SECTION 1

INTRODUCTION

BACKGROUND

During the period of August 1971 through April 1973, the Interdepartment Radio Advisory Committee (IRAC) had under study the accommodation of Department of Defense (DoD), Federal Aviation Administration (FAA), and Department of Commerce (DoC) radar operations in the band 2.7-2.9 GHz. A series of meetings was held between the agencies (Summary Minutes of the First (October 1972) and Second (December 1972) OTP Meetings) to determine if new FAA air traffic control radars could be accommodated in this band without degrading their performance, and what impact these radars would have on the performance of existing radars in the band. An initial assessment of the problem (Maiuzzo, 1972) determined that the addition of new radars to the band could create a potential problem. To resolve the immediate problem of accommodating the new FAA Air Traffic Control Radars, the following actions were taken:

a. The band 3.5-3.7 GHz was reallocated by footnote to provide for co-equal primary Government use by both the Aeronautical Radionavigation and Radiolocation Services. The footnote reads as follows:

> G110 - Government ground-based stations in the aeronautical radionavigation service may be authorized between 3.5-3.7 GHz where accommodation in the 2.7-2.9 GHz band is not technically and/or economically feasible.

Agencies were requested to cooperate to the maximum extent practicable to ensure on an area-by-area, case-by-case basis that the band 2.7-2.9 GHz is employed effectively.

b. The Spectrum Planning Subcommittee was tasked to develop a long-range plan for fixed radars with emphasis on the 2.7-2.9 GHz and 3.5-3.7 GHz bands. The SPS plan (SPS Ad Hoc Committee, 1974) was completed and approved by the IRAC.

The Office of Telecommunications Policy (OTP)* subsequently tasked the Office of Telecommunications (OT)* to perform a spectrum resource assessment of the 2.7-2.9 GHz band. The intent of this assessment was to provide a quantitative understanding of potential problems in the band of concern as well as to identify options available to spectrum managers for dealing with

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* OTP and OT have been reorganized into the National Telecommunications and Information Administration (NTIA) within the Department of Commerce.

these problems. One of the primary reasons for initiating the assessment was to ensure identification of problems during the early phases of design and planning rather than after-the-fact, i.e., after a system has been designed and hardware fabricated. By making these band assessments early, necessary actions can be taken to assure that appropriate communication channels are established between agencies whose systems are in potential conflict. This will enhance the early identification of solutions which are mutually satisfactory to all parties involved.

A multiphase program to the solution of the 2.7-2.9 GHz Spectrum Resource Assessment task was undertaken by NTIA.

Phase I - The first phase involved the identification of systems existing in and planned for the band in question, determination of available technical and operational data for each system, identification of the potential interactions between systems, and the generation of a plan that leads to an overall assessment of the band's potential congestion. A Phase I report (Hinkle and Mayher, 1975) for the 2.7-2.9 GHz Spectrum Resource Assessment was completed.

Phase II - The second phase encompasses several tasks:

1. A detailed measurement and model validation program in the Los Angeles and San Francisco areas. The objective of this task was to validate models and procedures used to predict radar-to-radar interference, and assess the capability of predicting band congestion. This task was completed and the findings are given in a report by Hinkle, Pratt, and Matheson (1976).

2. Investigation of the signal processing properties of primary radars in the 2.7-2.9 GHz band and the Automated Radar Terminal System (ARTS-IIIA) to assess the capability of the radars to suppress asynchronous interference and the trade-offs in suppressing asynchronous signals.

3. Investigation of the potential band congestion and band efficiency in eight designated congested areas (New York, Philadelphia, Atlanta, Miami, Chicago, Dallas, Los Angeles, and San Francisco) based on the technical findings of Tasks 1 and 2.

4. Development of engineering and management aids to assist the frequency manager in determining if new radars can be accommodated in the 2.7 - 2.9 GHz band, and a methodology for assessing how efficiently the band is being utilized.

This report is the second Phase II report in a series of reports related to the Spectrum Resource Assessment of the 2.7-2.9 GHz band. The nature of the 2.7-2.9 GHz spectrum resource problem requires a rigorous, analytical, and measurement investigation into the signal processing properties of the radars presently in and planned for the 2.7-2.9 GHz band as well as the ARTS-IIIA post processor used in the FAA Terminal radars. This report contains the investigation of the signal processing properties of the radars and post processors to noise, desired signal, and interfering signals to access the capability of the equipment to suppress asynchronous signals and the trade-offs to the desired signal in suppressing asynchronous signals. This investigation was necessary to assure that the investigation of potential band congestion will be based on sound technical procedures.

OBJECTIVE

In order to promote effective use of the band, it is necessary to determine the electromagnetic compatibility of present and future radars planned for deployment in the 2.7-2.9 GHz band. The second task of the Phase II program encompassed a detailed investigation into the signal processing properties of the primary radars and ARTS-IIIA post processor. The objectives of this extensive signal processing investigation were to:

1. Determine the signal processing properties of radars presently operating or planned for the 2.7-2.9 GHz band and the terminal radar ARTS-IIIA Radar Data Acquisition System (RDAS).

2. Investigate the trade-offs to desired signal detection in suppressing asynchronous interfering signals, and determine methods to minimize these trade-offs.

3. Determine methods of obtaining more efficient utilization of the band by using interference suppression techniques.

APPROACH

In order to accomplish the objectives related to the radar signal processing task, the following approach was taken:

1. Conduct a preliminary investigation to determine the radar nomenclatures presently operating in the band, and the new radars and post processors planned to be used in the band.

2. Perform a cursory investigation into the operating modes (i.e., normal, log-normal, Moving Target Indicator (MTI), weather background, etc.), types of circuitry and processing techniques (analog or digital) used by radars in the band to determine the representative radars to be analyzed in detail.

3. Perform a detailed signal processing investigation of the transfer properties of the representative radars to noise, desired signal, and interfering signals using analytical techniques, measurements, and simulation.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

GENERAL

The following is a summary of the conclusions and recommendations as a result of a detailed investigation into the signal processing properties of the primary radars in the 2.7 to 2.9 GHz band, and the Automated Radar Terminal System (ARTS-IIIA) post processor planned for use by the Federal Aviation Administration (FAA) on the Airport Surveillance Radars (ASRs). The investigation included the signal processing properties of the primary radars and the ARTS-IIIA to noise, desired signal, and asynchronous interference along with a detailed parametric analysis of the trade-offs to the desired signal in suppressing asynchronous interference.

The signal processing of the primary radars was based primarily on the ASR-7 (AN/GPN-12) and ASR-8 radars which are late model digital processing type radars. However, the analysis is in general applicable to the older analog processing type radars in the 2.7 to 2.9 GHz band. The signal processing properties of the primary radars are discussed in Section 3 and Appendices A, B, C, D and E.

The signal processing investigation of the ARTS-IIIA included only the Radar Data Acquisition Subsystem (RDAS) since it is the portion of the ARTS-IIIA which processes the 2.7 to 2.9 GHz radar signals. The signal processing properties of the ARTS-IIIA are discussed in Section 4 and Appendix F.

GENERAL CONCLUSIONS

The following is a summary of general conclusions as a result of the signal processing investigation:

1. Radar signal processing techniques can be used to obtain more efficient spectrum utilization. These techniques may include the elimination of processing in the range-azimuth bin containing interference, the use of integration techniques, or variable thresholding techniques. With properly designed signal processing techniques, the suppression of asynchronous interference in low duty cycle radars will have minimal effects on target azimuth shift, angular resolution, and desired signal sensitivity.

2. Since a complete redesign of existing hardware would be required to obtain the full advantage of signal processing techniques for interference elimination, emphasis must be placed upon design standards for new equipment.

3. The cost of realignment or retrofit of existing systems to

eliminate interference must be weighed against the problems created by interference and the cost of other interference reduction techniques such as waveguide filtering.

PRIMARY RADAR CONCLUSIONS

The following conclusions on the signal processing properties of the primary radars in the 2.7 to 2.9 GHz band are based on a combination of measurements, analytical analysis, and simulation:

1. The investigation showed that the ASR-7 binary integrator and ASR-8 feedback integrators can suppress asynchronous interference in the Normal, Moving Target Indicator (MTI), and log-FTC channels with minimal trade-offs in target azimuth shift, angular resolution, and desired signal sensitivity.

2. The desired signal trade-offs in suppressing asynchronous interference are less for the FAA modified binary integrator than for the feedback integrator.

3. In theory the feedback integrators in the analog radars (ASR-4, 5, 6, etc.) should also be capable of suppressing asynchronous interference.

4. The primary radar MTI canceller circuitry produces several synchronous interfering pulses for each interfering asynchronous pulse. Therefore, asynchronous interference in the MTI channel has the potential to be enhanced by the feedback or binary integrator. Thus, if the integrator (enhancer) is not adjusted properly, the level of interference can be greater with the integrator on than with it off.

5. When operating in the log-FTC mode with weather background displayed, interference could potentially be displayed on the PPI since the weather background channel does not have an integrator (enhancer). Since only the master channel of the frequency diversity radars provides the weather background video, proper choice of the master channel may eliminate the potential interference.

ARTS-IIIA POST PROCESSING CONCLUSIONS

The following conclusions are based on a combination of analytical analysis and simulation. Worst-case interference and desired signal level assumptions were made, and consequently, the conclusions may be slightly pessimistic in regard to the impact of interference. The investigation considered the interference effect on a per antenna rotation basis (as opposed to multiple antenna rotation tracking ability) with the ARTS-IIIA interfaced with an ASR-7 or ASR-8 radar. A parametric range of interfering pulse widths between 0.5 μsec and 4.0 μsec were considered in the investigation. Conclusions 1 through 7 are based on the Radar Data Acquisition Subsystem (RDAS) detection parameter combinations that FAA National Aviation Facility Experimental Center (NAFEC) recommended for operational use (rank quantizer threshold 23, hit count threshold 9, miss count threshold 3).

1. For interference levels in currently congested U.S. terminal areas, the reduction in the probability of a target being detected in one antenna rotation would typically be less than 2.5 percent. A congested area interference level is considered to consist of one radar interfering at a given time and interference coupling over 50 percent of the victim radar antenna rotation.

2. If the level of congestion increases in the future to the point where a victim radar receives interference from three radars simultaneously over its entire antenna rotation, the probability of detection would be significantly decreased. The analysis indicated that for a worst-case combination of interfering and victim radars, the probability of target detection could be decreased by as much as 15 percent, and the false alarm probability from 4.6×10^{-7} to 11.7×10^{-7}.

3. Interference has a greater impact on the probability of detection and false alarm when the ARTS-IIIA is connected to the radar MTI channel than when connected to the normal channel because the MTI circuits generate several synchronous interfering pulses for each asynchronous interference pulse at its input. For example, the worse-case (three continually interfering radars), reduction in probability of detection for the MTI channel was 15 percent while that for the normal channel was 5 percent.

4. In general, the impact of interference on the probability of target detection depends on the victim radar's range bin characteristics (width, hold, and sample time), and the interfering radar pulse width and PRF. For the case in which the interfering pulse width is less than the sum of the victim radar range bin width and hold time, the level of interference increases as a function of the interfering radar duty cycle. For the case in which the interfering pulse width is greater than the sum of the victim radar range bin width and hold time, the impact of interference is independent of the interfering radar pulse width and increases only with interfering radar PRF.

5. Asynchronous pulse interference will not significantly affect the RDAS automatic video select (Normal or MTI channel) control function. The probability of an incorrect video channel select decision due to worst-case continual interference from three radars was found to be much less than 0.002.

6. Asynchronous pulse interference will not significantly affect the RDAS's automatic MTI hit count threshold control. The probability of an MTI hit count threshold change due to worst-case continual interference from three radars was found to be insignificant.

7. A rank quantizer threshold of 23 gives superior desired signal detector performance and interference suppression performance over a rank quantizer threshold of 24. For a rank quantizer threshold setting of 23, the analysis indicated the optimum hit/miss count threshold which gives the maximum desired signal detection probabilities with or without interference is (9,4).

GENERAL RECOMMENDATIONS

1. An Ad Hoc committee consisting of Government agencies using radiodetermination services should be established to determine what standards should be adopted in regard to radar interference suppression techniques and the trade-offs in their utilization. The committee findings should then be incorporated in the technical standards of the NTIA Manual of Regulations and Procedures for Radio Frequency Management, and implemented at the systems review level and frequency assignment review level.

2. All new radar systems and post processing systems include during the conceptual design stage of development, a performance evaluation in the presence of asynchronous interference, in addition to clutter and noise, in all designed modes of operation.

3. All technical manuals used in the field on radars and post processors include instructions on how to suppress asynchronous interference while minimizing the trade-offs of the desired signal performance.

PRIMARY RADAR RECOMMENDATIONS

1. In order to ensure that an investigation into the accommodation of future planned radar systems in the 2.7 to 2.9 GHz band is based on sound technical procedures, a measurement program should be undertaken to:

    a. Investigate the operational capability of the feedback and binary integrators (enhancers) to suppress asynchronous interference.

    b. Accurately determine the frequency/distance separation requirements necessary for the new radars using filtered magnetrons, klystrons, or Traveling Wave Tube (TWT) transmitter output devices.

2. The accommodation of projected future radar deployments in congested areas should then be investigated using the measurement results and findings in this report.

3. In congested areas consideration should be given to equipping ASR-8 radars with the FAA modified binary integrator used in the ASR-7 radars. The binary integrator provides superior performance over the feedback integrator in minimizing the desired signal trade-offs while suppressing asynchronous interference.

ARTS-IIIA POST PROCESSING RECOMMENDATIONS

1. Since a rank quantizer threshold setting of 23 provides significantly more interference suppression than a threshold setting of 24 without sacrificing over-all radar performance, it is recommended that a rank quantizer threshold setting of 23 be employed on operational ARTS-IIIAs. NAFEC has also recommended a rank quantizer threshold of 23 based on measurements on desired signal performance.

2. Measurements should be performed on the ARTS-IIIA in congested U.S. areas to determine the particular hit/miss count threshold setting combinations that provide an optimum trade-off between target detection and interference suppression.