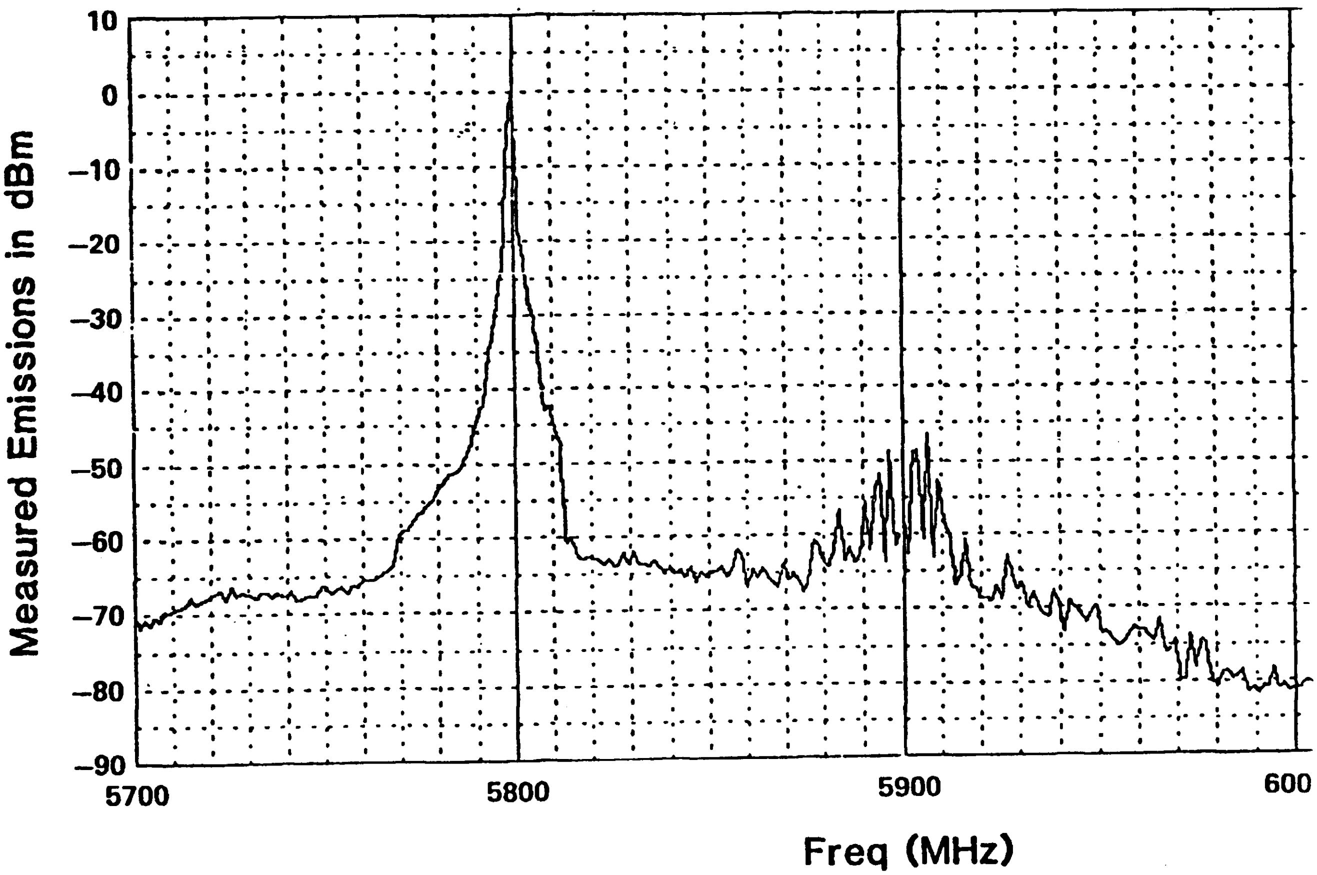


Figure 13. Measured AN/FPS-16 Emission Spectrum.

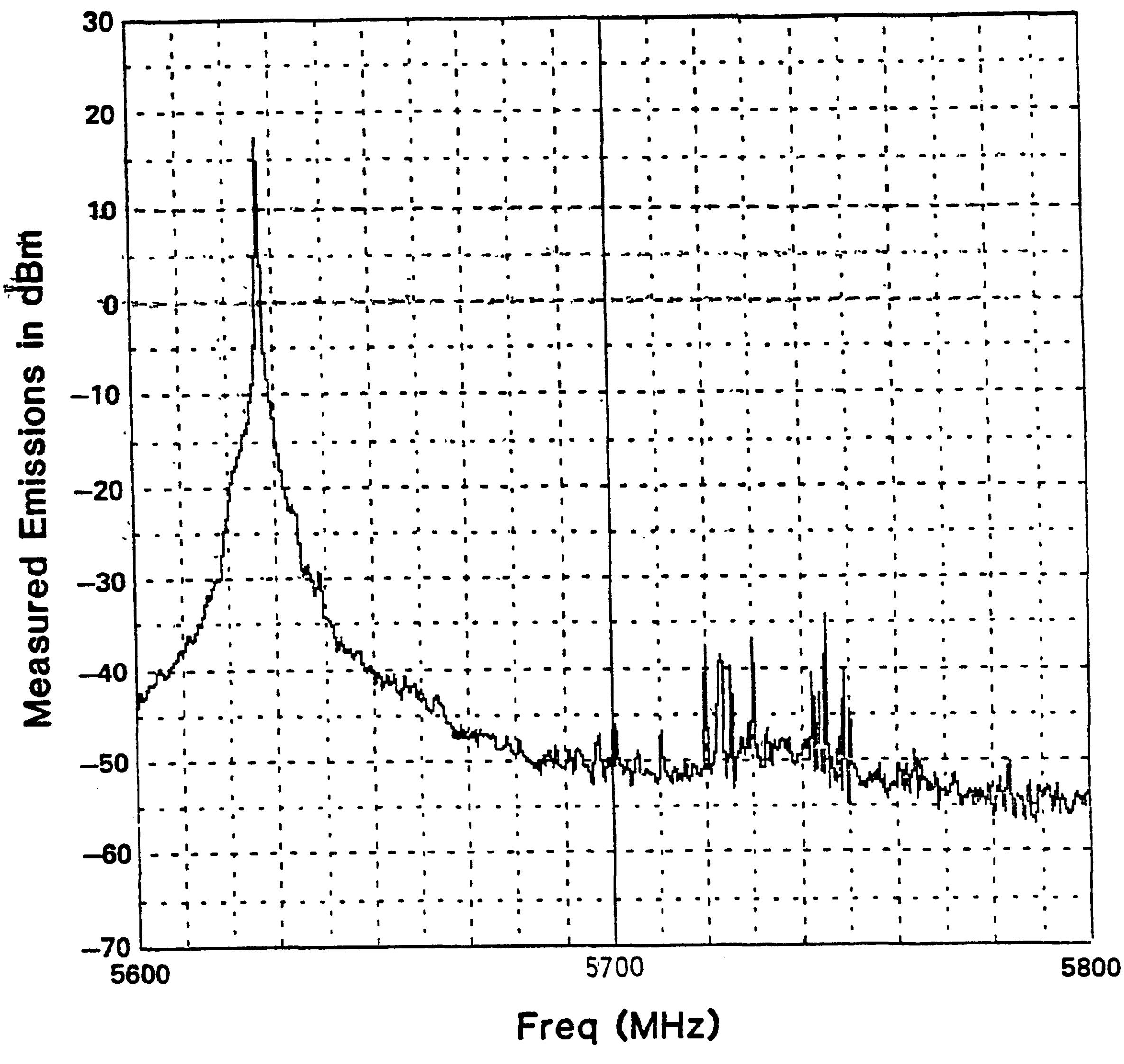


Figure 14. WSR 74-C Western Radar Boston.

When measurements are made in a given band such as 5650-5925 MHz there are often spikes such as these from a lower adjacent band that must be identified. Many of the radars in the band are not easily measured when in a tracking mode because of the narrow beam antennas, the position of the RSMS with respect to the radar when general measurements are being conducted in a given area, or the amount of power transmitted. In general, a radar band such as the one under study here will show less use than actual due to the inability of the RSMS to capture all transmitted signals. This is particularly true at ranges such as the White Sands Missile Range in New Mexico.

MAJOR SYSTEMS AND SELECTED TECHNICAL CHARACTERISTICS

This portion of the 5650-5925 MHz Spectrum Resource Assessment will identify the major systems and summarize selected technical characteristics. These sources include the GMF, NGMF, an ECAC FAL, and MIL-HDBK-162B. The majority of the systems used in the 5650-5925 MHz band can broadly be classed as radars and radar activated transponders. A pictorial representation of system usage including the new satellite usage is shown in Figure 15. There are a few assignments used for experimental development of new Government systems and antenna testing.

One feature common to these systems is the necessary bandwidth of the transmitted pulse waveform. This is defined in the NTIA manual as

$$BW_N(-20\ dB) = \frac{1.79}{\sqrt{t_r t}} \quad \text{or} \quad \frac{6.36}{t},$$

whichever is less, where t_r is the pulse rise time and t is the pulse length. In most cases, the pulse rise time, t_r, is not immediately available, therefore, $BW_N = 6.36/t$ will be used in the tables to follow. This will yield a comparative number for the majority of the systems considered in this report.

RADIOLOCATION

Shipborne Radar Systems

The U.S. Navy has a number of shipborne radars at sea with an area of operation specified as "World Wide Use". The technical characteristics of most of these radars are readily available in the sources named above. The two principal categories of Navy radars in this band are surface search and missile guidance control. The AN/ nomenclature of these systems is discussed below.

Surface Search

AN/SPS-4. The AN/SPS-4 is a medium power surface and zenith search radar. It has a special dual antenna which permits observation of either targets on and near the surface of the water or limited observation of approaching aircraft overhead.

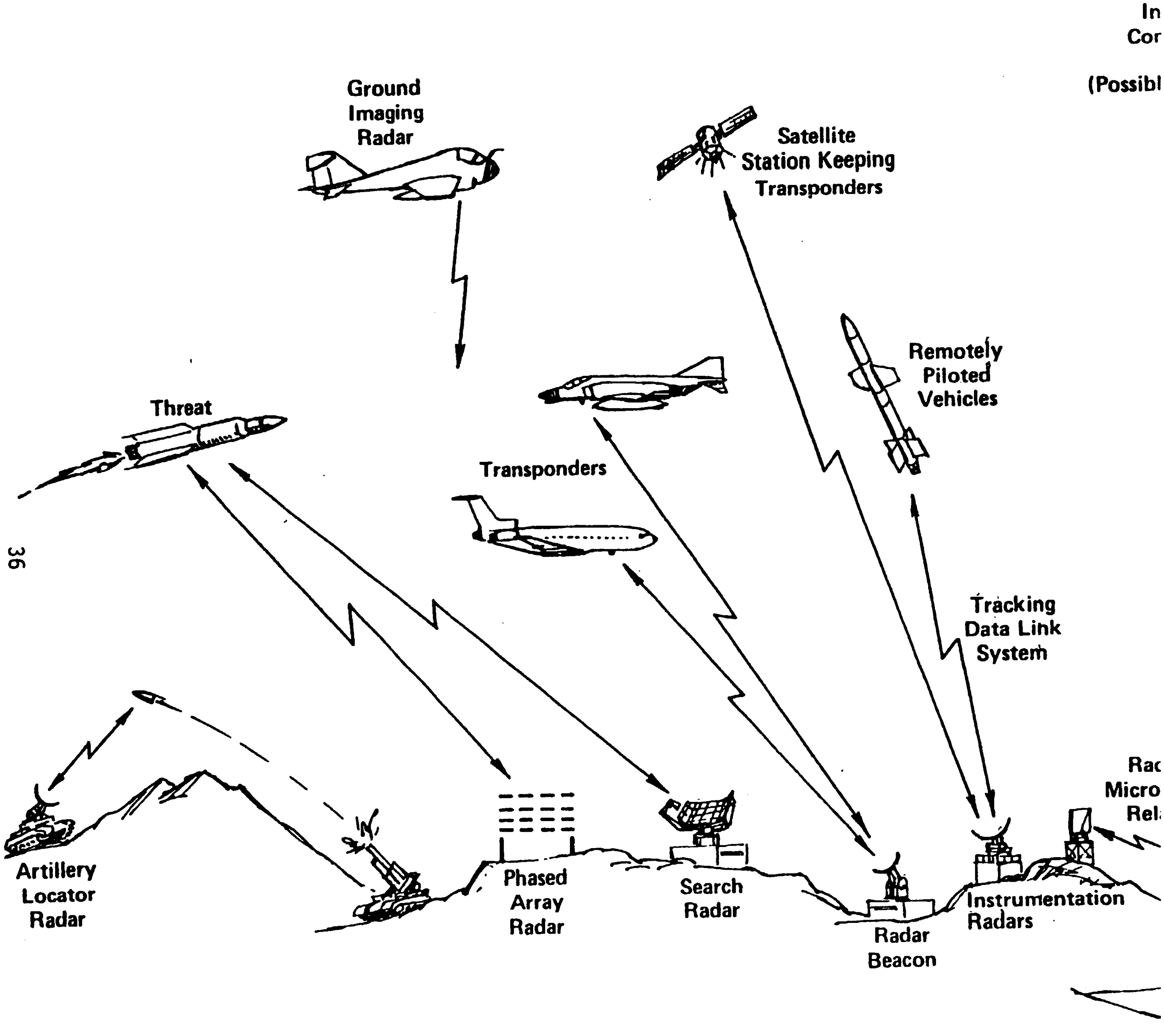


Figure 15. Typical 5650-5925 MHz Spectrum Usage.

Table 4. AN/SPS-4 Technical Characteristics

Frequency Range:	5450-5900 MHz
Power Output:	180 kW peak
Pulse Width:	0.37 to 1.3 μs
Necessary Bandwidth:	17.2 MHz
Pulse Repetition Rate:	625 to 650 pps
Antenna Data:	
Gain:	32 dB
Rotation:	5 or 15 rpm cw in automatic, manual in either direction
Beamwidth (Half-Power Points)	
Surface Reflector	
Horizontal Plane:	1.7 to 2.3°
Vertical Plane:	14 to 16°
Zenith Reflector	
Horizontal Plane:	Approx. 3.0°
Vertical Plane:	Fanshaped with max radiation at 21° above the horizon

AN/SPS-5. The AN/SPS-5 is designed as a medium-power, light-weight, surface-search radar for installation on light vessels.

Table 5. AN/SPS-5 Technical Characteristics

Frequency Range:	5450 to 5900 MHz
Power Output:	250 to 350 kW peak
Pulse Width:	0.5 μs
Necessary Bandwidth:	12.7 MHz
Pulse Repetition Rate:	683.03 pps
Antenna Data:	
Gain:	39 dB
Rotation:	17 rpm
Beamwidth (Half-Power Points)	
Horizontal Plane:	1.7°
Vertical Plane:	15°
Polarization:	Horizontal
High Angle Coverage:	Approx. CSC^2 + 7 to 22°

AN/SPS-10. There is a large family of the AN/SPS-10 series radars beginning as -10, -10B, ..., -10G. All these systems are basically the same radar with minor external system performance changes in antenna patterns. The AN/SPS-10's are designed for shipboard installation but may also be employed at a shore station. They are used for detection, ranging and tracking of surface targets, and to a limited extent, air targets. Means are also provided for Beacon and IFF operation.

Only the technical characteristics of the SPS-10G will be listed in Table 6 as they will adequately describe all SPS-10's. Measured emission spectrum and antenna patterns for the AN/SPS-10G are shown in Figures 9 to 12.

Table 6. AN/SPS-10G Technical Characteristics

Frequency Range:	5450 to 5825 MHz
Power Output:	190 to 285 kW peak
Pulse Width:	0.25 or 1.3 μs
Necessary Bandwidth:	25.4 MHz
Pulse Repetition Frequency:	635 to 660 pps
Antenna Data:	
Gain	32 dB
Rotation:	15 rpm cw
Beamwidth (Half-Power Points)	
Horizontal Plane:	1.5°
Vertical Plane:	14°
Polarization:	Horizontal
Beacon	
Frequency Range:	5450 ± 2 MHz
Power Output:	
Pulse Width:	2.25 μs
Pulse Repetition Frequency:	312 to 350 pps
Antenna Data:	
Rotation:	15 rpm cw
Beamwidth (Half-Power Points)	
Horizontal Plane:	6°
Vertical Plane:	22°

AN/SPS-67. The AN/SPS-67 is designed as a medium-power, light-weight, surface-search radar designed for variable range and variable pulse duration.

Table 7. AN/SPS-67 Technical Characteristics

Frequency Range:	5450-5825 MHz
Power Output:	285 kW peak
Pulse Width:	0.1, 0.25, 1.0 μs
Necessary Bandwidth	63.6 MHz
Pulse Repetition Rate:	2400, 1200, 750 pps

Missile Guidance Control

AN/SPQ-5. The AN/SPQ-5 is designed to supply TERRIER (beam rider type) missile guidance and/or precise gun laying information. The only information given in MIL-HDBK-162B is that the system is pulse modulated (PO) and tunable over the 5400-5900 MHz range.

AN/SPG-49, -55, and -55B. These radar systems are used in the TALOS, TARTER, and TERRIER Weapons systems, respectively. The function of all these systems is similar to that of the AN/SPQ-5; i.e., target detection and missile guidance.

Ground Based Radar Systems

The ground based radar systems operating in the 5650-5925 MHz frequency band are a sophisticated mixture of tracking and/or instrumentation radars. The majority of these systems are located at the various missile test ranges within CONUS. The common features of all these radars are that they are characterized by:

(a) high peak pulse power of 150 kw to 5000 kW,

(b) short pulse widths ranging from 0.1 to the order of 10 μsec,

(c) variable pulse repetition rates,

(d) P0 and/or P9 modulation designators,

(e) pencil beam antennas of the order of 1° and gains of the order of 35 to 45 dBi, and

(f) antenna pointing capabilities which usually cover the complete upper hemisphere above the radar location.

A brief list of ground based radar systems with their use and peak power outputs is shown in Table 8. The last entries in Table 8, although not designated as an AN/ system, are representative of a number of similar systems deployed throughout the world. Systems such as the VEGA 6104 are used by the various military agencies for control of Remotely Piloted Vehicles (RPV's) for reconnaissance and/or training purposes. It is worthy of note that, although the VEGA systems are not radars in the usual sense of the meaning, most of the instrumentation radars are capable of operation in an IF translation mode which is very similar to the operation of the VEGA systems. The SCR-584 radar listed in Table 8 is somewhat unique in that it is a modified World War Two system originally designed to operate around 3 GHz.

Table 8. Typical Ground Based Radar Systems, Uses, and Powers

Radar	Use	Peak Power (KW)	Necessary Bandwidth MHz
AN/FPQ-4	Instrumentation	3000	25.4
AN/FPQ-6	"	2800	25.4
AN/FPQ-10	"	1000	25.4
AN/FPQ-13	"	5000	4.2
AN/FPQ-14	"	2800	25.4
AN/FPQ-15	"	5000	6.4
AN/FPS-16	"	≤ 5000	25.4
AN/FPS-105	"	1000	25.4
AN/MPQ-32	Artillery Locator	5000	12.7
AN/MPS-19	Tracking	250	8.0
AN/MPS-25	Instrumentation	1000	25.4
AN/MPS-26	Tracking	250	25.4
AN/MPS-36	Instrumentation	1000	25.4
SCR-584	"	250	8.0
AN/TPQ-18	"	2800	25.4
AN/TPQ-39	"	250	4.2
AN/TPS-68	Weather	150	3.2
VEGA 6104	Control of Remotely Piloted Vehicles	3.5	25.4
VEGA 657	" " "	1.5	31.8
VEGA 811C	" " "	1.2	21.2

The commonality of the radars listed do not warrant a detailed listing of all their individual specifications; thus, only the AN/FPS-16 (AN/MPS-25), AN/TPQ-39, and VEGA 6104 are listed in detail in the following Tables.

Table 9. AN/FPS-16 (MPS-25) Technical Characteristics

Type	Instrumentation
Frequency	5450-5900 MHz
Power	1 MW Peak 1 kW Average
Ant. Size	3.66 or 4.88 Meter Diameter
Ant. Gain	44.5 or 47 dB
Beam Shape	Pencil
Type Scanner	Mechanical
No. Beams	1
Beamwidth	1.1° or 0.8° EL and AZ
Angular Coverage	-10° TO + 190° EL 360° AZ
Scan Rate	25°/SEC EL 45°/SEC AZ
PRF	145 to 1364/ (12 Values)
Pulse Width	0.25, 0.50, 1.0 μs
Necessary Bandwidth	25.4 MHz
Transmitter Tube	Magnetron or Coaxial Magnetron
Noise Figure	11 dB Max
Range	278 km (1m^2) 334 km Detection 222 km Accurate Track
Polarization	Linear and/or Circular
Receiver BW	8.0 or 1.6 MHz

A measured emission spectrum of an AN/FPS-16 with a coaxial magnetron is shown in Figure 13.

Table 10. AN/TPQ-39 Technical Characteristics

Type:	Digital Instrumentation Radar
Frequency Range:	5400-5900 MHz
Power Output:	250 kW peak
Pulse Width:	1.5 μs
Necessary Bandwidth:	4.2 MHz
Pulse Repetition Frequency:	640 pps
Antenna Data:	
Shape:	Parabolic
Gain:	37 dBi
Angular Coverage:	0° to + 90° EL 360° Azimuth

Table 11. VEGA 6104 Target Tracking Control System

Type:	Control of RPV's
Frequency Range:	5400-5900 MHz
Power Output:	3.5 kW peak
Pulse Width:	0.25-0.45 μs
Necessary Bandwidth:	25.4 MHz
Pulse Repetition Frequency:	320 or 500 pps
Emission Designator:	P9
Antenna Data:	
Elevation:	-10° to + 80° Fan Beam
Azimuth:	360° scan

Transponders

Transponders are a unique group of devices in the 5650-5925 MHz frequency band:

(a) they do not transmit until they receive a radar pulse,

(b) in some cases they will not transmit until they receive a series of coded pulses,

(c) they may reply in code at a frequency different than that of the interrogation frequency,

(d) their power output may range from 0.1W to 1 kW depending upon the mission, and

(e) their antennas are mostly omnidirectional.

There are at least three distinct configurations of radar-transponder systems which may be utilized in various applications. These configurations are best described by Figures 16, 17, and 18 which display both the frequency usage and timing diagrams for the systems. The following symbols are used in the figures:

f_{IF} = intermediate frequency,

f_R = radar frequency,

f_{LO} = local oscillator frequency,

S = power spectral density (W/Hz),

τ = radar delay time to target echo,

T = radar pulse repetition period,

A = signal amplitude,

d = fixed transponder delay time,

f_T = transponder reply frequency,

f_{OLO} = offset local oscillator frequency,

BW_{IF} = IF bandwidth,

PPC = pulse position code.

Figure 16 illustrates the usual radar system with the addition of a transponder to the target for enhanced skin tracking. Note that the addition of the transponder into this system will not change the distribution of frequencies depicted in Figure 16(a). The transponder delay time, d, is predetermined and fixed thus making the true target range simple to either calculate or measure by adding a delayed trigger in the radar range display. The primary reason for the delay time is to prevent the transponder from receiving and transmitting at the same time and possibly shocking itself into sustained oscillation.

Figure 17 illustrates the operation of a radar in operation with a transponder which replies at a frequency, f_T, not equal to the radar frequency, f_R. The radar local oscillator is offset to a frequency, f_{OLO}, so it beats f_T into the radar IF bandwidth. Since this offset is made larger than the IF bandwidth, the normal radar echoes are not detected and the radar time display is clutter free.

Figure 18 typifies a Target Tracking Control System (TTCS) such as the VEGA 6104. Note that the VEGA 6104 is not designed as a skin tracking radar and does not suffer an R^{-4} range loss; thus, it can perform adequately with the relatively low 3.5 KW peak power. The basic function of this type of system is control of Remotely Piloted Vehicles (RPV's) which are used for military reconnaissance and/or training purposes. Similar control systems may also be added to radars such as the FPS-16 or TPQ-39. Figure 18(b) shows the PPC command message towards the end of the radar pulse timing interval, T. This is convenient for radars such as the FPS-16 or TPQ-39 which may also act as skin trackers. Figure 18(c) shows the nature of a coded reply received from the transponder. The reply can carry information about acceptance of the previous command, platform elevation, platform status, range, etc.

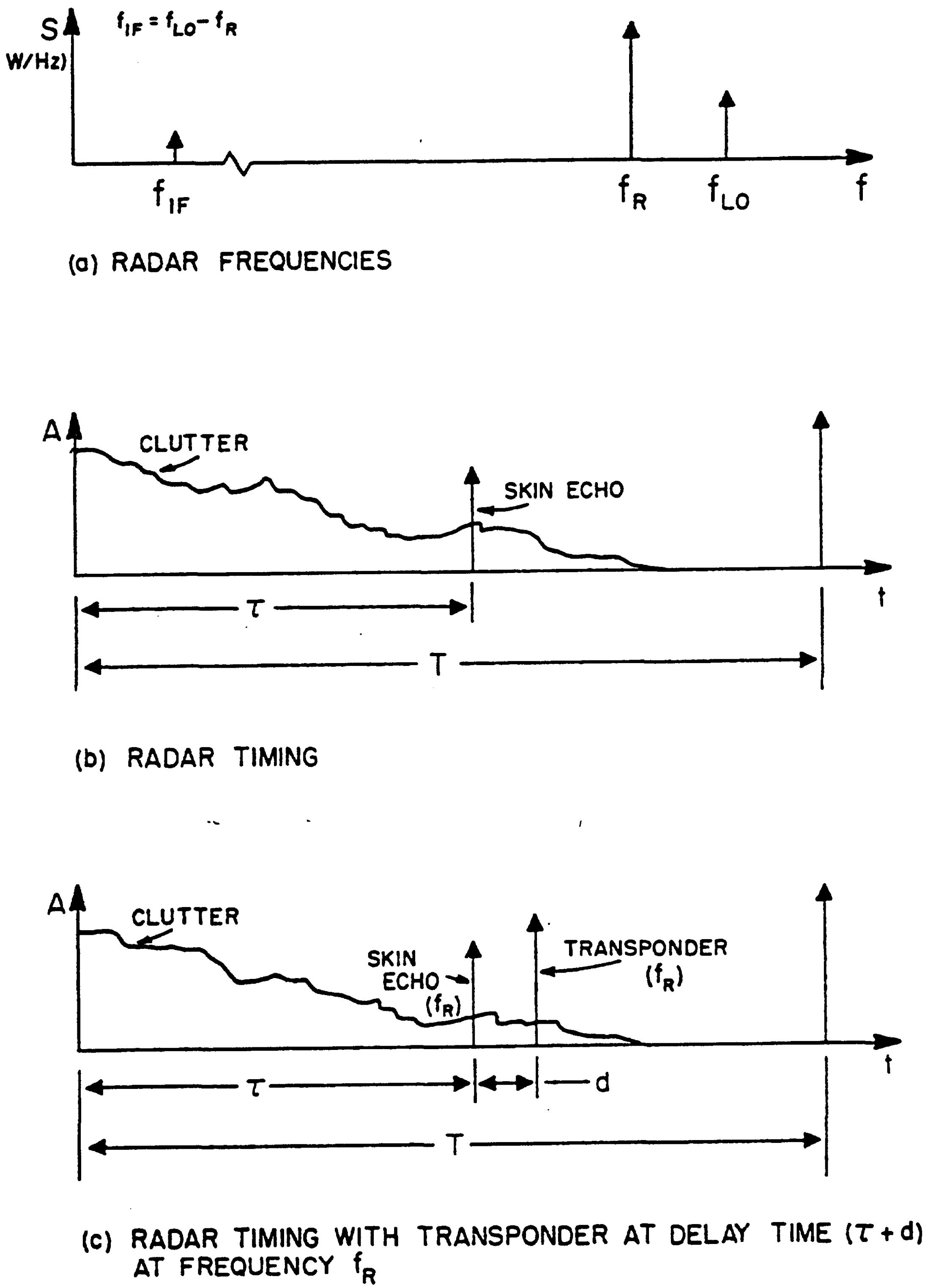
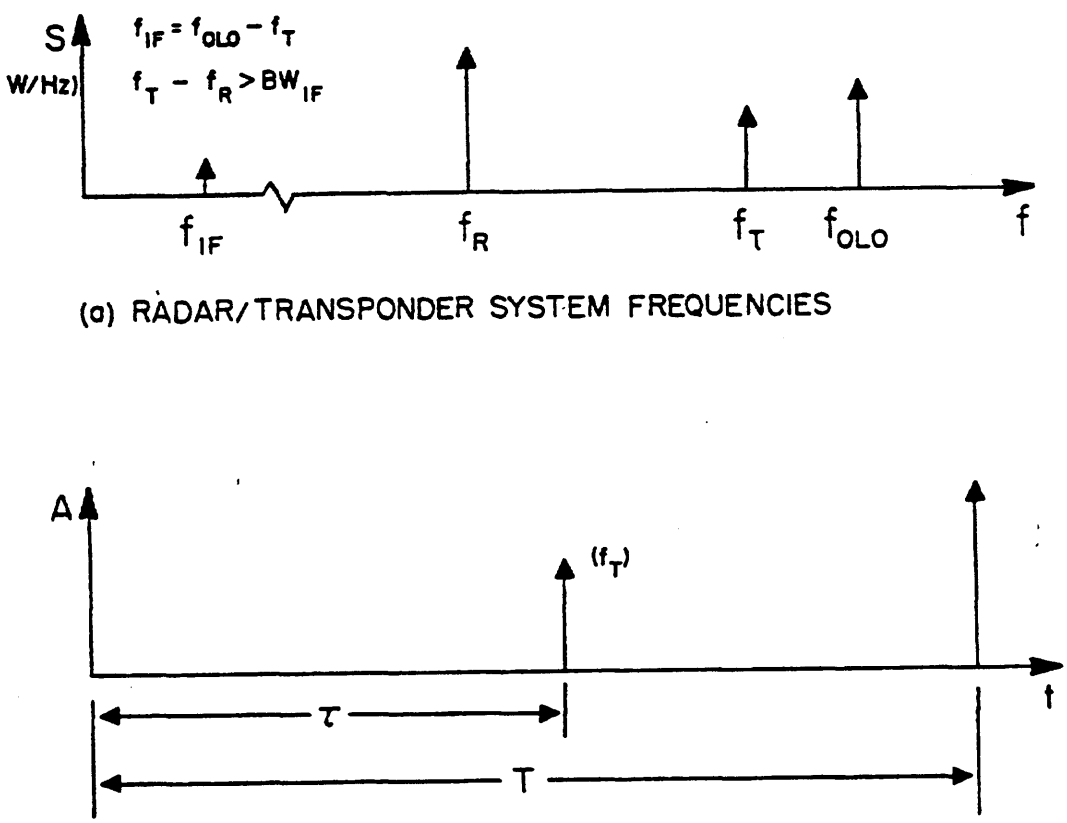


Figure 16. Normal Radar with Added Transponder.



(a) RADAR/TRANSPONDER SYSTEM FREQUENCIES

(b) RADAR/TRANSPONDER TIMING

Figure 17. Radar and Offset Transponder.

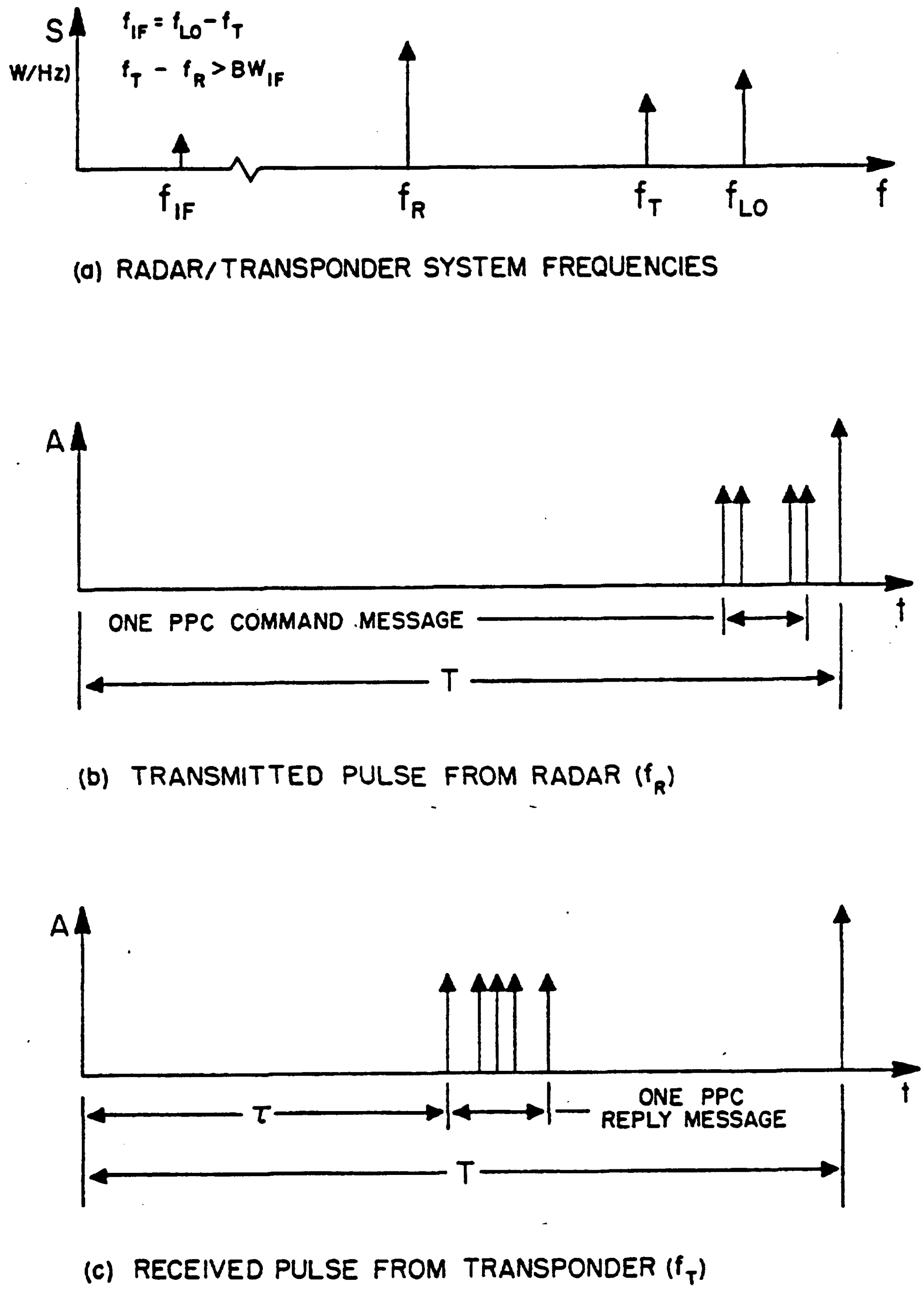


Figure 18. VEGA Target Tracking Control System (TTCS) (no skin track).

A list of the many types of radar transponders known to have been in use or currently in use is shown in Table 12. The peak powers listed are, in most cases, the largest peak powers found in the various sources of information. In several instances it appears the peak power of a transponder is tailored to fit the mission being undertaken.

Table 12. Transponder Types and Powers

Transponder	Peak Power (KW)	Necessary Bandwidth (MHz)
AN/DPN-31	0.05	16.0
AN/DPN-42	0.10	9.8
AN/DPN-55	0.40	31.8
AN/DPN-63	0.40	8.6
AN/DPN-66	0.50-1.0	25.4
AN/DPN-71	≤ 0.4	8.5
CSI 550C	0.50	12.7
MOT SST 131C	0.50	10.6
MOT SST 171C	1.05	15.9
MOT SST 174C	0.10	15.9
MOT SST 175C	0.10	14.1
MOT SST 176C	1.00	15.9
MOT SST 271C	0.40	15.9
MOT 10-22390	0.10	7.1
PD4	0.005	25.4
VEGA 207C	0.40	25.4
VEGA 228C	0.005	25.4
VEGA 302C	≤ 0.70	31.8
VEGA 306C	0.40	12.7
VEGA 321C	0.30	15.9
VEGA 345C	0.05	15.9
VEGA 349C	≤ 0.05	21.2
VEGA 355C	0.10	14.1
VEGA 366C	0.05	13.5
VEGA 616C	≤ 0.50	12.7
VEGA SA 2255	≤ 1.00	12.7
VEGA SA 2772	0.10	15.9
VEGA 303530	0.25	12.7

Here again, the commonality of these systems does not warrant a detailed listing of all their individual specifications. Their emission designators are either P0 and/or P9; many transponders are switchable to either mode of operation. As the majority of these systems are mounted on airborne platforms which may have more than one possible mission termination, the antennas used are some form of an omnidirectional antenna (∿3 dBi). The MOT SST 171C, VEGA 302C, and VEGA 366C are listed in detail in the following Tables as an indication of the diversity of transponders currently in use.

Table 13. MOT SST - 171C (AN/DPN-81) Technical Characteristics

Transmitter	
Frequency	5400-5900 MHz
Power	400 W peak
Pulse Width	0.5 ± 0.1 μs
PRF	-
Pulse Code	Single or double
Receiver	
Bandwidth	11 ± 3 MHz
Sensitivity	-70 dBm

Table 14. VEGA 302C-8 Technical Characteristics

Transmitter	
Frequency	5400-5900 MHz
Power	700 W Peak
Pulse Width	0.3 ± 0.1 μs
PRF	100 to 4160
Pulse Code	Single or multiple with external modulation
Receiver	
Bandwidth	11 ± 3 MHz
Sensitivity	-70 dBm
Telemetry out	
Amplitude	1.5 V min. (50 ohms)
Pulse width	0.4 ± 0.1 μs

Table 15. VEGA 366C Technical Characteristics

Transmitter	
Frequency	5400-5900 MHz
Power	50 W peak
Pulse Width	0.47 to 0.53 μs
PRF	100 to 2600/sec
Pulse Code	Replies to single or multiple radars
Receiver	
Bandwidth	11 ± 5 MHz
Sensitivity	-65 dBm

OTHER MAJOR EQUIPMENT

Radiolocation

AN/MPQ-32. This system is a mobile artillery locator radar used to determine the origin of hostile artillery fire. The exceptionally high transmitter power (5 MW) is required for detecting and tracing the ballistic trajectory of the small targets involved in a tactical situation.

Patriot Radar and Other Phased Array Systems. The patriot radar and other experimental phased array systems in the band have, in general, classified performance characteristics. It can be stated that the performance of most phased array systems are very similar: (1) the antenna beam and pattern is computer controlled and capable of tracing many targets simultaneously without mechanical motion of the antenna; (2) the tracing beams are of the order of 1°; (3) they may be capable of controlling a counter strike mission and (4) the transmitted power and pulse length is of the order of 100 kW and 10's of microseconds. Many of these systems have pulse compression capabilities for enhanced range resolution.

Radar Transponders. Transponders are, in general, low power ($\leq$ 1 kW) pulse devices utilized on airborne platforms for separating the target from clutter and hand-off to other tracking radars.

Radar Beacons. Beacons are, in principle, very similar to transponders except they are intended for the interrogation and collection of information from cooperative aircraft. This information is then utilized for control of the air corridors.

The remaining equipments used in the 5650-5925 MHz band are primarily used for experimental development of new Government systems, antenna testing, or routine ground tests of missiles before firing. A few systems are used for calibration of shipboard equipment. In general, it is noted that these diverse equipments are of moderate power ($\leq$ 2 kW), have directive antennas, and are generally directed towards a surface target receiver located nearby or within the 4/3 earth radius view of the transmitter.

Industrial, Scientific and Medical. There were no equipments found operating in the band which would fit the ISM category. Typically, the kinds of ISM equipment would be like Industrial Heating Equipment, Medical Diathermy Equipment and RF Stabilized Arc Welders. These devices, although not required to be licensed, do have to be certified attesting to compliance with spurious and harmonic emissions specified in Part 18 of the FCC Rules and Regulations. No certification for equipment in this band was found on file with the FCC.

Restricted Radiation Devices. The FCC Rules and Regulations, Part 15, states that certain restricted radiation devices may operate in the designated frequency 5800 $\pm$ 75 MHz. Specifically, the devices named are Low Power Communication Devices used for the measurement of the characteristics of materials, Radio Control Transmitters used for a door opener, and Field Disturbance Sensors which typically are microwave intrusion sensors, and devices that use RF energy for production line counting and sensing. There were no such systems found to be certified for, or operating in the 5650-5925 MHz band, but since licensing is not a requirement, positive identification of equipment is difficult.

Fixed-Satellite Service. The FSS may operate international communication satellite uplink systems in the band. These would be like the INTELSAT VI series now planned to be operational by the mid-1980s. At present there are transponders aboard a number of Satellites such as GOES-F, SPOT, RCA-C1, D,E &F, Westar-D,E etc. that use 5690 MHz as an up-link frequency and 5765 MHz as down-link. These transponders are used for station keeping and tracking purposes. They are interrogated by a radar and respond upon interrogation. The information returned is used for ephemeris up-date and positive tracking by Earth based radars.

Amateur. The amateur service may use the band 5650-5925 MHz on a secondary basis. There are two specific sub-bands given to the amateur-satellite service, 5650-5670 MHz (earth-to-space) and 5830-5850 MHz (space-to-earth). At present, no use of the band by the amateurs could be documented. The ARRL had no input from its members concerning use of this band.

SECTION 5

PROBLEM DEFINITION

INTRODUCTION

The preceding sections have defined frequency usage, the various classes of systems, and major systems operating in the 5650-5925 MHz band. This section presents potential interference problems in the form of a matrix which identifies the relative degree of compatibility between services using the band. The potential problems identified are analyzed in a more in-depth study in the following sections.

PROBLEM ASSESSMENT MATRIX

The matrix of Figure 19 is based on data presented in this report and represents potential interference problems in the 5650-5925 MHz band. Three categories of compatibility problems are used in the matrix and are defined as follows:

No problem implies that the systems involved are separated sufficiently in frequency, distance or time such that no interference would be expected.

Manageable problem is defined as an interaction where interference is possible, under worst-case conditions, but which can be avoided by using standard frequency management techniques.

Potential problems are defined as a category that requires additional study to fully define and resolve compatibility issues. The resolution of these problems may require operational restrictions of systems involved, system design changes, technical standards revision, and/or new operations procedures.

POTENTIAL PROBLEMS

The one potential problem area that merits further study in the 5650-5925 MHz band is the impact of radiolocation on the newly allocated fixed-satellite service (FSS) from 5850-5925 MHz. Some of the radar systems used in the Radiolocation Service have large peak power capability (including megawatt pulse power). This amount of power, in-band, presents an incompatible interference problem to satellite receivers of the INTELSAT type when the radar beam intercepts the satellite receiving antenna.

MANAGEABLE PROBLEMS

Compatibility problems in this category are considered manageable by standard spectrum management techniques and do not require further analytical study.

Interactions between the various systems operating in the Radiolocation Service are considered manageable. As mentioned in previous sections most of the radar systems operating in the band are on vessels at sea, on military test ranges in CONUS or perimeter radars used in the national defense. The various area frequency coordinators under the direction of the range commanders council manage the frequency spectrum assigned to the DOD test ranges. Along with the test range area frequency coordinators, there are various regional frequency coordinators for each DOD department or agency. Through this sytem there is very tight management of the band as well as EMC analysis of many systems in the band carried out by ECAC and responsible DOD agencies. Standard frequency management techniques should apply here.

Transponders aboard satellites used for station keeping and positive tracking purposes are very similar to transponders used for other positive tracking situations such as missile and rocket launches. Generally the same type of radars are used such as the AN/FPS-16. These types of transponders have been operating compatibility with other systems in the band for some years and should not pose a new problem with the introduction of the FSS.

There are possible interactions between FSS up-link transmission and radar receivers in the band. However, as pointed out in Section 6, this would seem to be a manageable problem with a combination of distance separation and frequency separation.

The Radiolocation Service, as primary, would not seem to have a particular problem with restricted radiation devices which must operate on a secondary non-interference basis. However, hypothetically if an unlicensed and popular device were to be designed for the 5650-5925 MHz band and a large percentage of the population were to own such a device, great pressure could come to bear on the Government if the large radars in the Radiolocation Service caused unacceptable interference. This is considered a manageable problem if steps are taken now to assure that no such devices are developed and allowed to proliferate in the band.

Interactions between earth station transmitters in the Fixed-Satellite Service and radiolocation transponders are remotely possible. However, as pointed out in Section 6 for the Jamesburg, CA, and Andover, ME, sites as candidates for the FSS up-path transmitter locations on either coast, possible interaction should be manageable.

Restricted radiation devices in the 5650-5925 MHz band operate on a non-interference basis. No reported incidents of interference with authorized service could be found. However, because of the importance of the military Radiolocation Service, the impact of such devices should be analyzed for new systems or services in the band. The restricted radiation devices should share compatibly with the Fixed-Satellite-Service in the band using standard spectrum management techniques.

At present there is no known use of the 5650-5925 MHz band by the amateur service. However, there is a new amateur-satellite allocation for an up-link at 5650-5670 MHz, and a down-link at 5830-5850 MHz. This allocation is on a secondary non-interference basis, but as use of this band is developed by the amateur-satellite-service, an analytic assessment would be required.

As previously mentioned, no present use of the ISM band (5800 $\pm$ 75 MHz) could be found. However, since the Radiolocation Service has a large number of assignments in the ISM band and ISM equipment has no restrictions on <u>in-band</u> radiated fields, possible interactions could present a problem at a future date. This is considered a manageable problem if the potential is recognized and coordination between the FCC, manufacturers of ISM equipment and the IRAC is maintained in this area.

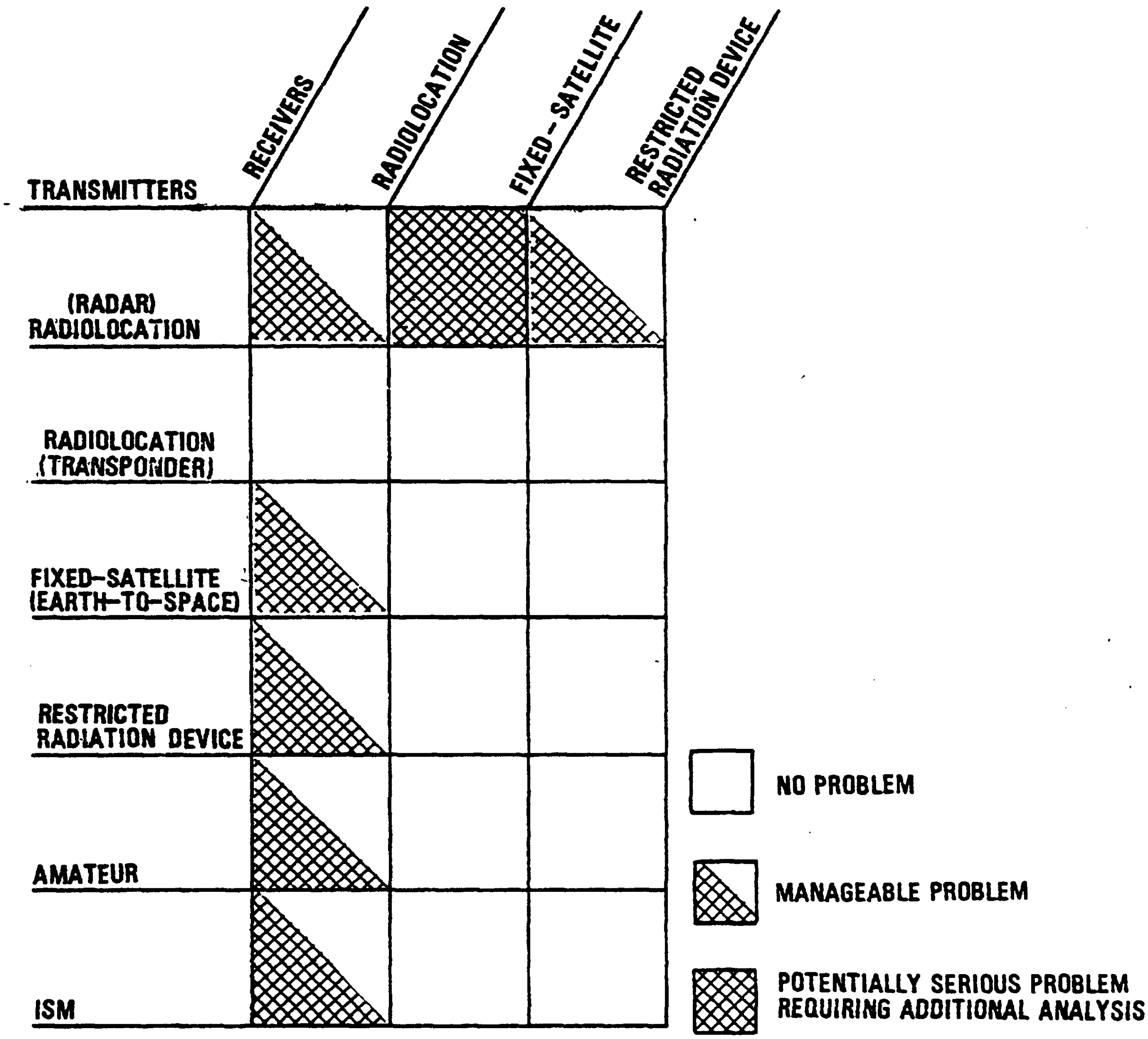


Figure 19. Problem Assessment Matrix.