference control and sidelobe control, fall clearly in the domain of a typical adaptive problem of placing nulls at jammer locations. The next two applications can be reduced to an adaptive problem by artificially introducing a feedback signal: This feedback signal could be thought of as a "jammer" in the direction of which the adaptive system tries to place either a null or a peak depending on the application. In particular, for the precision beam forming application, the artificial signal is provided from ground stations, whereas, for the in-orbit adjustments application, the signal is generated on spacecraft.

The last application utilizes many of the adaptive antenna components in conjunction with a ground command to combat weather related performance degradation. Furthermore, the effect of phenomenons such as lightning on communications systems can also be reduced by adaptive means. In this regard, an estimate of noise in the communications signal can be obtained by sampling the lightning independently. This noise estimate could be subtracted from the corrupted signal to produce a better signal quality. This is also clearly an adaptive antenna application.

In conclusion, all three commercial communications systems could benefit if an adaptive concept is incorporated within the system. The specific benefits are tabulated in Table II). A more detailed discussion of these benefits is presented in the accompanying final report.

Table II) Potential Benefits of Adaptive Functions

| <u>Adaptive Functions</u> | <u>Potential Benefits</u> |
|-------------------------------------|---|
| Interference Control | <ul style="list-style-type: none"> • Enhance satellite capability • Improve frequency and orbit utilization • Decrease margin requirements |
| Sidelobe Control | <ul style="list-style-type: none"> • Enhance satellite capability • Improve frequency utilization |
| Accurate Beam Forming | <ul style="list-style-type: none"> • Enhance satellite capability • Decrease margin requirements |
| In-orbit Testing and Adjusting | <ul style="list-style-type: none"> • Increase reliability • Reduce cost |
| Compensation of Propagation effects | <ul style="list-style-type: none"> • Decrease margin requirements |

Also presented in the final report are the hardware requirements for implementation of the adaptive antenna concepts to the different commercial communications systems discussed above. In this regard it is concluded that all the components necessary for implementing an adaptive concept to a commercial communications system is readily available at the present time.

Task II) Pointing Error Compensation Study for a Multiple Scanning/Fixed Spot Beam Reflector Antenna System

The Task II efforts were concentrated on the scanning/fixed spot beam antenna system and the applicability of the reconfigurable antenna concept to such a system. As pointed out earlier, the reconfigurable antenna concept can be thought of as a simplified version of an adaptive antenna concept. In the case of commercial communications systems, the interference was assumed to be unintentional and slowly varying. This particular fact allowed the simplification of the adaptive antenna system (see Figure 2-1), yielding the reconfigurable system of Figure 2-2.c with feedback loop. The lack of couplers on the antenna elements are compensated for by slowly modulating the VBFN. The signal received in each feed and the realized parameters of the VBFN behind the feeds can be determined by observing the variations in the output port of the network. While this is possible in a commercial setting, such a system would be unacceptably slow for more typical applications of an adaptive system such as a military one. Elimination of the front end couplers in return represented a substantial cost saving. Hence, starting with the assumption that the interference is unintentional and

slowly varying, a simpler and less expensive version of an adaptive system, namely a reconfigurable concept, was developed. Indeed all three reconfigurable systems mentioned above (see Figures 2-2.a,b,c) possess similar characteristics, i.e. simpler, slower and less costlier than an adaptive antenna.

During the course of the contract, various methods were investigated for determining the size and direction of the pointing error for the ACTS system. Of those, a detection scheme based on the received amplitude strength of feeds was chosen as the most suitable method. In this method, first, the three feeds receiving the largest signals were identified. Based on the signal strength in each of the three feeds, a method was designed to determine the direction and the size of the pointing error. The above-described method was preferred over more conventional direction finding techniques. This is because, in a reflector antenna such as ACTS, amplitude variations between feeds can be detected more accurately than phase variations. Conventional direct radiating direction finding antennas use phase information to determine the signal direction from the sum and difference pattern. Such a method would not be as accurate as the one chosen here for the indirect radiating ACTS system.

Two methods were identified for correcting the beam pointing error for the open-loop system. In both methods, it was assumed that the beam is generated by a seven feed cluster. For the first method, feed coefficients were adjusted to direct the beam peak to the newly determined pointing direction. Subsequently, it was observed that it was possible to provide a higher gain in the new pointing direction by actually moving the beam peak in a slightly different direction. Hence, as a second method, the antenna gain was expressed in terms of the singlet patterns of the seven-feed cluster. The differentiation of this expression yields the optimal feed coefficients which maximize the gain in the direction of interest. This second method was used as the pointing error correction mechanism for the ACTS system as it provided a higher gain.

Next a closed-loop reconfigurable system was developed (see Figure 2-2.c). The closed-loop system did not have couplers in the front end of the antenna. However, the necessary information was obtained by systematically perturbing the VBFN and observing the gain variation at the antenna output port. The resulting information can be used in determining the direction of the pointing error. Also an algorithm was derived to repoint the beam in the newly chosen direction. This algorithm was based on the gradient (i.e. the incremental change in the output port gain per incremental change in the feeding coefficient) of the reconfigurable antenna output.

Neither adaptive nor reconfigurable antenna concepts are new. Adaptive antennas have been used in military applications for some time. Reconfigurable antennas with switches, variable power dividers and variable phase shifters have found uses in both commercial and

military applications. Devices such as MMIC's have also been developed and are available for use in adaptive/reconfigurable systems. It is the finding of this study then that a commercial adaptive/reconfigurable antenna system could be implemented without the need of any new hardware. Furthermore, it is expected that the entry of adaptive/reconfigurable systems into the commercial area could reduce the presently prevailing prices as the cost of the capital expenditure is spread over a larger number of units.