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ELECTROMAGNETIC COMPATIBILITY ANALYSIS OF THE PREDATOR UAV LINE-OF-SIGHT DATA LINK TERMINAL WITH THE COMMUNICATIONS-ELECTRONICS ENVIRONMENT AT INDIAN SPRINGS AIR FORCE AUXILIARY FIELD

Prepared for

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PROJECT REPORT

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14. ABSTRACT
The Joint Spectrum Center conducted an electromagnetic compatibility analysis to determine the potential for electromagnetic interference (EMI) between the Predator UAV Line-of-Sight Data Link Terminal and the communications-electronics (C-E) environment near Indian Springs Air Force Auxiliary Field. This analysis included the 4.4-4.94, 5.25-5.85, 14.4-14.83, and 15.15-15.35 GHz frequency bands. Each frequency band had a potential for EMI between the terminals and various C-E systems in the environment. Environmental systems analyzed included, but were not limited to: radar systems (fixed and mobile), terrestrial microwave links, telemetry systems, satellite downlink systems, and radio astronomy telescopes. Where potential EMI was noted, mitigation techniques were recommended. The data presented in this report was current as of 18 July 2003.

15. SUBJECT TERMS
Predator, UAV, C-Band, Ku-Band, Data Link, FSK, Intersite, ISAFAF, EMI

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EXECUTIVE SUMMARY

The Predator Unmanned Aerial Vehicle (UAV) line-of-sight (LOS) command link (CL) and return link (RL) frequency assignments permit simultaneous operations of four General Atomics Aeronautical Systems Predator air vehicles at Indian Springs Air Force Auxiliary Field (ISAFAF). With increased operations of RQ-1/MQ-1 Predator and the introduction of MQ-9 Hunter-Killer (Predator B) operations, the requirement was identified for simultaneous operations of seven Predator UAVs at ISAFAF and an eighth set of frequencies for ground testing. The Air Combat Command UAV Special Mission Office (ACC/DR-UAV) requested that the Joint Spectrum Center (JSC) investigate ways to satisfy the eight Predator frequency requirements.

The JSC conducted an electromagnetic compatibility (EMC) analysis to determine the potential for electromagnetic interference (EMI) between the Predator UAV LOS Data Link Terminal and the communications-electronics (C-E) environment near ISAFAF for four candidate frequency bands: 4.4-4.94, 5.25-5.85, 14.4-14.83, and 15.15-15.35 gigahertz (GHz). Since integration of Tactical Common Data Link (TCDL) terminals into the UAV and ground data terminal (GDT) is planned, this analysis also included determining the potential for EMI between the TCDL configured Predator and the C-E environment near ISAFAF for the 14.4-14.83 and 15.15-15.35 GHz frequency bands.

Each frequency band had a potential for EMI between the terminals and various C-E systems in the environment. Environmental systems analyzed included, but were not limited to: radar systems (fixed and mobile), terrestrial microwave links, telemetry systems, satellite downlink systems, and radio astronomy (RA) telescopes.

Where potential EMI was noted, mitigation techniques were recommended. Analysis of the interactions where the RL transmitter was the source of the interference to terrestrial microwave links indicates that the 14.4-14.8 GHz band RL transmitter may cause interference to select transportable microwave links. It is recommended that RL transmitter operations be coordinated with the Department of Energy. For six Department of Justice (DOJ) fixed microwave links, it is recommended that there be a minimum frequency separation of 11 megahertz (MHz) between the RL transmitter and fixed microwave link. All of the DOJ microwave links operate in the upper portion of the 4400-4940 MHz band, and therefore it is recommended that the RL for this band be located in the lower portion of this band below 4749 MHz. For RA systems, frequency separation is required to preclude interference to the very long baseline array at Owens Valley Radio Observatory, Owens Valley, CA. There were no interactions involving radar systems, telemetry systems, and satellite downlink systems that resulted in predicted EMI.

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GLOSSARY

ACC	Air Combat Command
AF	Air Force
AR	Army
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
C/N	Carrier-to-Noise Ratio
C-E	Communications-Electronics
CCIR	International Radio Consultative Committee
CL	Command Link
dB	Decibels
dBm	Decibels Referenced to One Milliwatt
DMS	Degrees Minutes Seconds
DOE	Department of Energy
EMC	Electromagnetic Compatibility
EME	Electromagnetic Environment
EMI	Electromagnetic Interference
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDR	Frequency Dependent Rejection
FDRCAL	Frequency Dependent Rejection Calculation
FEC	Forward Error Correction
FRRS	Frequency Resource Record System
FSK	Frequency Shift Keyed
GCS	Ground Control Station
GDT	Ground Data Terminal
GHz	Gigahertz
GMF	Government Master File
I	Interference Power
IF	Intermediate Frequency
I/N	Interference-to-Noise
ISAFAF	Indian Springs Air Force Auxiliary Field
J	Joules
JSC	Joint Spectrum Center

K	Degrees Kelvin
km	Kilometer
kbps	Kilobits per Second
LNA	Low Noise Amplifier
LOS	Line-of-Sight
Mbps	Megabits per Second
MER	Message Error Rate
MHz	Megahertz
mW	Milliwatts
NASA	National Aeronautics and Space Administration
NAvail	Not Available
N/A	Not Applicable
NTSC	National Television System Committee
O-QPSK	Offset-Quadrature Phase Shift Keying
PD	Power Density
PFDR	Peak Frequency Dependent Rejection
RA	Radio Astronomy
RECAP	Radar Electromagnetic Compatibility Analysis Program
RF	Radio Frequency
RL	Return Link
S	Signal Power
S/I	Signal-to-Interference Ratio
S/N	Signal-to-Noise Ratio
STATGN	Statistical Antenna Gain
TACAN	Tactical Air Navigation
TCDL	Tactical Common Data Link
TIREM	Terrain Integrated Rough Earth Model
UAV	Unmanned Aerial Vehicle
USAF	United States Air Force
VLBA	Very Long Baseline Array
W	Watts

SECTION 1 – INTRODUCTION

1.1 BACKGROUND

The Predator Unmanned Aerial Vehicle (UAV) line-of-sight (LOS) command link (CL) and return link (RL) frequency assignments permit simultaneous operations of four General Atomics Aeronautical Systems Predator air vehicles at Indian Springs Air Force Auxiliary Field (ISAFAF). With increased operations of RQ-1/MQ-1 Predator and the introduction of MQ-9 Hunter-Killer (Predator B) operations, the requirement was identified for simultaneous operations of seven Predator UAVs at ISAFAF and an eighth set of frequencies for ground testing. Air Combat Command UAV Special Mission Office (ACC/DR-UAV) requested that the Joint Spectrum Center (JSC) investigate ways to satisfy the eight Predator frequency requirements.

The JSC conducted an electromagnetic compatibility (EMC) analysis to determine the potential for electromagnetic interference (EMI) between the Predator UAV LOS data link terminal and the communications-electronics (C-E) environment near ISAFAF for four candidate frequency bands: 4.4-4.94, 5.25-5.85, 14.4-14.83, and 15.15-15.35 gigahertz (GHz). Since integration of Tactical Common Data Link (TCDL) terminals into the UAV and ground data terminal (GDT) is planned, this analysis also included determining the potential for EMI between TCDL configured Predator and the C-E environment near ISAFAF for the 14.4-14.83 and 15.15-15.35 GHz frequency bands.

1.2 OBJECTIVES

The objectives of the analysis were to:

- Assess the potential for EMI between the Predator UAV and GDT LOS data link terminals and the C-E environment at ISAFAF
- Identify mitigation techniques required to reduce, or eliminate, any potential interference

1.3 APPROACH

C-E systems were selected from four operating frequency bands (4.4-4.94, 5.25-5.85, 14.4-14.83, and 15.15-15.35 GHz) that were identified by ACC/DR-UAV. The C-E environment for each fundamental frequency band and second through fifth harmonic and subharmonic bands were identified by accessing the Federal Communications Commission (FCC), Frequency Resource Record System (FRRS), and the Government Master File (GMF) databases available at the JSC. Each fundamental frequency band included a 5% margin above and below the band. The specific frequency bands are listed in Table 1-1. The database selects were constrained to an area defined by the four points 35°N 114°W, 35°N 118°W, 39°N 114°W, and 39°N 118°W. The ISAFAF is located 36° 35' 12" N, 115° 40' 24" W. Figure 1-1 shows the ISAFAF geographical area. The electromagnetic environment (EME) definition included equipment listed in the JSC databases.

Table 1-1. Database Select Frequency Criteria

	4400-4940 MHz Frequency Band (MHz)	5250-5850 MHz Frequency Band (MHz)	14400-14830 MHz Frequency Band (MHz)	15150-15350 MHz Frequency Band (MHz)
5th Subharmonic	880-988	1,050-1,170	2,880-2,966	3,030-3,070
4th Subharmonic	1,100-1,235	1,313-1,463	3,600-3,708	3,788-3,838
3rd Subharmonic	1,467-1,647	1,750-1,950	4,800-4,943	5,050-5,117
2nd Subharmonic	2,200-2,470	2,625-2,925	7,200-7,415	7,575-7,675
Fundamental Including Adjacent Bands	4,180-5,187	4,988-6,143	13,680-15,572	14,393-16,118
2nd Harmonic	8,800-9,880	10,500-11,700	28,800-29,660	30,300-30,700
3rd Harmonic	13,200-14,820	15,750-17,550	43,200-44,490	45,450-46,050
4th Harmonic	17,600-19,760	21,000-23,400	57,600-59,320	60,600-61,400
5th Harmonic	22,000-24,700	26,250-29,250	72,000-74,150	75,750-76,750
MHz – megahertz				

Because of the large number of systems in the environment (7000 records), calculations of the potential for interference with Predator UAV data link terminals were based on successively more rigorous levels of analysis in order to reduce the number of systems analyzed at each level. For the Level One analysis, a generic interference-to-noise ratio (I/N) within the receiver intermediate frequency (IF)-amplifier (or filter) -3-dB bandwidth was used. For the Level Two analysis, I/N thresholds applicable to the specific type of receiver under analysis were used. The Level Three analysis applied specific performance criteria for each type of environmental receiver which included antenna coupling scenarios and receiver signal processing. For each system examined in the Level Three analysis, a degradation threshold related to the C-E system function was used.

For the Level One and Level Two analyses, received interference power (I) at the input to the receiver was calculated for each receiver. The JSC Terrain Integrated Rough Earth Model (TIREM)[1-1] was

[1-1] D. Eppink, W. Kuebler, *TIREM/SEM Handbook*, ECAC-HDBK-93-076, Annapolis, MD: DoD Joint Spectrum Center, March 1994.

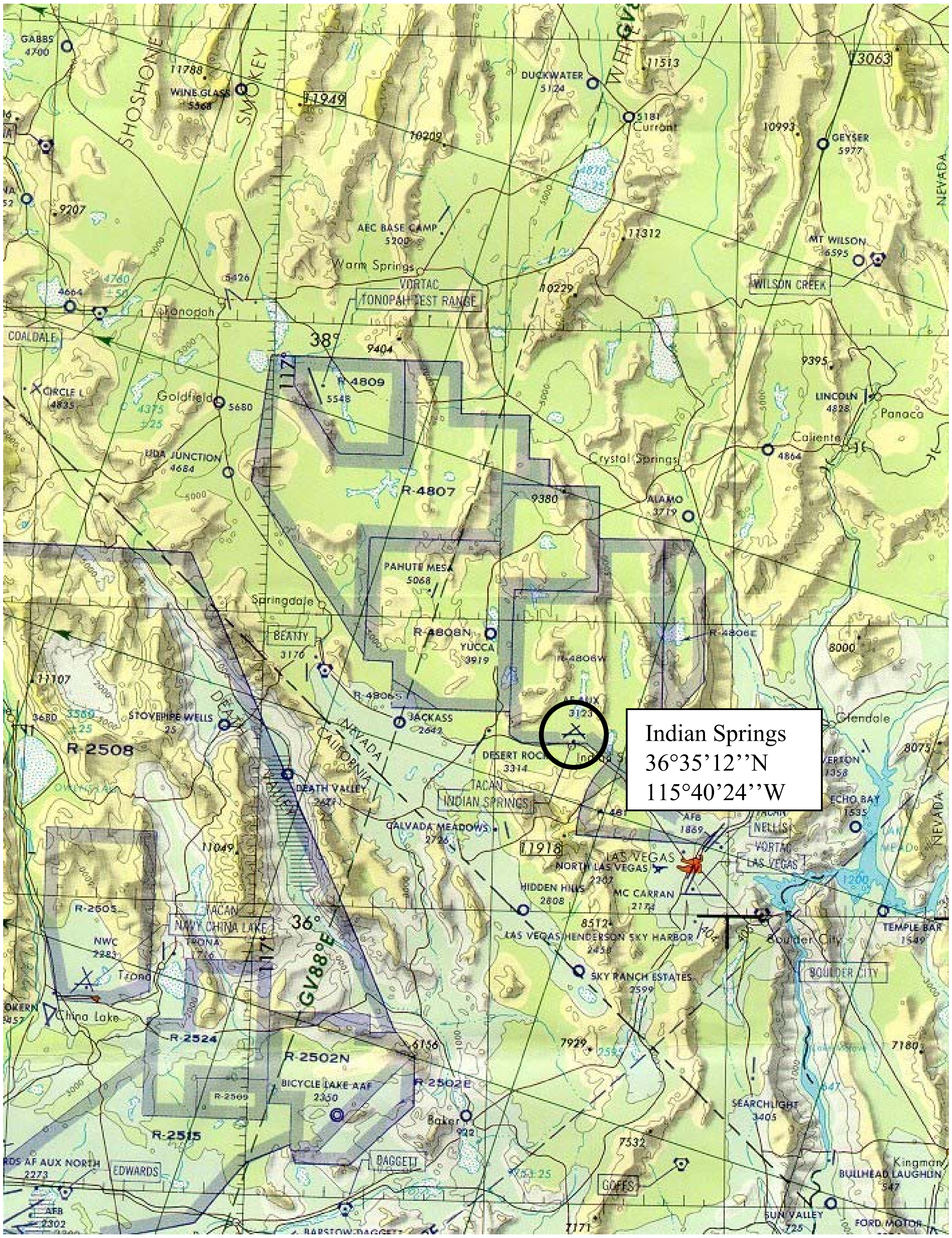

Figure 1-1. Indian Springs at 36° 35' 12" N, 115° 40' 24" W and Surrounding Geographical Area

utilized to calculate propagation loss. The JSC Statistical Antenna Gain (STATGN) model[1-2] was utilized to estimate off-axis antenna gain. When not defined, the gain of the data link terminal transmitter antenna in the direction of the receiver antenna, and the gain of the receiver antenna in the direction of the data link terminal, were calculated using the assumption that 90 percent of the time the antenna mainbeams would be off-axis to each other by more than 18 degrees. The receiver thermal noise power (N) was calculated. The I/N was calculated. The I/N was compared to the appropriate interference-to-noise power ratio threshold $(I/N)_T$ to determine the potential for EMI for Level One and Level Two analyses.

The Level Three analysis of the terrestrial microwave links entailed calculating desired carrier-to-noise ratio (C/N), fade margin availability without interference, C/(I+N), and availability with interference. Availability was then compared to appropriate thresholds of 0.99999 for Federal Aviation Administration (FAA) links and 0.99975 for all others.

Level Three radar calculations were based on I/N ratios. The peak frequency dependent rejection (PFDR) and required separation distances (based on the great circle path and relative effective antenna heights) were calculated using the JSC Radar EMC Analysis Program (RECAP).[1-3] The statistical antenna gain values were calculated using the STATGN program. Propagation loss was calculated using TIREM. I/N ratios were compared to an I/N_T of -6 dB to determine the potential for EMI.

Level Two EMI to satellite downlink systems was not predicted, therefore, a Level Three analysis was not performed.

The Level Three telemetry systems analysis entailed calculating desired received signal power (S). Signal-to-interference (S/I) ratios were then calculated. Calculations for S and I include use of TIREM. Calculations for I utilize STATGN. S/I ratios were compared to signal-to-interference thresholds $(S/I)_T$ of 12 dB for current terminals and 7 dB for TCDL terminals to determine the potential for EMI.

The Level Three radio astronomy (RA) analysis involved calculations of I and power density (PD) at the antenna terminals and at the antenna location, respectively. The power level of maximum tolerable

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[1-2] W.R. Klocko, T. L. Strickland, Environmental Analysis System (EASY) Statistical Gain Model for Fixed-Azimuth Antennas, ECAC-TN-85-023, Annapolis, MD: DoD ECAC (now DoD JSC), April 1979.

[1-3] G. Benoit, M. Haberman, S. Leach, *Radar Electromagnetic Compatibility Analysis Program (RECAP)*, ECAC-TN-92-003, Annapolis, MD: DoD ECAC (now DoD JSC), February 1992.

interference at the antenna terminals, ΔPH, and maximum tolerable power density, PD_1, were determined. I was compared to ΔPH, and PD was compared to PD_1, to determine the potential for EMI.

Required frequency and distance separation to preclude EMI was determined for cases where EMI was predicted.

SECTION 2 – SYSTEM DESCRIPTION

The Predator data link provides command and control, payload data, and status information. The command and control information is provided from the ground control station (GCS) to the UAV using the CL. The payload data and status information is provided from the UAV to the GCS using the RL. The transmitter and receiver units can be software configured to perform CL or RL functions. The Predator data link utilizes two CLs and two RLs. The data link system uses 16-bit messages (15 information bits plus one parity bit).

The installed CL-configured terminals can transfer randomized 15-bit no return to zero data at 19.2 kilobits per second (kbps) and 200 kbps using frequency shift keyed (FSK) modulation. The installed RL-configured terminals can transfer either National Television System Committee (NTSC) formatted video, with a data subcarrier at 6.8 MHz or 7.5 MHz offset, or FSK data without the subcarriers at 3.2 Megabits per second (Mbps).

The TCDL CL transmitter utilizes binary phase shift keying (BPSK) in both clear and direct sequence spread spectrum modes. The data rate for both modulations is 200 kbps.

The TCDL RL transmitter utilizes offset-quadrature phase shift keying (O-QPSK). The data rate planned for the Predator UAV will be 10.71 Mbps.

The GCS contains computers, voice communications equipment, displays, user interfaces, and accommodations for a pilot and payload operator. The GCS is connected to the GDT that includes an antenna system, a diplexer that permits full-duplex operation, and a custom-built low noise amplifier (LNA). The LNA is used to reduce the impact of the long radio frequency (RF) cable runs on the system noise figure. The Predator System data link RF configuration is shown in Figure 2-1. The TCDL RF configuration is shown in Figure 2-2.

The dual Predator UAV data link system contains transmitters, receivers, diplexer, and a shared computer. The diplexer permits full-duplex operation. The computer performs parity checks to validate message data, select the optimum command link, and discard erroneous messages.

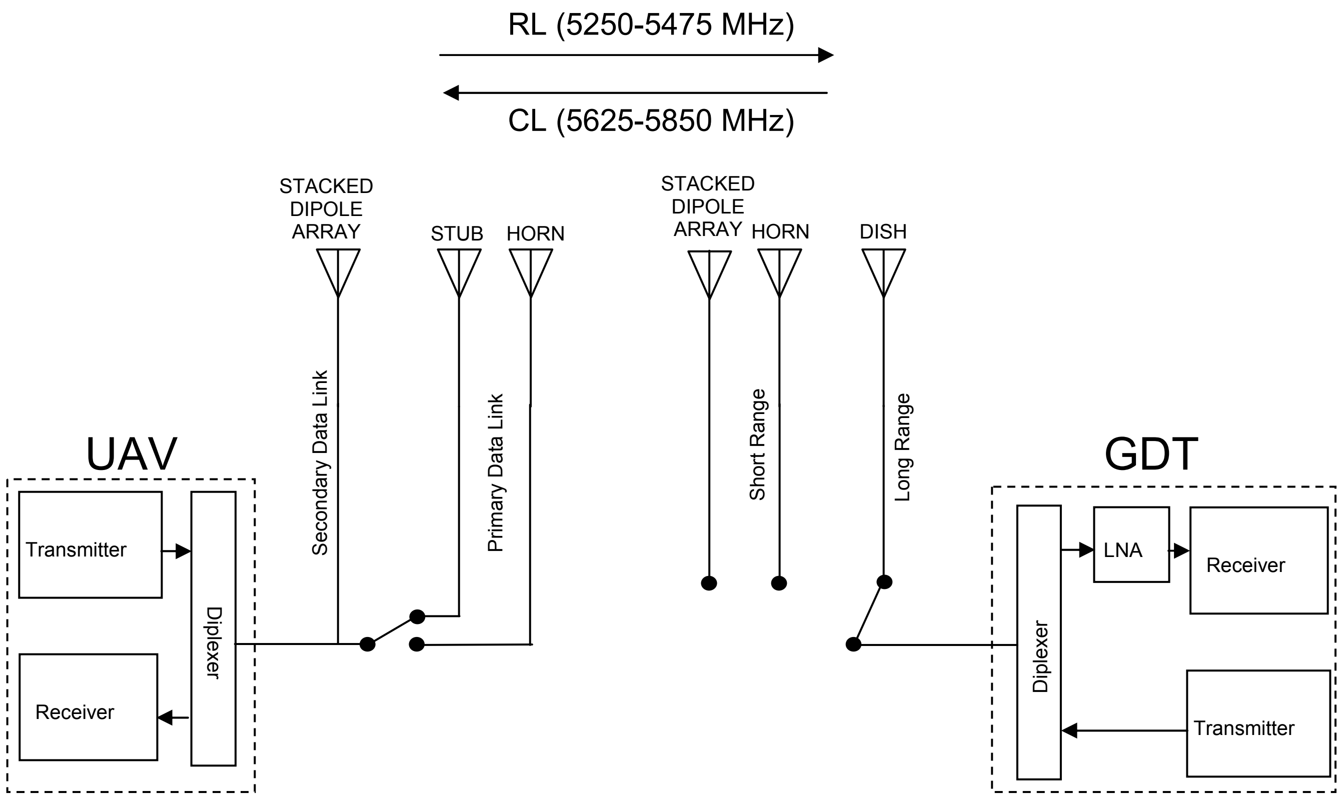

Figure 2-1. Predator System Data Link RF Configuration

The data link component RF characteristics are listed in Table 2-1 for current terminals, and Table 2-2 for TCDL terminals.[2-1]

[2-1] *Application for Equipment Frequency Allocation (DD Form 1494) for Predator C-Band MAE UAV Medium Altitude Endurance Unmanned Aerial Vehicle*, J/F-12/7253, Washington, DC: MCEB, 9 April 2003.

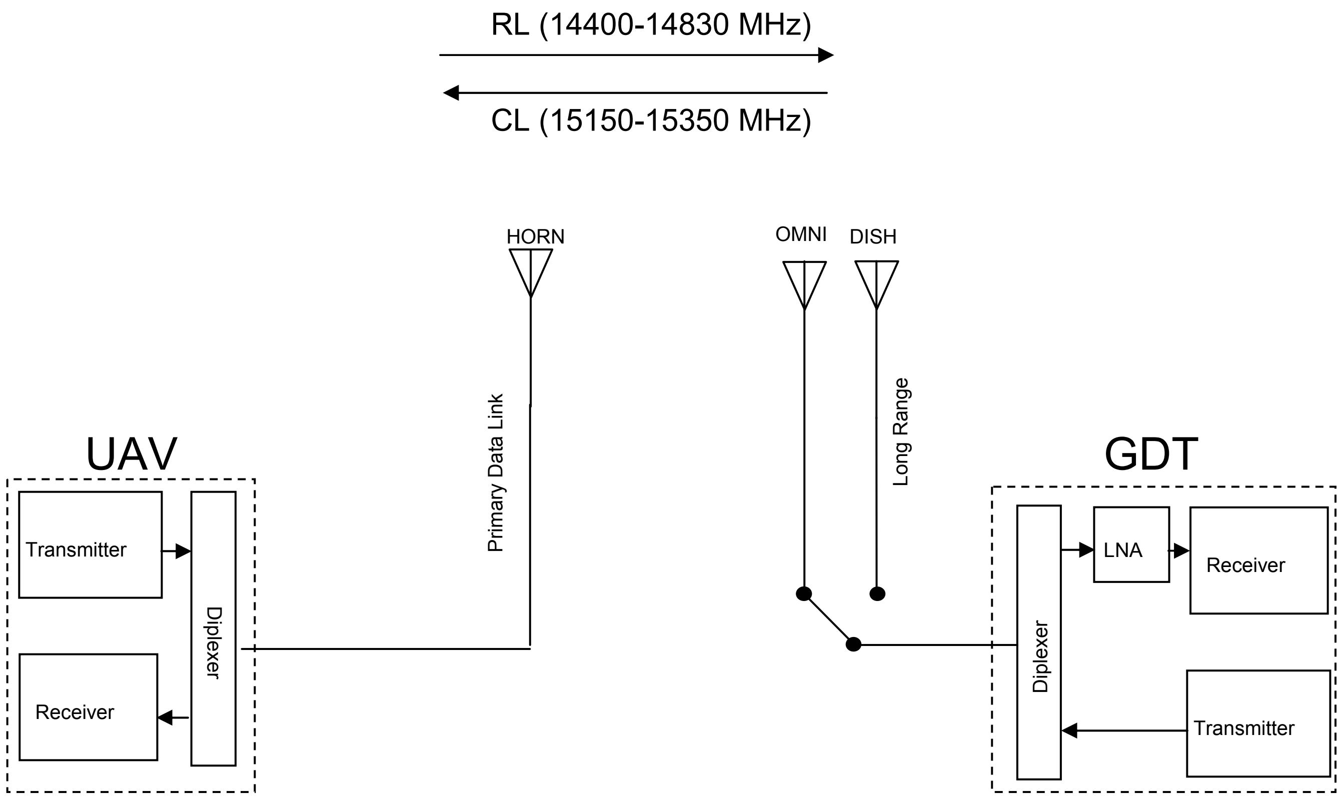

Figure 2-2. TCDL RF Configuration

The Predator data link component RF characteristics are listed in Table 2-1 (Reference 2-1). The TCDL data link component RF characteristics are listed in Table 2-2.[2-2]

[2-2] *Application for Equipment Frequency Allocation (DD Form 1494) for L3 Communications Tactical Common Data Link (TDCL)*, J/F 12/7834/1, Washington, DC: MCEB, 18 February 1999.

Table 2-1. Predator Data Link Technical Characteristics

Characteristic	Specifications			
Transmitter				
Tuning Range, MHz	5250-5850			
Alternate Tuning Ranges in Consideration, MHz	4400-4940, 14400-14830 (RL only),and 15150-15350 (CL only)			
Tuning Increment, MHz	1			
Transmitter Power, dBm	40			
Spurious/Harmonic Attenuation, dB	65			
Link Type	CL		RL	
Emission Designators	560KF1D	88K3F1D	17M0F9F	4M72F1D
Emission Bandwidth, MHz				
-3 dB	0.34	0.063	8.5	2.8
-20 dB	0.42	0.088	18.0	20.0
-40 dB	NAvail	0.219	NAvail	NAvail
-60 dB	1.2	0.671	46.2	66.0
Receiver				
Tuning Range, MHz	5250-5850			
Alternate Tuning Range in Consideration, MHz	4400-4940, 14400-14830 (RL only), and 15150-15350 (CL only)			
RF Selectivity, MHz				
-3 dB	303			
-20 dB	375			
-60 dB	525			
1st IF Selectivity, MHz				
-3 dB	35			
-20 dB	55			
-60 dB	115			
Link Type	CL		RL	
2nd IF Selectivity, MHz				
-3 dB	1		20	
-20 dB	3.2		22.5	
-60 dB	4		28	
Sensitivity, dBm	-98	-98	-84	-86
Sensitivity Criterion	1×10^{-6} BER[a]	1×10^{-6} BER[a]	23-dB S/N[b]	1×10^{-6} BER[a]
Noise Figure, dB	2			
Spurious Rejection, dB	50			
Diplexer				
Low-Band Port Frequency Band, MHz	5250-5475			
Cross-Over Frequency Band, MHz	5475-5625			
High-Band Port Frequency Band, MHz	5625-5850			
GDT LNA				
Manufacturer	JCA Technologies			
Gain, dB	18			
Noise Figure, dB	1.8			

[a] Bit Error Rate (BER)
[b] Signal-to-Noise Ratio (S/N)
NAvail – not available

Table 2-2. TCDL Technical Characteristics

Characteristic	Specifications			
Transmitter				
Tuning Range, GHz	14.4-14.83 (RL) and 15.15-15.35 (CL)			
Tuning Increment, MHz	5			
Transmitter Power, dBm	33			
Spurious/Harmonic Attenuation, dB	65			
Link Type	RL and CL			
Emission Designators	800KG1D	64M0G1D	8M00G1D	21M4G1D
Emission Bandwidth, MHz				
-3 dB	0.354	28	3.5	9.4
-20 dB	2.1	101	21.4	57.4
-40 dB	NAvail	274	NAvail	NAvail
-60 dB	108	90	181	219
Receiver				
Tuning Range, GHz	14..4-14.83 (RL) and 15.15-15.35 (CL)			
Link Type	RL		CL	
RF Selectivity, MHz				
-3 dB	430		200	
-20 dB	500		410	
-60 dB	750		560	
Link Type	RL and CL			
1st IF Selectivity, MHz				
-3 dB	200			
-20 dB	450			
-60 dB	1500			
Link Type	RL and CL			
2nd IF Selectivity, MHz				
-3 dB	90			
-20 dB	300			
-60 dB	850			
Sensitivity, dBm (RL)	-99.4	-92.1	-85.9	-109.4
Sensitivity, dBm (CL)	-99.2	-91.9	-85.7	-109.2
Sensitivity Criterion	$1X10^{-8}$ BER			
Noise Figure, dB (RL)	3.7			
Noise Figure, dB (CL)	3.9			
Spurious Rejection, dB	85			

SECTION 3 – ANALYSIS OVERVIEW

Due to the large number of systems in the environment (7000 records), calculations of the potential for interference with Predator data link terminals were based on successively more rigorous levels of analysis in order to reduce the number of systems analyzed at each level.

For the Level One and Level Two analysis, the undesired power level at the input to the receiver was calculated for each receiver considering the frequency dependent rejection (FDR) provided by the IF filter. The TIREM model was utilized to calculate propagation loss. For ground-to-ground interactions, the TIREM model calculated the distance between the systems under analysis based on the longitude and latitude and used this distance in the propagation loss calculations. For air-to-ground and ground-to-air interactions, a slant range distance of 29.4 km was calculated based on the typical Predator UAV altitude of 7620 m and the edge of the mainbeam being 15 degrees below the horizon. This slant distance was then used in calculating the propagation loss by the TIREM model. The STATGN model was utilized to estimate off-axis antenna gain. When not defined, the gain of the data link terminal transmitter antenna in the direction of the receiver antenna, and the gain of the receiver antenna in the direction of the data link terminal, were calculated using the assumption that 90 percent of the time the antenna mainbeams would be off-axis to each other by more than 18 degrees. The noise power in the receiver -3 dB IF bandwidth was calculated. The calculated I/N was then compared to the appropriate $(I/N)_T$ to determine the potential for EMI. For the Level One analysis, a generic I/N within the receiver IF-amplifier (or filter) -3 dB bandwidth was used. For the Level Two analysis, I/N thresholds applicable to the specific type of receiver under analysis were used.

The Level Three analysis applied specific performance criteria for each type of environmental receiver which included antenna coupling scenarios and receiver signal processing. For each system examined in the Level Three analysis, a degradation threshold related to the C-E system function was used.

The potential for interference between the Predator UAV data link and in-band/adjacent-band systems was determined by first calculating I/N within the IF amplifier bandwidth. I/N was calculated as:

$$I/N = P_T + G_T + G_R - L_P - N - L_S - PFDR - L_{PR} - L_{mm} - H_{Att} \tag{3-1}$$

where I/N = interference-to-noise ratio, in dB

P_T = interfering transmitter peak power, in dBm

G_T = gain of the transmitting antenna in the direction of the receiving antenna, in dBi

G_R = gain of the receiving antenna in the direction of the transmitting antenna, in dBi
L_P = terrain propagation loss between the transmitting antenna and the receiving antenna, in dB
N = noise power in the receiver IF bandwidth, in dBm
L_S = total (transmitter and receiver) system losses for the undesired path, in dB
PFDR = peak frequency dependent rejection, in dB
L_{PR} = receiver processing loss, (used only in the Level Three analysis), in dB
L_{mm} = antenna mismatch loss, in dB
H_{Att} = harmonic attenuation (used only in the sub-harmonic and harmonic frequencies), in dB

In Equation 3-1, PFDR is defined as the peak-power-input-to-peak-power-output ratio. FDR is the average-power-input-to-average-power-output ratio. For the majority of the analyses conducted for the Predator UAV data link, the peak power at the output of the receiver IF filter was calculated.

When calculating for average power, FDR may be substituted into Equation 3-1. Whenever FDR is substituted, P_T is average power. In this report, PFDR was used in Equation 3-1 unless noted otherwise.

The noise power (N) was calculated as follows:

$$N = -114 + 10 \text{ Log } (B_{IF}) + NF \tag{3-2}$$

where N = receiver noise power, in dBm
B_{IF} = -3 dB bandwidth of the IF amplifier/filter, in MHz
NF = receiver noise figure, in dB

3.1 LEVEL ONE ANALYSIS

The peak I/N was calculated within the IF amplifier (or filter) bandwidth. For this analysis, the maximum power of 40 dBm for the Predator UAV data link was applied. The propagation loss term was calculated using the TIREM model. TIREM calculates propagation loss by considering the effects of irregular terrain along the propagation path. TIREM also considers the effects of free-space spreading, earth-reflected wave propagation, surface-wave propagation, diffraction, and atmospheric absorption, but does not consider man-made obstructions or foliage. Fifteen-second digital terrain elevation data were used for this analysis. The receiving antenna gain in the direction of the Predator

UAV data link was calculated based on a statistical gain model. To determine the on-tune-rejection for PFDR used in the Level One analysis (see Equation 3-1), the frequency dependent rejection calculation (FDRCAL) program[3-1] was used. The antenna mismatch loss (L_{mm}) was assumed to be 0 dB for all systems in the environment. The total system losses (L_S) were assumed to be 3 dB. For land mobile systems in the environment, the radius of mobility, unless specified, was assumed to be 16 km. For the Level One analysis, the -3 dB IF bandwidth was calculated as follows:

$$B_{IF} = \frac{B_N}{2x10^{\frac{17}{40}}} \tag{3-3}$$

where B_N = necessary bandwidth as denoted in the emission designator

The necessary bandwidth of the C-E system is denoted in the emission designator. The calculated -3 dB IF bandwidth was then used to estimate the bandwidth levels by assuming a 40 dB/decade slope for the receiver and a 20 dB/decade slope for the transmitter. The noise figure for all the systems was assumed to be 5 dB. The calculated peak I/N was compared to a degradation threshold of -9 dB.[3-2] For those systems exceeding the -9 dB I/N threshold, a Level Two analysis was performed.

3.2 LEVEL TWO ANALYSIS

The Level Two analysis applied specific I/N degradation thresholds based on the type of C-E systems remaining in the environment. Five main system types remained in the EME: radar systems (fixed and mobile), terrestrial microwave links, satellite downlink systems, telemetry systems, and RA telescopes.

A peak I/N threshold of -6 dB was established for all radar systems in this analysis. The analysis assumed all radar systems had either narrowband receiver/processors (e.g., pulse-Doppler processing), or adaptive constant false alarm rates. This threshold is equivalent to a 1 dB increase in the system noise level, or approximately a 5% decrease in detection range. For terrestrial microwave links operating in the environment, a peak I/N of 0 dB was established as a threshold for this analysis.[3-3] Due to satellite

[3-1] Kenneth Clubb, et al., *Technology Transfer Programs for IBM-Compatible Personal Computers: User's Manual*, ECAC-UM-87-045, Annapolis, MD: ECAC (now DoD JSC), September 1987, Includes Change 1, September 1988.

[3-2] M. Coleman-Ragland, L. McIntyre, et al., *EMC Analysis Handbook*, JSC-CR-97-010, Annapolis, MD: DoD Joint Spectrum Center, March 1997.

[3-3] T. Keech, M. O'Hehir, and T. Hensler, *$JSMS_W$ Interference Analysis Algorithms*, JSC-CR-96-016B, Annapolis, MD: DoD Joint Spectrum Center, April 1998.

downlinks typically operating at marginal signal-to-noise levels, the peak I/N threshold used in the Level One analysis could not be further relaxed and any systems remaining after the Level One analysis were addressed in the Level Two analysis. In addition to the -9 dB I/N threshold, the C-E systems operating in the adjacent 5% above or below the Predator UAV data link bands were identified and the PFDRs were recalculated to account for off-tuned rejection due to frequency separation between the environmental systems and the Predator UAV data link. For single dish radio telescope antennas, the equations used to establish threshold levels for interference considered harmful to radio astronomy observations are specified in Report 224-7 of the International Radio Consultative Committee (CCIR).[3-4] The thresholds specified in this report are explained in more detail in Section 3.3.5.

3.3 LEVEL THREE ANALYSIS

For those systems that exceeded the I/N thresholds established in Level One and Level Two analyses, a more detailed analysis (Level Three) was conducted. The Level Three analysis applied specific performance criteria for each type of environmental receiver including antenna coupling scenarios and receiver signal processing. The appropriate EMI analysis was performed based on the types of C-E systems found in the environment.

3.3.1 Radar Systems

Calculation of the potential for interference between the Predator UAV data link and in-band/adjacent-band radar systems was based on the I/N within the IF amplifier (or filter) -3 dB bandwidth. Equation 3-1 was used to calculate the peak I/N. The PFDR and required separation distances (based on the great circle path and relative effective antenna heights) were calculated using the JSC RECAP model. The statistical antenna gain values were calculated using the STATGN program. Propagation loss was calculated using TIREM.

3.3.2 Terrestrial Microwave Links

The potential for interference from the Predator UAV data link to in-band/adjacent-band terrestrial microwave links was analyzed by calculating the C/N of the existing link design. The C/N was calculated as:

[3-4] *Interference Protection Criteria for the Radio Astronomy Service*, CCIR Report 224-7, Geneva: CCIR, 1990, Volume 2 (annex), pages 556-567.

$$C/N = EIRP - L_{PF} + G_R - N - OFR \tag{3-4}$$

where C/N = carrier-to-noise power ratio, in dB
EIRP = effective isotropic radiated power, in dBm
L_{PF} = free-space propagation loss between the transmitting antenna and the receiving antenna, in dB
OFR = Additional isolation provided by frequency separation from the adjacent-band, in dB

and all other terms are as defined previously.

Free-space propagation loss (L_{PF}) was calculated as:

$$L_{PF} = 20\ \mathrm{Log}(F) + 20\ \mathrm{Log}(D) + 32.45 \tag{3-5}$$

where F = transmit frequency of the carrier, in MHz
D = link distance, in km

and all other terms are as defined previously.

The noise power (N) was calculated as:

$$N = 10\ \mathrm{Log}(kT_S B_{IF}) + 90 \tag{3-6}$$

where N = noise power, in dBm
T_S = system noise temperature (290 K)
k = Boltzmann's constant (1.38×10^{-23} J/K)

and all other terms are as defined previously.

The calculated C/N was compared to the performance threshold $(C/N)_T$ to determine the allowable fade margin. The maximum allowable fade margin of the existing link was determined by:

$$FM1 = C/N - (C/N)_T \tag{3-7}$$

where FM1 = maximum allowable fade margin of existing link without interference, in dB

and all other terms are as defined previously.

The climatic and geographic condition around ISAFAF is comparable to a Type A link. Type A links have paths where the formation of tropospheric layers and calm weather are rare resulting in limited link fading. As a consequence Type A paths require less link margin to protect against fading. The availability for the existing link design was calculated on the basis of Type A fading.[3-5] The availability of a Type A path when the Predator UAV data link is not transmitting, was determined by:

$$\text{Type A:} \quad A = 1 - (16 \times 10^{-7} FD^2 \times 10^{-FM1/10}) \tag{3-8}$$

where A = availability, unitless

and all other terms are as defined previously.

To assess the effect of interference from the Predator data link, the peak carrier-to-interference-plus-noise ratio [C/(I+N)] was calculated as:

$$C/(I+N) = C - 10 \text{ Log}(10^{I/10} + kT_S B_{IF}) \tag{3-9}$$

$$I = P_T + G_T + G_{R2} - L_P - L_S - PFDR \tag{3-10}$$

where C = carrier power, in dB

C/(I+N) = peak carrier-to-interference-plus-noise power ratio, in dB

G_{R2} = receiver antenna gain in the direction of the interfering transmitting antenna, in dBi

and all other terms are as defined previously.

[3-5] Roger L Freeman, *Radio System Design for Telecommunications*, New York, NY: John Wiley & Sons, Inc, 1987.

The G_{R2} term in Equation 3-10 was calculated using a statistical gain model based on receiver antenna directionality. The terrain propagation loss was calculated using TIREM for the GDT-to-terrestrial microwave links and terrestrial microwave links-to-GDT interactions. For the UAV-to-terrestrial microwave links and the terrestrial microwave links-to-UAV interactions, the free space loss was calculated using Equation 3-5. The PFDR term was calculated using FDRCAL.

To assess the effect of interference on the existing link, the C/(I+N) was compared to the $(C/N)_T$ to determine the allowable fade depth. The fade margin for the links with interference present was calculated as:

$$FM2 = C/(I+N) - (C/N)_T \tag{3-11}$$

where FM2 = maximum allowable fade margin of existing link with interference present, in dB

and all other terms are as defined previously.

The availability in the presence of interference from the Predator data link was then calculated. The availability was based on the percentage of time that the Predator data link would be transmitting annually at a given location. The availability for a Type A path was calculated as:

$$\text{Type A: } A = 1 - [(16 \times 10^{-7} FD^2 \times 10^{-FM1/10} \times P_{NI}) + (16 \times 10^{-7} FD^2 \times 10^{-FM2/10} \times P_I)] \tag{3-12}$$

where P_{NI} = ratio of time that Predator data link is not transmitting per year, unitless

P_I = ratio of time that Predator data link is transmitting per year, unitless

and all other terms are as defined previously.

For the FAA safety-of-life systems in the environment, the availability was calculated assuming that the Predator UAV transmitted continually throughout the year (24 hours/day, 7 days/week, and 52 weeks/year).

For FAA safety-of-life links, the minimum availability required in the presence of interference was 0.99999.[3-6] For FCC licensed microwave links, where the required availability of the link was not known, the minimum availability in the presence of interference was 0.99999.[3-7] For those systems in the environment that did not have an availability of 0.99999 in the desired link (without interference from the Predator UAV), a threshold of 0.99975 was used.[3-8]

In the scenario where Predator UAV data link was the source of interference to the microwave links, the availability criteria was used, however, the S/I criteria was used for the scenario where microwave link was the source of interference to the Predator data link. The potential for interference from the terrestrial microwave links to the Predator UAV data link was analyzed by first calculating S/I. S/I was calculated as:

$$S/I = ERP - L_{PF} + G_R - I \tag{3-13}$$

$$I = P_{TI} + G_{TI} + G_{R2} - L_P - L_S - PFDR \tag{3-14}$$

where S/I = signal-to-interference ratio, in dB

ERP = effective radiated power of the transmitter antenna, in dBm

P_{TI} = interferer transmitter power

G_{TI} = interferer transmitter gain

and all other terms are as defined previously.

The calculated S/I was compared to the degradation threshold to evaluate system performance. For the Level Three analysis, the Predator UAV data link receiver S/I threshold was 12 dB.[3-9]

When EMI was predicted for fixed microwave receivers, the minimum required C/(I+N) to achieve 0.99975 link availability was determined. The required FDR was determined by calculating the

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[3-6] T. Blakely, Contact report: Visit to Air Force Frequency Management Agency, Alexandria, VA, Subject: *CLOVerS*, Annapolis, MD: JSC, 18 April 2002.

[3-7] *Interference Criteria for Microwave Systems*, TIA/EIA Telecommunications Systems Bulletin, TSB10-F, Washington DC: Telecommunications Industry Association, June 1994.

[3-8] *DCS Digital Line of Sight Link Design*, Engineering Publication 1-90, Reston VA: Defense Communications Engineering Center, April 1990.

[3-9] R. H. Haines, *An EMC Analysis of the GPS Ground Antenna and Monitor Station at Kwajalein Island*, ECAC-CR-82-113, Annapolis, MD: DoD ECAC (now DoD Joint Spectrum Center), March 1983.

difference between $C/(I+N)_T$ and C/(I+N). From the required FDR, the minimum frequency separation was then determined by using the FDRCAL program.

3.3.3 Satellite Downlink Systems

All satellite downlink systems were culled out in the Level Two analysis.

3.3.4 Telemetry Systems

The potential for interference from the Predator data link to in-band/adjacent-band telemetry systems was analyzed by first calculating the S/I, using Equation 3-13.

The value of P_I was taken from Tables 2-1 and 2-2. The mainbeam gain of the receiver antenna was used for G_R. The G_{R2} term was calculated using the STATGN model based on receiver antenna directionality. The free-space propagation loss was calculated using Equation 3-5. The terrain propagation loss was calculated using TIREM.

The calculated S/I was compared to the degradation threshold to evaluate system performance. For the Level Three analysis, the S/I threshold was 12 dB (see Reference 3-9).

3.3.5 Radio Astronomy Telescopes

The interference from the Predator UAV data link to single-dish RA telescopes in the environment was assessed using the equations specified in Report 224-7 CCIR (Reference 3-4). From Reference 3-4, the receiver sensitivity can be expressed as:

$$\Delta T = \frac{T_S}{\sqrt{2\Delta f t}}$$

(3-15)

where ΔT = smallest detectable change in equivalent temperature of the output terminal of the antenna, in K

Δf = noise bandwidth, in Hz

t = integration time, in sec

and all other terms are as defined previously.

The smallest power level change at the radiometer input which can be detected and measured by the radiometer is ΔP. The sensitivity equation can be used to relate ΔP to the total system sensitivity (noise fluctuations) expressed in temperature units through the Boltzmann constant (k) as:

$$\Delta P = k\Delta T_S \tag{3-16}$$

Assuming an introduced error of 10% in the measurement of ΔP, the power level of maximum tolerable interference, ΔP_H, at the antenna terminals is as follows:

$$\Delta P_H = 0.1\Delta P\Delta f \tag{3-17}$$

where all terms have been defined previously.

The CCIR also identifies calculations for interference expressed in terms of power flux-density incident at the antenna. For convenience, the equation is given for an antenna having a gain, in the direction of arrival of the interference, equal to that of an isotropic antenna:

$$PD_I = 10\text{Log}(\Delta P_H) + 20\text{Log}(F) - 38.6 \tag{3-18}$$

where PD_I = maximum tolerable power density (average power density), in dBW/m^2

Since the CCIR identifies calculations for both power flux-density and received power at the radio telescopes, the interference from the Predator data link was assessed by calculating both. However, the received power levels at the telescopes (P_R) are more indicative of the estimated degradation of the telescopes.

To evaluate the effects of the Predator data link signal on the RA telescopes in the environment, the interference power levels (peak and average) at the radio astronomy telescopes were calculated as follows:

$$P_R = P_T + G_T - PFDR - L_P - L_S - L_{PR} - L_B - 30 \tag{3-19}$$

where P_R = received power at the RA telescope, in dBW

L_B = attenuation due to building blockage, as appropriate, in dB

For the Predator data link radiating toward the RA telescopes, the expected power density levels incident on the RA telescopes were calculated as follows:

$$PD = P_T + G_T - P_{BW} - L_p + 20\ \mathrm{Log}(F) - 68.5 \qquad (3\text{-}20)$$

where PD = average power density, in dBW/m^2

P_{BW} = attenuation for the transmitter power of the Predator data link in the RA telescope bandwidth, in dB

and all other terms are as defined previously.

SECTION 4 – RESULTS AND RECOMMENDATIONS

The in-band/adjacent-band environment within the geographic area defined by corners at 35°N 114°W, 35°N 118°W, 39°N 114°W and 39°N 118°W contained 7000 records within the Predator data link frequency bands. For those systems not culled out in the Level One and Level Two analyses, a Level Three analysis was performed. Table 4-1 shows the number of systems per database analyzed in each level.

Table 4-1. Analysis Levels for Records in the Environment at ISAFAF

Band MHz	Database	Level One Analysis (# of systems)	Level Two Analysis (# of systems)	Level Three Analysis (# of systems)
4400-4940	FRRS	878	256	182
	GMF	237	115	71
	FCC	2887	443	172
	RA	21	21	21
	NASA	10	10	10
	Total	4033	845	456
5250-5850	FRRS	742	338	111
	GMF	148	93	53
	FCC	952	599	455
	RA	22	22	22
	NASA	6	6	6
	Total	1870	1058	647
14400-14830	FRRS	203	111	60
	GMF	115	54	24
	FCC	196	31	0
	RA	21	21	21
	NASA	1	1	1
	Total	536	218	106
15150-15350	FRRS	202	79	20
	GMF	112	55	0
	FCC	233	74	0
	RA	14	14	14
	Total	561	222	34

The five main system types are: radar systems (fixed and mobile), terrestrial microwave links, telemetry systems, satellite downlink systems, and RA telescopes.

4.1 RADAR SYSTEMS

There were 96 interactions involving radar systems in the environment near ISAFAF that required a Level Three analysis. These systems and their functions are listed in Tables 4-2 through 4-6. TACAN was considered as a radar because it utilizes a pulse waveform.

Table 4-2. Environmental Radar Systems Interfering with GDT RL Requiring Level Three Analysis

System Name	Latitude (DMS)	Longitude (DMS)	Distance to GDT (km)	Frequency (MHz)	Function
AN/FPS-20	363512N	1154024W	31.1	1331	Surveillance
AN/FRN-45	363512N	1154024W	0.3	1174	TACAN
AN/GPN-20	363512N	1154024W	1.3	2780 & 2860	Airport Surveillance
AN/GRN-19A	363512N	1154024W	0.3	1154	TACAN
DMS – Degrees, minutes, seconds					

Table 4-3. Environmental Radar Systems Interfering with the Predator UAV CL Requiring Level Three Analysis

System Name	Latitude (DMS)	Longitude (DMS)	Distance to Predator UAV (km)	Frequency (MHz)	Function
AN/APN-194	353958N	1173550W	29.4	4300	Airborne Radar/Navigation
AN/FPS-105	354100N	1174100W	29.4	5690	Fixed Radar/Detecting
AN/FPS-16	374800N	1162800W	29.4	5800	Fixed Radar/Detecting
AN/FPS-20	361907N	1153433W	29.4	1335	Surveillance
AN/FPS-20	361907N	1153433W	29.4	1331	Surveillance
AN/FPS-6	374200N	1163000W	29.4	2715	Height Finder
AN/FPS-6	374200N	1163000W	29.4	2735	Height Finder
AN/FPS-67B	350456N	1173456W	29.4	1329	Surveillance
AN/FPS-67B	350456N	1173453W	29.4	1320	Surveillance
AN/FRN-45	374726N	1164642W	29.4	1164	TACAN
AN/FRN-45	381857N	1161702W	29.4	1173	TACAN
AN/GPN-20	363450N	1154107W	29.4	2780 & 2860	Airport Surveillance
AN/MPQ-4B	352158N	1163713W	29.4	15840-16160	Mortar Locating
AN/MPS-25	374400N	1164300W	29.4	5657	Ground Mobile Radar
AN/MPS-26	354100N	1174100W	29.4	5820	Ground Mobile Radar
AN/PPS-5	352158N	1163713W	29.4	16000-16500	Surveillance
AN/TPN-24	363515N	1154020W	29.4	2875	Airport Surveillance
AN/TPQ-45	352158N	1163713W	29.4	14860	Simulator
AN/TPQ-45	352158N	1163713W	29.4	15000	Simulator
AN/TPQ-45	352158N	1163713W	29.4	14900	Simulator
AN/TPS-75	373740N	1164534W	29.4	2910-3100	Surveillance
ASDE-3	360458N	1150848W	29.4	15700-16200	Airport Surveillance
ASR-8	360203N	1171611W	29.4	2865	Airport Surveillance
ASR-8	360203N	1171611W	29.4	2735	Airport Surveillance

Table 4-3. Environmental Radar Systems Interfering with the Predator UAV CL Requiring Level Three Analysis (Continued)

System Name	Latitude (DMS)	Longitude (DMS)	Distance to Predator UAV (km)	Frequency (MHz)	Function
ASR-8	354813N	1172042W	29.4	2710	Airport Surveillance
ASR-8	350337N	1170052W	29.4	2775	Airport Surveillance
ASR-8	350337N	1170052W	29.4	2895	Airport Surveillance
ASR-9	361346N	1150313W	29.4	2885	Airport Surveillance
ASR-9	361346N	1150313W	29.4	2715	Airport Surveillance
ASR-9	360414N	1150758W	29.4	2730	Airport Surveillance
ASR-9	360414N	1150758W	29.4	2750	Airport Surveillance
MOTFALCONIV	354100N	1174100W	29.4	5480	Radar
MOTSST171C	360400N	1150800W	29.4	5657	Transponder
MOTSST271C	352158N	1163713W	29.4	5590	Transponder
TDWR	361000N	1151000W	29.4	5645	Weather
VEG0302C-14	353958N	1173550W	29.4	5735	Transponder
VEG0302C-14	353958N	1173550W	29.4	5765	Transponder
VEG108K	354100N	1174009W	29.4	15925	Transponder
VEG207C	374700N	1164500W	29.4	5715	Transponder
VEG207C	374700N	1164500W	29.4	5765	Transponder
VEG302C	374800N	1164700W	29.4	5655	Transponder
VEG302C	374800N	1164700W	29.4	5750	Transponder
VEG302C-2	354148N	1173935W	29.4	5630	Transponder
VEG322K	361409N	1150201W	29.4	15725	Transponder
VEG322K	354100N	1174009W	29.4	15725	Transponder
VEG349C-1	374730N	1164530W	29.4	5435	Transponder
VEG366C	353958N	1173550W	29.4	5800	Transponder
VEGA321C	380200N	1171300W	29.4	5620	Transponder
VEGA321C	380200N	1171300W	29.4	5765	Transponder
VEGA616C	380200N	1171300W	29.4	5690	Simulator
VEGA616C	380200N	1171300W	29.4	5490	Simulator
WSR-88D	350552N	1173336W	29.4	2922	Weather
WSR-88D	354204N	1145330W	29.4	2860	Weather

Table 4-4. The Predator UAV RL Interfering with Environmental Radar Systems Requiring Level Three Analysis

System Name	Latitude (DMS)	Longitude (DMS)	Distance to Predator UAV (km)	Frequency (MHz)	Function
AN/APN-194	353958N	1173550W	29.4	4300	Airborne Radar/Navigation
AN/FPS-105	354100N	1174100W	29.4	5690	Fixed Radar/Detecting
AN/FPS-16	374800N	1162800W	29.4	5665	Fixed Radar/Detecting
AN/FPS-16	374800N	1162800W	29.4	5700	Fixed Radar/Detecting
AN/MPS-25	374400N	1164300W	29.4	5400-5900	Ground Mobile Radar
AN/MPS-26	374700N	1164500W	29.4	5715	Ground Mobile Radar
AN/MPS-26	354100N	1174100W	29.4	5820	Ground Mobile Radar
AN/MPS-26	374700N	1164500W	29.4	5765	Ground Mobile Radar
AN/TPQ-45	352158N	1163713W	29.4	13730	Simulator
AN/TPQ-45	352158N	1163713W	29.4	13790	Simulator
AN/TPQ-45	352158N	1163713W	29.4	13850	Simulator
AN/TPQ-45	352158N	1163713W	29.4	14860	Simulator
AN/TPQ-45	352158N	1163713W	29.4	15000	Simulator
AN/TPQ-45	352158N	1163713W	29.4	14900	Simulator
MOTFALCONIV	354100N	1174100W	29.4	5480	Radar
MOTFALCONIV	354100N	1174100W	29.4	5570	Radar
MOTSST171C	360400N	1150800W	29.4	5400-5900	Transponder
MOTSST271C	352158N	1163713W	29.4	5590	Transponder
MRS252-3	353958N	1173550W	29.4	5800	Transponder
MRS252-3	374800N	1162800W	29.4	5800	Transponder
TDWR	361000N	1151000W	29.4	5645	Transponder
VEG0302C-14	353958N	1173550W	29.4	5735	Transponder
VEG0302C-14	353958N	1173550W	29.4	5765	Transponder
VEG302C-2	354148N	1173935W	29.4	5775	Transponder
VEG321C	380200N	1171300W	29.4	5690	Transponder
VEG349C-1	374730N	1164530W	29.4	5555	Transponder
VEG349C-1	374730N	1164530W	29.4	5620	Transponder
VEG349C-1	374730N	1164530W	29.4	5435	Transponder
VEG349C-1	374730N	1164530W	29.4	5690	Transponder
VEG366C	353958N	1173550W	29.4	5600	Transponder
VEG366C	353958N	1173550W	29.4	5675	Transponder
VEG366C	353958N	1173550W	29.4	5650	Transponder
VEG6571	374800N	1164700W	29.4	5655	NAvail
VEG6571	374800N	1164700W	29.4	5750	NAvail
VEGA321C	380200N	1171300W	29.4	5490	Transponder

Table 4-5. Predator UAV TCDL RL Interfering with Environmental Radar Systems Requiring Level Three Analysis

System Name	Latitude (DMS)	Longitude (DMS)	Distance to GDT (km)	Frequency (MHz)	Function
AN/TPQ-45	352158N	1163713W	29.4	14860	Simulator

Table 4-6. Environmental Radar Systems Interfering with Predator UAV TCDL CL Requiring Level Three Analysis

System Name	Latitude (DMS)	Longitude (DMS)	Distance to GDT (km)	Frequency (MHz)	Function
AN/MPQ-4B	352158N	1163713W	29.4	15840-16160	Mortar Locating
VIT545-1	354100N	1174100W	29.4	2901-3100	NAvail
AN/TPS-75	373740N	1164534W	29.4	2910-3100	Surveillance

An I/N threshold of -6 dB (Reference 3-2) was used for the radar systems located near ISAFAF. An I/N analysis for all of the radar systems found in the environment was conducted using Equation 3-1. All of the interactions involving the environmental radar systems interfering with the Predator UAV data link and the interactions involving the Predator UAV data link interfering with the environmental radar systems were below the -6 dB I/N threshold 90% of the time following the Level Three analysis.

4.2 TERRESTRIAL MICROWAVE LINKS

A Level Three analysis for the Predator UAV data link was performed for 36 microwave links as a victim of interference from the data link, and 142 microwave links as a source of interference to the data link operating near ISAFAF. Of the 178 total links analyzed, 25 are transmit and receive links over the same path. The agency numbers for the 153 unique links are annotated in Table 4-7.

A Level Three analysis was also performed for 14 microwave links as a victim of interference from the Predator UAV TCDL. These links are listed in Table 4-8.

For the mobile microwave systems, the maximum authorized radius of mobility was used for the link distance (i.e., DOE 950413 has a link distance of 161 km).

Table 4-7. Terrestrial Microwave Links Requiring Level Three Analysis

Agency Number	Nomenclature	Receiver Latitude (DMS)	Receiver Longitude (DMS)	Transmitter Latitude (DMS)	Transmitter Longitude (DMS)	Frequency (MHz)	Link Distance (km)
AF 865363	TERTCM602	375341N	1143447W	372732N	1142800W	4588.50	49.5
AF 865364	TERTCM602	372732N	1142800W	375341N	1143447W	4752.50	49.5
AR 921837	TERTCM602	361420N	1150215W	361420N	1150215W	4745.00	80.0
DOE 010302	TERTCM602C	360408N	1150830W	360408N	1150830W	4587.50	161.0
DOE 680741	COLMW908D	365605N	1160313W	365605N	1160313W	14420.00	64.0
DOE 680742	COLMW908D	365605N	1160313W	365605N	1160313W	14820.00	64.0
DOE 702045	COLMW908D	365605N	1160313W	365605N	1160313W	14460.00	64.0
DOE 710447	TERTCM608B	365605N	1160313W	365605N	1160313W	14780.00	NAvail
DOE 950413	TERTCM602C	360408N	1150830W	360408N	1150830W	4490.50	161.0
DOE 950415	TERTCM602C	360408N	1150830W	360408N	1150830W	4590.50	161.0
DOE 950417	TERTCM602C	360408N	1150830W	360408N	1150830W	4651.50	161.0
DOE 950419	TERTCM602C	360408N	1150830W	360408N	1150830W	4751.50	161.0
DOE 960312	TERTCM602C	360408N	1150830W	360408N	1150830W	4437.50	161.0
DOE 960314	TERTCM602C	360408N	1150830W	360408N	1150830W	4637.50	161.0
DOE 960315	TERTCM602C	360408N	1150830W	360408N	1150830W	4737.50	161.0
DOE 960316	TERTCM602C	360408N	1150830W	360408N	1150830W	4487.50	161.0
DOE 960317	TERTCM602C	360408N	1150830W	360408N	1150830W	4931.50	161.0
DOE 960704	COLMW908D	365605N	1160313W	365605N	1160313W	14516.25	48.0
DOE 960705	COLMW908D	365605N	1160313W	365605N	1160313W	14541.25	48.0
DOE 960706	COLMW908D	365605N	1160313W	365605N	1160313W	14581.25	48.0
DOE 960707	COLMW908D	365605N	1160313W	365605N	1160313W	14621.25	48.0
DOE 960708	COLMW908D	365605N	1160313W	365605N	1160313W	14661.25	48.0
DOE 960709	COLMW908D	365605N	1160313W	365605N	1160313W	14688.75	48.0
DOE 960710	TERTCM608B	365605N	1160313W	365605N	1160313W	15156.25	48.0
DOE 960711	TERTCM608B	365605N	1160313W	365605N	1160313W	15181.25	48.0
DOE 960712	TERTCM608B	365605N	1160313W	365605N	1160313W	15226.25	48.0
FAA 851214	TERTCM608	361241N	1151214W	360500N	1150853W	14516.25	15.1
FCC 0805D9	NAvail	350608N	1163245W	350608N	1163245W	4190.00	59.6
FCC 0805DB	NAvail	352609N	1155529W	352609N	1155529W	4190.00	67.5
FCC 0805DC	NAvail	344010N	1165555W	344010N	1165555W	4198.00	59.6
FCC 0805DD	NAvail	352903N	1153313W	352903N	1153313W	4198.00	34.0
FCC 080658	NAvail	353029N	1150731W	353029N	1150731W	4190.00	38.9
FCC 080659	NAvail	352609N	1155529W	352609N	1155529W	4190.00	34.0
FCC 080940	NAvail	355534N	1175447W	361135N	1180031W	5974.80	30.9
FCC 080947	NAvail	345458N	1173126W	352106N	1174024W	6034.20	50.3
FCC 080949	NAvail	345458N	1173126W	352106N	1174024W	5974.80	50.3
FCC 08094A	NAvail	353515N	1180655W	352106N	1174024W	5945.20	47.8
FCC 08094B	NAvail	353515N	1180655W	352106N	1174024W	6004.50	47.8
FCC 08094C	NAvail	353515N	1180655W	352106N	1174024W	6063.80	47.8
FCC 08094D	NAvail	355534N	1175447W	352106N	1174024W	6063.50	67.4
FCC 08094E	NAvail	345458N	1173126W	352106N	1174024W	6063.80	50.3
FCC 080B11	NAvail	350526N	1165622W	345405N	1170202W	5989.70	22.7
FCC 0813E6	NAvail	NAvail	NAvail	NAvail	NAvail	4200.00	NAvail
FCC 08157C	NAvail	350550N	1135341W	350550N	1135341W	4190.00	51.5
FCC 08157D	NAvail	350550N	1135341W	351911N	1142333W	6004.50	51.5
FCC 08157E	NAvail	350550N	1135341W	351911N	1142333W	6063.80	51.5
FCC 08157F	NAvail	350550N	1135341W	351911N	1142333W	6123.10	51.5
FCC 081586	NAvail	353029N	1150731W	353029N	1150731W	4190.00	69.6

Table 4-7. Terrestrial Microwave Links Requiring Level Three Analysis (Continued)

Agency Number	Nomenclature	Receiver Latitude (DMS)	Receiver Longitude (DMS)	Transmitter Latitude (DMS)	Transmitter Longitude (DMS)	Frequency (MHz)	Link Distance (km)
FCC 081587	NAvail	353029N	1150731W	351911N	1142333W	5974.80	69.6
FCC 081588	NAvail	353029N	1150731W	351911N	1142333W	6034.20	69.6
FCC 081589	NAvail	353029N	1150731W	351911N	1142333W	6093.50	69.6
FCC 081591	NAvail	350550N	1135341W	351911N	1142333W	5974.80	51.5
FCC 081592	NAvail	350550N	1135341W	351911N	1142333W	6034.20	51.5
FCC 081593	NAvail	350550N	1135341W	351911N	1142333W	6093.50	51.5
FCC 08159B	NAvail	353029N	1150731W	351911N	1142333W	6004.50	69.6
FCC 08159C	NAvail	353029N	1150731W	351911N	1142333W	6063.80	69.6
FCC 08159D	NAvail	353029N	1150731W	351911N	1142333W	6123.10	69.6
FCC 08159F	NAvail	352903N	1153313W	352903N	1153313W	4198.00	38.9
FCC 0815A3	NAvail	361245N	1155950W	355333N	1152942W	6131.13	57.5
FCC 081FC2	NAvail	350206N	1142212W	351119N	1140308W	6063.80	33.6
FCC 081FC3	NAvail	351119N	1140308W	350639N	1135312W	6049.00	17.4
FCC 0821E3	NAvail	380542N	1171112W	380542N	1171112W	4190.00	39.2
FCC 0821E4	NAvail	380641N	1164422W	380641N	1164422W	4198.00	39.2
FCC 0823FD	NAvail	355722N	1152945W	363940N	1143414W	5945.20	114.1
FCC 0823FE	NAvail	355722N	1152945W	363940N	1143414W	6063.80	114.1
FCC 083755	NAvail	351534N	1164125W	351419N	1164442W	6078.60	5.5
FCC 083756	NAvail	350526N	1165622W	351419N	1164442W	6019.30	24.2
FCC 083DED	NAvail	345923N	1173230W	352106N	1174027W	6004.50	42.0
FCC 083DEE	NAvail	355532N	1175449W	352106N	1174027W	6123.10	67.4
FCC 083F39	NAvail	353515N	1180655W	353650N	1174008W	5989.70	40.5
FCC 083F3A	NAvail	353515N	1180655W	353650N	1174008W	6048.98	40.5
FCC 083F3B	NAvail	353515N	1180655W	353650N	1174008W	6108.30	40.5
FCC 083F3D	NAvail	353515N	1180655W	353650N	1174008W	6137.92	40.5
FCC 084987	NAvail	351456N	1144437W	354206N	1145327W	5974.80	52.1
FCC 08498C	NAvail	354748N	1150021W	354206N	1145327W	6004.50	14.8
FCC 08498E	NAvail	351456N	1144437W	350739N	1143626W	6004.50	18.3
FCC 08498F	NAvail	351456N	1144437W	350739N	1143626W	6123.10	18.3
FCC 0850B8	NAvail	353151N	1150934W	354748N	1150021W	6137.90	32.7
FCC 086A5F	NAvail	373856N	1153713W	372150N	1150953W	5945.20	51.2
FCC 086A60	NAvail	373856N	1153713W	372150N	1150953W	6004.50	51.2
FCC 086B12	NAvail	375543N	1142711W	381429N	1142349W	6004.50	35.1
FCC 086B14	NAvail	390119N	1142355W	381429N	1142349W	6123.10	86.8
FCC 086E44	NAvail	364818N	1140409W	370913N	1135254W	6093.45	42.2
FCC 0875E7	NAvail	353743N	1174006W	352839N	1174201W	6093.45	17.0
FCC 08A5F4	NAvail	351448N	1144439W	345023N	1143624W	5945.20	46.9
FCC 08C94B	NAvail	355328N	1171659W	360132N	1170241W	6093.45	26.1
FCC 08C94C	NAvail	360132N	1170241W	362802N	1165148W	6093.45	51.7
FCC 08E066	NAvail	354237N	1165318W	355327N	1171658W	6108.30	40.8
FCC 08E068	NAvail	352840N	1174200W	355327N	1171658W	6137.90	59.4
FCC 08F893	NAvail	354206N	1145327W	355333N	1152942W	6108.30	58.5
FCC 08F897	NAvail	352609N	1155529W	355333N	1152942W	6019.30	63.9
FCC 08FB1C	NAvail	352609N	1155529W	354559N	1161943W	6108.30	51.8
FCC 08FB81	NAvail	352840N	1174200W	353210N	1180825W	6108.30	40.4
FCC 090034	NAvail	370225N	1160226W	365604N	1160413W	6123.10	12.1
FCC 090035	NAvail	365841N	1160227W	365604N	1160413W	5945.20	5.5

Table 4-7. Terrestrial Microwave Links Requiring Level Three Analysis (Continued)

Agency Number	Nomenclature	Receiver Latitude (DMS)	Receiver Longitude (DMS)	Transmitter Latitude (DMS)	Transmitter Longitude (DMS)	Frequency (MHz)	Link Distance (km)
FCC 090036	NAvail	365841N	1160227W	365604N	1160413W	5945.20	5.5
FCC 090037	NAvail	361907N	1153431W	365604N	1160413W	6093.50	81.5
FCC 090039	NAvail	364126N	1155856W	365604N	1160413W	5945.20	28.2
FCC 09003A	NAvail	371247N	1161925W	365604N	1160413W	6004.50	38.3
FCC 09003C	NAvail	371143N	1160913W	365604N	1160413W	5974.80	29.9
FCC 09003F	NAvail	364534N	1160701W	364558N	1161124W	5974.80	6.5
FCC 090040	NAvail	364126N	1155856W	364558N	1161124W	5945.20	20.3
FCC 090041	NAvail	364818N	1161620W	364558N	1161124W	6034.20	8.5
FCC 091844	NAvail	344946N	1162011W	350614N	1154638W	5945.20	59.4
FCC 091848	NAvail	344841N	1153643W	350614N	1154638W	5974.85	35.8
FCC 091849	NAvail	344946N	1162011W	350614N	1154638W	6004.50	59.4
FCC 0973B4	NAvail	381519N	1154819W	384600N	1152744W	6111.36	64.2
FCC 098275	NAvail	385138N	1175539W	383408N	1180212W	6111.36	33.8
FCC 0995C4	NAvail	350419N	1162226W	345944N	1165018W	6034.15	43.1
FCC 0995C5	NAvail	350419N	1162226W	345944N	1165018W	5945.20	43.1
FCC 0995CF	NAvail	350419N	1162226W	352927N	1153330W	6034.15	87.5
FCC 09A435	NAvail	361907N	1153431W	361205N	1150807W	6123.10	41.5
FCC 09A542	NAvail	351615N	1140151W	350452N	1135416W	5945.20	24.0
FCC 09A543	NAvail	351615N	1140151W	350452N	1135416W	6004.50	24.0
FCC 09A544	NAvail	351615N	1140151W	350452N	1135416W	6123.10	24.0
FCC 09A545	NAvail	351615N	1140151W	350452N	1135416W	6063.80	24.0
FCC 09F730	NAvail	361908N	1153427W	360843N	1150645W	6063.80	45.7
FCC 0A03D0	NAvail	351457N	1144438W	354203N	1145330W	6142.00	52.0
FCC 0AAEEE	NAvail	353743N	1174006W	352839N	1174201W	6004.50	17.0
FCC 0AE9F4	NAvail	351133N	1140313W	350453N	1135417W	6093.45	18.3
FCC 0B164C	NAvail	350418N	1162224W	343839N	1163736W	5974.85	52.9
FCC 0B1664	NAvail	352610N	1155529W	350758N	1161223W	5945.20	42.3
FCC 0B167D	NAvail	345005N	1143703W	351506N	1144454W	6063.80	47.9
FCC 0B167F	NAvail	353029N	1150731W	351506N	1144454W	6004.50	44.5
FCC 0B1681	NAvail	353029N	1150731W	352928N	1153329W	5945.20	39.2
FCC 0B1682	NAvail	352610N	1155529W	352928N	1153329W	6063.80	33.8
FCC 0B22B8	NAvail	360352N	1145554W	361056N	1150759W	6108.89	22.3
FCC 0B2F92	NAvail	383112N	1131711W	381416N	1142256W	5945.20	100.5
FCC 0B2F93	NAvail	390939N	1143652W	381416N	1142256W	6063.80	104.6
FCC 0B3DD0	NAvail	380307N	1171334W	382035N	1175826W	5945.20	72.9
FCC 0B3DD1	NAvail	380129N	1175233W	382035N	1175826W	6004.50	36.4
FCC 0B3DD2	NAvail	380506N	1191014W	382035N	1175826W	6103.33	108.4
FCC 0B4287	NAvail	361908N	1153427W	361054N	1150746W	6034.15	42.7
FCC 0B5928	NAvail	350648N	1135303W	355148N	1140551W	5945.20	85.6
FCC 0B5EEA	NAvail	361920N	1145547W	363330N	1144802W	6116.30	28.7
FCC 0B5EEB	NAvail	364109N	1143114W	363330N	1144802W	6121.86	28.7
FCC 0B5EEC	NAvail	364109N	1143114W	364532N	1140833W	6111.36	34.7
FCC 0B6D46	NAvail	361918N	1145545W	360603N	1150852W	6093.45	31.4
FCC 0B9BCF	NAvail	354351N	1143221W	350539N	1135418W	5974.85	91.2
I 940429	MNIMICRONET-DS3	355946N	1145149W	360056N	1144420W	14521.25	11.4
I 940432	MNIMICRONET-DS3	355849N	1145022W	355946N	1145149W	14671.25	2.8
J 000607	GMEMTF2000ARF	361000N	1150831W	360839N	1151028W	4708.00	3.8
J 000608	GMEMTF2000ARF	361000N	1150831W	360839N	1151028W	4732.00	3.8

Table 4-7. Terrestrial Microwave Links Requiring Level Three Analysis (Continued)

Agency Number	Nomenclature	Receiver Latitude (DMS)	Receiver Longitude (DMS)	Transmitter Latitude (DMS)	Transmitter Longitude (DMS)	Frequency (MHz)	Link Distance (km)
J 000609	GMEMTF2000ARF	361000N	1150831W	360839N	1151028W	4760.00	3.8
J 000610	GMEMTF2000ARF	361000N	1150831W	360839N	1151028W	4784.00	3.8
J 971017	GMEMTF2000ARF	361000N	1150831W	360839N	1151028W	4808.00	3.8
J 971018	GMEMTF2000ARF	361000N	1150831W	360839N	1151028W	4832.00	3.8
J 971019	GMEMTF2000ARF	361000N	1150831W	360839N	1151028W	4860.00	3.8
J 971020	GMEMTF2000ARF	361000N	1150831W	360839N	1151028W	4884.00	3.8
N 774055	AN/TXQ1	354630N	1174639W	354153N	1173726W	4775.00	16.3
N 774056	AN/TXQ1	354312N	1174317W	354630N	1174639W	4800.00	7.9
N 794329	TERTCM608	354100N	1174100W	354100N	1174100W	14780.00	56.0
N 794330	TERTCM608	354100N	1174100W	354100N	1174100W	14860.00	56.0
N 794331	TERTCM608	354100N	1174100W	354100N	1174100W	14950.00	56.0
N 794332	TERTCM608	354100N	1174100W	354100N	1174100W	15050.00	56.0

NAvail – Not available
Agency Codes:
AF – Air Force
AR – Army
DOE – Department of Energy
FAA – Federal Aviation Administration
FCC – Federal Communications Commission
I – Department of the Interior
J – Department of Justice
N – Navy

Table 4-8. Terrestrial Microwave Links Interacting with the Predator UAV TCDL Requiring Level Three Analysis

Agency Number	Nomenclature	Receiver Latitude (DMS)	Receiver Longitude (DMS)	Transmitter Latitude (DMS)	Transmitter Longitude (DMS)	Frequency (MHz)	Link Distance (km)
DOE 680741	COLMW908D	365605N	1160313W	365605N	1160313W	14420.00	64.0
DOE 680742	COLMW908D	365605N	1160313W	365605N	1160313W	14820.00	64.0
DOE 702045	COLMW908D	365605N	1160313W	365605N	1160313W	14460.00	64.0
DOE 710447	TERTCM608B	365605N	1160313W	365605N	1160313W	14780.00	56.0
DOE 960704	COLMW908D	365605N	1160313W	365605N	1160313W	14516.25	48.0
DOE 960705	COLMW908D	365605N	1160313W	365605N	1160313W	14541.25	48.0
DOE 960706	COLMW908D	365605N	1160313W	365605N	1160313W	14581.25	48.0
DOE 960707	COLMW908D	365605N	1160313W	365605N	1160313W	14621.25	48.0
DOE 960708	COLMW908D	365605N	1160313W	365605N	1160313W	14661.25	48.0
DOE 960709	COLMW908D	365605N	1160313W	365605N	1160313W	14688.75	48.0
FAA 851214	TERTCM608	361241N	1151214W	360500N	1150853W	14516.25	15.1
I 940429	MNIMICRONET-DS3	355946N	1145149W	360056N	1144420W	14521.25	11.4
I 940432	MNIMICRONET-DS3	355849N	1145022W	355946N	1145149W	14671.25	2.8
N 794329	TERTCM608	354100N	1174100W	354100N	1174100W	14780.00	56.0

In the Level Three analysis, the location of the antenna, orientation of the antenna, and isolation due to frequency separation were taken into consideration. Due to the location of the ISAFAF, worst-case Type A fade conditions were used.[4-1] The $(C/N)_T$ used was 26.5 dB. For this analysis, the following conditions were assumed: maximum fade, mainbeam antenna coupling, no propagation blockage, and no forward error correction (FEC). The interactions involving the Predator data link and TCDL that remain a problem following the Level Three analysis are presented in Table 4-9. There were no interactions involving the terrestrial microwave links interfering with the Predator data link or the TCDL. The maximum authorized radius of mobility for mobile systems was used for the link distance. This radius of mobility distance represents the worst-case link distance, not the actual operational link distance. Thus, the link availability with and without interference calculated for the mobile systems was worst-case. In actuality, the mobile systems will operate at a distance less than that of the authorized maximum operating link distance. Therefore, the actual desired signal strength and link availability will be greater than the calculated values. Under less than worst-case conditions, it is possible that the greater link availability of the mobile microwave links identified in Table 4-9 will result in no interference from the Predator UAV data link or TCDL.

Table 4-9. Microwave Links That Do Not Meet the Required Availability

Agency Number	Nomenclature	Frequency (MHz)	Latitude (DMS)	Longitude (DMS)	Fixed/ Mobile
DOE 680741	COLMW908D	14420.00	365605N	1160313W	Mobile
DOE 680742	COLMW908D	14820.00	365605N	1160313W	Mobile
DOE 702045	COLMW908D	14460.00	365605N	1160313W	Mobile
DOE 710447	TERTCM608B	14780.00	365605N	1160313W	Mobile
DOE 960704	COLMW908D	14516.25	365605N	1160313W	Mobile
DOE 960705	COLMW908D	14541.25	365605N	1160313W	Mobile
DOE 960706	COLMW908D	14581.25	365605N	1160313W	Mobile
DOE 960707	COLMW908D	14621.25	365605N	1160313W	Mobile
DOE 960708	COLMW908D	14661.25	365605N	1160313W	Mobile
DOE 960709	COLMW908D	14688.75	365605N	1160313W	Mobile
FAA 851214	TERTCM608	14516.25	361241N	1151214W	Mobile
J 000609	GMEMTF2000ARF	4760.00	361000N	1150831W	Fixed
J 000610	GMEMTF2000ARF	4784.00	361000N	1150831W	Fixed
J 971017	GMEMTF2000ARF	4808.00	361000N	1150831W	Fixed
J 971018	GMEMTF2000ARF	4832.00	361000N	1150831W	Fixed
J 971019	GMEMTF2000ARF	4860.00	361000N	1150831W	Fixed
J 971020	GMEMTF2000ARF	4884.00	361000N	1150831W	Fixed

[4-1] H. Brodhage and W. Hormuth, *Planning and Engineering of Radio Relay Links,* 8th ed., London: Siemens-Heyden & Son Ltd., 1978.

4.3 SATELLITE DOWNLINK SYSTEMS

All satellite downlink systems were culled out in the Level One analysis.

4.4 TELEMETRY SYSTEMS

A Level Three analysis was performed for thirty-eight telemetry systems interacting with the Predator UAV data link. In the Level Three analysis, an S/I analysis was conducted for the systems found in the environment, using Equation 3-13. The S/I threshold for the telemetry systems was 12 dB (Reference 3-9). Telemetry receiver reception will be lost for S/I values less than or equal to 12 dB. The S/I criterion was not exceeded with the Predator UAV RL as the source of the interference to C-E systems near the ISAFAF. Table 4-10 lists, by agency number, the systems which have undergone a Level Three analysis. Thirty-four of the thirty-eight systems were analyzed as both an interferer to and a victim of the Predator UAV data link.

Table 4-11 lists Level Three analysis results of the Predator UAV data link as the source of the interference to the telemetry receiving systems. All systems listed in this table have met the 12 dB S/I threshold.

Table 4-12 lists Level Three analysis results of the Predator UAV data link as the victim of the interference and the telemetry systems as the source. All systems listed in this table have met the 12-dB S/I threshold.

Table 4-10. Telemetry Systems Requiring Level Three Analysis

Agency Number	Nomenclature	Latitude (DMS)	Longitude (DMS)	Frequency (MHz)
AF 823471	RHGMTV4.7	373729N	1165157W	4610.00
AF 853492	TERTCM602B	374222N	1162002W	4588.50
AF 853493	TERTCM602B	373841N	1152405W	4752.50
AF 872527	TERTCM602	371705N	1164845W	4780.00
AF 872528	TERTCM602	371705N	1164845W	4420.00
AF 872530	TERTCM602	361910N	1153419W	4880.00
AF 872534	TERTCM602	373945N	1165445W	4880.00
AF 885107	RHGMTV4.7	372304N	1165003W	4610.00
AF 885405	RHGMTV4.7	372304N	1165003W	4730.00
AF 885406	RHGMTV4.7	372157N	1165214W	4520.00
AF 885408	RHGMTV4.7	372157N	1165214W	4403.00
AF 885410	RHGMTV4.7	372157N	1165214W	4460.00
AF 908092	RHGMTV47	372524N	1163409W	4580.00
AF 908094	RHGMTV47	372915N	1163455W	4780.00
AF 908096	TERTCM602	364118N	1153853W	4580.00
AF 908097	TERTCM602	363959N	1153910W	4880.00
AF 908099	RHGMTV47	372546N	1165232W	4535.00
AF 945156	TERTCM602	373945N	1165444W	4580.00
AF 945157	TERTCM602	365116N	1152813W	4690.00
DOE 710447	TERTCM608B	NAvail	NAvail	14780.00
DOE 731908	COLMS508C/D	361907N	1153429W	4662.50
DOE 731910	LLNL ATLAS DIAGNOS	361907N	1153429W	4812.50
DOE 731911	LLNL ATLAS DIAGNOS	361907N	1153429W	4912.50
DOE 731912	LLNL ATLAS DIAGNOS	361230N	1150800W	4412.50
DOE 731913	LLNL ATLAS DIAGNOS	361230N	1150800W	4512.50
DOE 731914	LLNL ATLAS DIAGNOS	361230N	1150800W	4612.50
DOE 731916	COLMS508C/D	365605N	1160313W	4862.50
DOE 731917	COLMS508C	365605N	1160313W	4970.50
DOE 732001	TERTR602	NAvail	NAvail	4487.50
DOE 790623	TERTCM606B	365605N	1160313W	14940.00
DOE 990837	RFT RF 423	361330N	1150100W	4707.50
DOE 990838	RFT RF 423	361330N	1150100W	4857.50
N 840107	AN/DKW-003	354100N	1174100W	4437.50
N 840108	AN/TSW-10	354100N	1174100W	4535.50
N 840109	AN/DKW-001	354100N	1174100W	4540.00
N 840110	AN/TSW-9	354100N	1174100W	4637.50
N 840121	AN/TSW-010	354100N	1174100W	4735.00
N 840122	AN/TSW-9	354100N	1174100W	4740.00

Table 4-11. Analysis Results for Predator Data Link Interfering with the Telemetry Systems

Agency Number	Nomenclature	Frequency (MHz)	I (dBm)	Calculated S/I (dB)
AF 823471	RHGMTV4.7	4610.00	-118	90
AF 853492	TERTCM602B	4588.50	-125	93
AF 853493	TERTCM602B	4752.50	-126	94
AF 872527	TERTCM602	4780.00	-119	106
AF 872528	TERTCM602	4420.00	-119	109
AF 872530	TERTCM602	4880.00	-111	79
AF 872534	TERTCM602	4880.00	-120	89
AF 885107	RHGMTV4.7	4610.00	-115	64
AF 885405	RHGMTV4.7	4730.00	-125	92
AF 885406	RHGMTV4.7	4520.00	-116	81
AF 885408	RHGMTV4.7	4403.00	-116	81
AF 885410	RHGMTV4.7	4460.00	-116	81
AF 908092	RHGMTV47	4580.00	-117	75
AF 908094	RHGMTV47	4780.00	-116	76
AF 908096	TERTCM602	4580.00	-95	78
AF 908097	TERTCM602	4880.00	-104	62
AF 908099	RHGMTV47	4535.00	-114	73
AF 945156	TERTCM602	4580.00	-116	86
AF 945157	TERTCM602	4690.00	-101	78
DOE 710447	TERTCM608B	14780.00	-115	120
DOE 731908	COLMS508C	4662.50	-108	74
DOE 731910	LLNL ATLAS DIAGNOS	4812.50	-110	82
DOE 731911	LLNL ATLAS DIAGNOS	4912.50	-110	82
DOE 731912	LLNL ATLAS DIAGNOS	4412.50	-103	75
DOE 731913	LLNL ATLAS DIAGNOS	4512.50	-103	75
DOE 731914	LLNL ATLAS DIAGNOS	4612.50	-104	75
DOE 731916	COLMS508C	4862.50	-104	70
DOE 731917	COLMS508C	4970.50	-104	70
DOE 732001	TERTR602	4487.50	-108	42
DOE 990837	RFT RF 423	4707.50	-105	30
DOE 990838	RFT RF 423	4857.50	-105	30
N 840107	AN/TSW-10	4437.50	-133	30
N 840108	AN/TSW-10	4535.50	-133	30
N 840109	AN/TSW-10	4540.00	-133	30
N 840110	AN/TSW-9	4637.50	-133	30
N 840121	AN/TSW-9	4735.00	-134	30
N 840122	AN/TSW-9	4740.00	-134	30

Table 4-12. Analysis Results for Telemetry Systems Interfering with the Predator Data Link

Agency Number	Nomenclature	Frequency (MHz)	I (dBm)	Calculated S/I (dB)
AF 823471	RHGMTV4.7	4610.00	-92.08	32
AF 853492	TERTCM602B	4588.50	-93.03	34
AF 853493	TERTCM602B	4752.50	-93.34	35
AF 872527	TERTCM602	4780.00	-92.39	34
AF 872528	TERTCM602	4420.00	-91.71	34
AF 872530	TERTCM602	4880.00	-92.57	46
AF 872534	TERTCM602	4880.00	-92.57	32
AF 885107	RHGMTV4.7	4610.00	-85.57	27
AF 885405	RHGMTV4.7	4730.00	-85.79	27
AF 885406	RHGMTV4.7	4520.00	-85.40	27
AF 885408	RHGMTV4.7	4403.00	-85.17	27
AF 885410	RHGMTV4.7	4460.00	-85.28	27
AF 908092	RHGMTV47	4580.00	-89.02	31
AF 908094	RHGMTV47	4780.00	-92.40	34
AF 908096	TERTCM602	4580.00	-89.01	52
AF 908097	TERTCM602	4880.00	-89.57	54
AF 908099	RHGMLT45AN6	4535.00	-88.94	30
AF 945156	TERTCM602	4580.00	-92.01	32
AF 945157	TERTCM602	4690.00	-92.22	45
DOE 731908	COLMS508C/D	4662.50	-92.67	46
DOE 731910	LLNL ATLAS DIAGNOS	4812.50	-92.94	46
DOE 731911	LLNL ATLAS DIAGNOS	4912.50	-93.12	47
DOE 731912	LLNL ATLAS DIAGNOS	4412.50	-92.19	40
DOE 731913	LLNL ATLAS DIAGNOS	4512.50	-92.39	40
DOE 731914	LLNL ATLAS DIAGNOS	4612.50	-92.58	40
DOE 731916	COLMS508C/D	4862.50	-93.03	42
DOE 731917	COLMS508C/D	4970.50	-93.22	42
DOE 990837	RFT RF 423	4707.50	-82.98	29
DOE 990838	RFT RF 423	4857.50	-83.25	29
N 840107	AN/DKW-003	4437.50	-87.88	26
N 840108	AN/DKW-001	4535.50	-88.07	26
N 840109	AN/DKW-001	4540.00	-88.08	26
N 840110	AN/TSW-010	4637.50	-63.21	13
N 840121	AN/TSW-010	4735.00	-63.39	13
N 840122	AN/TSW-010	4740.00	-63.40	13
DOE 790623	TERTCM606B	14940.00	-103.27	47
NASA963067	NASA DESIGN	14800.00	-93.58	38

4.5 RADIO ASTRONOMY TELESCOPES

Listed in Table 4-13 are the RA telescopes that required a Level Three analysis.

Information for the RA telescope for which EMI is predicted is listed in Tables 4-14A and 4-14B.

Table 4-13. Radio Astronomy Telescopes Requiring Level Three Analysis

System	Frequency (MHz)	Latitude (DMS)	Longitude (DMS)	Location	
				City	State
39.6-m Telescope	4750-5150	371356N	1181737W	Big Pine	CA
39.6-m Telescope	10,695	371356N	1181737W	Big Pine	CA
39.6-m Telescope	19,000-24,000	371356N	1181737W	Big Pine	CA
39.6-m Telescope	42,600-43,400	371356N	1181737W	Big Pine	CA
Two Element Interferometer	1000-18,000	371356N	1181737W	Big Pine	CA
Two Element Interferometer	2400-8200	371356N	1181737W	Big Pine	CA
26-m Telescope	4500-5000	404904N	1212824W	Cassel	CA
26-m Telescope	10,500-11,000	404904N	1212824W	Cassel	CA
6-m Telescope	75,000-115,000,000	404904N	1212824W	Cassel	CA
Deep Space Network	8050-8900	352024N	1160739W	Goldstone	CA
Deep Space Network	22,000	352024N	1160739W	Goldstone	CA
VLBA	70,000-118,000,000	315712N	1113654W	Kitt Peak	AZ
VLBA	4600-5100	315736N	1113636W	Kitt Peak	AZ
VLBA	8000-8800	315736N	1113636W	Kitt Peak	AZ
VLBA	10,200-11,200	315736N	1113636W	Kitt Peak	AZ
VLBA	14,400-15,400	315736N	1113636W	Kitt Peak	AZ
VLBA	21,700-24,100	315736N	1113636W	Kitt Peak	AZ
VLBA	42,300-43,500	315736N	1113636W	Kitt Peak	AZ
VLBA	4600-5100	354648N	1061500W	Los Alamos	NM
VLBA	8000-8800	354648N	1061500W	Los Alamos	NM
VLBA	10,200-11,200	354648N	1061500W	Los Alamos	NM
VLBA	14,400-15,400	354648N	1061500W	Los Alamos	NM
VLBA	21,700-24,100	354648N	1061500W	Los Alamos	NM
VLBA	42,300-43,500	354648N	1061500W	Los Alamos	NM
VLBA	4600-5100	371348N	1181648W	Owens Valley	CA
VLBA	8000-8800	371348N	1181648W	Owens Valley	CA
VLBA	10,200-11,200	371348N	1181648W	Owens Valley	CA
VLBA	14,400-15,400	371348N	1181648W	Owens Valley	CA
VLBA	21,700-24,100	371348N	1181648W	Owens Valley	CA
VLBA	42,300-43,500	371348N	1181648W	Owens Valley	CA
VLBA	4600-5100	341800N	1080712W	Pie Town	NM
VLBA	8000-8800	341800N	1080712W	Pie Town	NM
VLBA	10,200-11,200	341800N	1080712W	Pie Town	NM
VLBA	14,400-15,400	341800N	1080712W	Pie Town	NM
VLBA	21,700-24,100	341800N	1080712W	Pie Town	NM
VLBA	42,300-43,500	341800N	1080712W	Pie Town	NM
VLA	4500-5000	340444N	1073704W	Plains of San Agustin	NM
VLA	8000-8800	340444N	1073704W	Plains of San Agustin	NM
VLA	14,400-15,400	340444N	1073704W	Plains of San Agustin	NM
VLA	22,000-24,000	340444N	1073704W	Plains of San Agustin	NM

Table 4-14A. Calculated Thresholds for Radio Astronomy Telescope

Band (MHz)	Latitude (DMS)	Longitude (DMS)	Type of RA Telescope	RA Site	RA Frequency	Threshold	
						Initial Power (dBW)	Power Density (dBW/m2)
4400-4940	371348N	1181648W	VLBA	OWENS VALLEY	4600-5100	-206.9382	-172.28304

Table 4-14B. Calculated Power and Power Density for Radio Astronomy Telescope

Calculated		dB to meet		Frequency Separation Required (MHz)	FDR Resulting from Frequency Separation (dB)
Received Power from UAV (dBW)	Power Density from UAV (dBW/m2)	Received Power Level Threshold	Power Density Level Threshold		
-189.7	-154.8285546	17.23820026	17.45448901	20	17.7

For RA telescope sites, EMI was predicted from the 4400-4940 MHz RL to the 4600-5100 MHz very long baseline array (VLBA) at the Owens Valley Radio Observatory, Owens Valley, CA, for cases where the RL is tuned within 20 MHz of the VLBA center frequency. Compatible operation is predicted for systems located at Big Pine, Cassel, Goldstone, Kitt Peak, Los Alamos, Owens Valley, Pie Town, and the Plains of San Agustin RA sites.

4.6 RECOMMENDATIONS

Terrestrial microwave links and RA telescopes pose a problem based on the results of the Level Three analysis. The analysis indicates that the Predator UAV data link will not experience system degradation from the terrestrial microwave links. However, the analysis indicates that when the Predator UAV data link was the interference source, the Predator UAV will cause noticeable interference to the terrestrial microwave links. Table 4-9 lists the terrestrial microwave links that pose a problem. One FAA microwave link failed the required availability of 0.99999. However, this FAA microwave link did not meet the required availability without interference from the Predator UAV data link; when the interference was present, the FAA microwave link was degraded by 0.002%. The mobile microwave links listed in Table 4-9 are located near Yucca. It is recommended that coordination with the users of these mobile systems be accomplished prior to Predator UAV flight in the area. For the fixed microwave links listed in Table 4-9, it is recommended that there be a minimum frequency separation of 11 MHz between the fixed microwave link and the Predator UAV data link. All of the terrestrial microwave links are operating in the upper portion of the 4400-4940-MHz band. Therefore, it is recommended that the Predator UAV return data link for this band be located in the lower portion of the band, below 4749 MHz.

For the RA telescope identified in the Level Three analysis as having a potential EMI problem, it is recommended that the UAV flight operation and the operational frequency be coordinated with Owens Valley Radio Observatory to preclude EMI. The analysis determined the operation frequency should be 20 MHz off-tune from the RA telescope operating frequency.

APPENDIX A – ENVIRONMENTAL EQUIPMENT CHARACTERISTIC ASSUMPTIONS

Listed in Tables A-1 through A-17 are the assumptions used to complete the environment equipment characteristics missing from the database queries used in this analysis.

Table A-1. Transmitter Antenna Height by Frequency

Condition						Assumption
Frequency (MHz)	Agency	Bureau Code	Modulation	Location	Station Class	Transmitter Antenna Height (meters)
896-959.9875	FCC	NAvail	12K0F3E	NAvail	FX0	6
896-959.9875	FCC	NAvail	16K0F3E	NAvail	FBBS	43
10551-10621.25	FCC	NAvail	1M60A7W	NAvail	FX0	11
1860-1940	FCC	NAvail	3M50A7W	NAvail	FX0	10
21825-23075	FCC	NAvail	16M0A9W	NAvail	FX0	6
18142-18580	FCC	NAvail	5M75C3F	NAvail	FX0	25
5945.2-6900	FCC	NAvail	10M0D7W	NAvail	FX0	28
10551-10678	FCC	NAvail	2M50D7W	NAvail	FX0	22
344.15-351.85	FCC	NAvail	300KD7W	NAvail	FX0	30
5945.2-6078.6	FCC	NAvail	30M0D7W	Barstow	FX0	32
10915-11565	FCC	NAvail	30M0D7W	Kingman	FX0	19
5945.2-6137.925	FCC	NAvail	30M0D7W	NAvail	FX0	26
10795-11605	FCC	NAvail	30M0D7W	NAvail	FX0	22
17835-18765	FCC	NAvail	NAvail	Henderson	FX0	26
5945.2-6123	FCC	NAvail	NAvail	Pioch	FX0	45
10616.88-10624.38	FCC	NAvail	D9W	Las Vegas	FX0	33
10551.88-10556	FCC	NAvail	D9W	N. Las Vegas	FX0	45
928-953	FCC	NAvail	D9W	Henderson	FX0	24
928-953	FCC	NAvail	F1D	Las Vegas	FX0	15
928-953	FCC	NAvail	11K0F2W	Las Vegas	FX0	3
928-953	FCC	NAvail	12K0F2W	Las Vegas	FX0	3
928-960	FCC	NAvail	F3D	Las Vegas	FX0	100
18755-19155	FCC	NAvail	F7W	Baker	FX0	30
18585-23175	FCC	NAvail	F7W	Beatty	FX0	4
18585-23175	FCC	NAvail	F7W	Goodspring	FX0	30
17715-19205	FCC	NAvail	F7W	Las Vegas	FX0	36
896-959.9875	FCC	NAvail	12K0F3E	NAvail	FX0	6
900.975-900.9875	FCC	NAvail	NAvail	NAvail	MOI	3
NAvail	DOE	NAvail	F9DWF	Nevada test site	FXE	12
21480-22800	DOD	NAvail	20M00F2D	NAvail	FX	2
1830	DOD	NAvail	3M00G7W	NAvail	FX	5
928.0063-952.7063	FCC	NAvail	12K5F1D	NAvail	FX0	18
932.825-959.6	FCC	NAvail	100KF9W	NAvail	FX0	7
928.0938-952.48	FCC	NAvail	12K0F2D	NAvail	FX0	98
928-959.9313	FCC	NAvail	12K5F3D	NAvail	FX0	48
933-959.15	FCC	NAvail	200KF9W	NAvail	FX0	18
1778-1830	DOD	NAvail	3M00G7W	NAvail	FX	1270
1129-1174	USAF	NAvail	650K00V1A	NAvail	AL	25
1853-1935	FCC	NAvail	8M00F9W	NAvail	FX0	13
880.02-931.8625	FCC	NAvail	NAvail	NAvail	N/A	31
890-893.97	NAvail	NAvail	NAvail	NAvail	MO	2
1756-1849	NAvail	NAvail	NAvail	NAvail	FLD	0
896.2125-939.637	NAvail	NAvail	13K6F3E	NAvail	NAvail	2
USAF – United States Air Force						

Table A-2. Transmitter Antenna Height by Latitude and Longitude

Condition					Assumption
Latitude	Longitude	Agency	Modulation	Station Class	Transmitter Antenna Height (meters)
360000N-360050N	1150025W-1150023W	NAvail	F7W	FX0	61
361015N-361010N	1150835W-1150849W	NAvail	F7W	FX0	110
365605N	1160313W	DOE	F9WWF	FX	9

Table A-3. Transmitter Antenna Height by Agency

Condition				Assumption
Agency	Data Source	Antenna type	Modulation	Transmitter Antenna Height (meters)
USAF	DoD	Stub or blade	1M34F7D 20M0F3F	10,000

Table A-4. Transmitter Antenna Height by Nomenclature

Condition		Assumption
Nomenclature	Antenna Gain (dBi)	Transmitter Antenna Height (meters)
AN/DKT-XXX	0 or -2	10,000

Table A-5. Transmitter Antenna Height by Antenna Usage

Condition	Assumption
Antenna usage	Transmitter Antenna Height (meters)
Cell tower	60

Table A-6. Receiver Antenna Height by Frequency

Condition			Assumption
Frequency (MHz)	Agency	Station Class	Receiver Antenna Height (meters)
1775-2267.5	DoD	MOEB	7

Table A-7. Antenna Height by Frequency

Condition						Assumption
Frequency (MHz)	Agency	Bureau Code	Modulation	Antenna Type	Station Class	Antenna Height (meters)
1350.5-1846.5	DoD	NTC	F9W	Parabolic	FX	14

Table A-8. Transmitter Antenna Gain by Frequency

Condition							Assumption
Frequency (MHz)	Agency	Station Class	Transmitter Antenna Horiontal Beamwidth (degrees)	Modulation	Call Sign	Manufacturer	Transmitter Antenna Gain (dBi)
900-939.4125	FCC	NAvail	NAvail	12K0F3E	KNNF727	NAvail	0
800-1000	NAvail	NAvail	360	NAvail	NAvail	Celwave, Decible, Sinclair, or Scala Radio	10
935.46-939.95	FCC	FB7	NAvail	13K6F3E	NAvail	NAvail	12

Table A-9. Transmitter Antenna Gain by Transmitter Antenna Horizontal Beamwidth

Condition		Assumption
Transmitter Antenna Horizontal Beamwidth (Degrees)	Station Class	Transmitter Antenna Gain (dBi)
180	EH	3
360	EH	0

Table A-10. Transmitter Antenna Gain by Frequency Only

Condition				Assumption
Frequency (MHz)	Nomenclature	Modulation	Station Class	Transmitter Antenna Gain (dBi)
890-1215	Blank	Blank	Blank	15.4
1865-2130	Blank	Blank	Blank	27.7

Table A-11. Transmitter Antenna Gain and Beamwidth by Antenna Type

Condition		Assumption	
Antenna Type	Station Class	Transmitter Antenna Gain (dBi)	Transmitter Antenna Horizontal Beamwidth (Degrees)
Dipole	Any Mobile	2.1	360
Blade	Any Mobile	2.1	360
Stub	Any Mobile	2.1	360
Spiral	Any Mobile	2	120

Table A-12. Receiver Antenna Height and Gain by Frequency

Condition				Assumption	
Frequency (MHz)	Agency	Modulation	Station Class	Receiver Antenna Height (meters)	Receiver Antenna Gain (dBi)
931.0125-959.9875	FCC	16K0F1D 16K0F3E	FBBS	27	29

Table A-13. Transmitter and Receiver Antenna Gain by Frequency

Condition		Assumption
Frequency (MHz)	Station Class	Transmitter and Receiver Antenna Gain (dBi)
903-927	LR	16
1177-1211	AL	Transmitter and receiver antenna gain are same.

Table A-14. Antenna Gain by Antenna Type

Condition		Assumption
Antenna Type	Station Class	Antenna Gain (dBi)
Parabolic	Deep Space Radio Telescope	55.5

Table A-15. Antenna Height and Gain by Frequency

Condition				Assumption
Frequency (MHz)	Agency	Modulation	Station Class	Antenna Height and Gain
1860-1940	FCC	A7W	FXO	Transmit antenna height equals receive antenna height and transmit antenna gain equals receive antenna gain
933-959	FCC	D1W	FX or FXO	Transmit antenna height equals receive antenna height and transmit antenna gain equals receive antenna gain

Table A-16. Transmitter Power by Frequency

Condition				Assumption
Frequency (MHz)	Data Source	Modulation	Station Class	Transmitter Power (kW)
931.0625-931.9875	FCC	F1D F3E	FBBS	0.129352

Table A-17. Transmitter Power by Transmitter Usage

Condition	Assumption
Transmitter usage	Transmitter Power(kW)
PCS Broadband	0.03

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