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INDIAN SPRINGS C-BAND LINE-OF-SIGHT FREQUENCY REQUIREMENTS ANALYSIS

Prepared for

AIR COMBAT COMMAND
UAV SPECIAL MISSION OFFICE (ACC/DR-UAV)
216 Sweeney Blvd, Room 109
Langley AFB, VA 23665

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PROJECT REPORT

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14. ABSTRACT
Current frequency assignments for the Predator Unmanned Aerial Vehicle (UAV) permit the simultaneous operation of four General Atomics Aeronautical Systems Incorporated 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, a requirement was identified for the simultaneous operation of seven Predator UAVs at ISAFAF requiring seven sets of frequencies and an additional set of frequencies for ground test. The Air Combat Command UAV Special Mission Office requested that the Joint Spectrum Center investigate alternative options that would allow all eight Predator frequency sets to operate simultaneously at the ISAFAF. This analysis supersedes the previous version by adding high power taxi, intermodulation products analysis, and modification of the desired SSI % benchmark from 30 % SSI return link to 50 % SSI command link. Of seven scenarios considered, two scenarios were recommended; the first, to modify the diplexer frequency band to enlarge the return link band, met the frequency requirements with unrestricted operations; the second, to improve diplexer filtering to enlarge the return link band, also met the frequency requirements. Two other scenarios were recommended, with reservations: one considered the addition of a new tactical common datalink and the other considered the addition of a new K_u-band analog datalink (both options to be used in addition to the existing C-band datalink).

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PREFACE

The Joint Spectrum Center (JSC), a field activity of the Defense Information Systems Agency (DISA), was established to provide advice and assistance on all matters regarding the electromagnetic battlespace. Support is provided to the Secretary of Defense, the Joint Staff, the military departments, combatant commands, defense agencies, and other agencies of the US Government. The JSC works closely with the Joint Staff, Director for Command, Control, Communications, and Computer Systems, and the Assistant Secretary of Defense for Networks and Information Integration on spectrum matters. Direct support is provided to the Unified Commands and Joint Task Force Commanders on electromagnetic battlespace issues, including spectrum management and electronic warfare deconfliction. Support to Department of Defense (DoD) components and the US Government is provided through a sponsor-reimbursed, electromagnetic compatibility (EMC) program that provides EMC analyses for specific projects.

Comments regarding this report should be submitted to the Commander, JSC, 2004 Turbot Landing, Annapolis, MD 21402-5064

EXECUTIVE SUMMARY

The Predator Unmanned Aerial Vehicle (UAV) line-of-sight command link and return link frequency assignments permit the simultaneous operation of four General Atomics Aeronautical Systems Incorporated 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, a requirement was identified for the simultaneous operation of seven Predator UAV frequency sets at the ISAFAF and an additional set of frequencies for ground testing. The Air Combat Command UAV Special Mission Office requested that the Joint Spectrum Center investigate alternative scenarios that would permit all eight Predator frequency sets to operate simultaneously at the ISAFAF.

This analysis supersedes the previous version by adding high-power taxi, intermodulation products analysis, and modification of the desired signal strength indicator (SSI) benchmark from 30 % SSI return link to 50 % SSI command link.

Of seven scenarios considered, one was not recommended due to operational complexity, and two were not recommended because they did not meet the minimum frequency requirements. Two scenarios were recommended; the first, to modify the diplexer frequency band to enlarge the return link band, met the frequency requirements with unrestricted operations; the second, to improve diplexer filtering to enlarge the return link band, also met the frequency requirements. The two remaining scenarios were recommended, with reservations: one considered the addition of a new tactical common datalink and the other considered the addition of a new K_u-band analog datalink (both scenarios to be used in addition to the existing C-band datalink).

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GLOSSARY

AGC	Automatic Gain Control
ASI	Aeronautical Systems Incorporated
BER	Bit Error Rate
CL	Command Link
C-E	Communications-Electronics
dBc	Decibels Referenced to the Carrier
DLOS	Digital Line-of-Sight
DOE	Department of Energy
DSRC	Dedicated Short-Range Communications
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FSK	Frequency Shift Keyed
GCS	Ground Control Station
GDT	Ground Data Terminal
IF	Intermediate Frequency
IM	Intermodulation
ISAFAF	Indian Springs Air Force Auxiliary Field
JSC	Joint Spectrum Center
LNA	Low-Noise Amplifier
LOS	Line-of-Sight
NAvail	Not Available
RL	Return Link
RLAN	Radio Local Area Network
RF	Radio Frequency
Rx	Receiver
S/N	Signal-to-Noise Power Ratio
SSI	Signal Strength Indicator
TCDL	Tactical Common Data Link
Tx	Transmitter
UAV	Unmanned Aerial Vehicle
U-NII	Unlicensed National Information Infrastructure

SECTION 1 – INTRODUCTION

1.1 BACKGROUND

The Predator Unmanned Aerial Vehicle (UAV) line-of-sight (LOS) command link and return link frequency assignments permit the simultaneous operation of four General Atomics Aeronautical Systems Incorporated (ASI) Predator air vehicles at the 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, a requirement was identified for the simultaneous operation of seven Predator UAV frequency sets at the ISAFAF and an additional set of frequencies for ground testing. The Air Combat Command UAV Special Mission Office requested that the Joint Spectrum Center (JSC) investigate ways to satisfy the Predator frequency requirements. This analysis supersedes the previous version by adding a high-power, taxi intermodulation products analysis, and modification of the desired signal strength indicator (SSI) % benchmark from 30 % SSI return link to 50 % SSI command link.

1.2 OBJECTIVE

The objective of this task was to develop a plan that would accommodate the simultaneous operation of seven Predator UAV frequency sets at the ISAFAF and provide an additional set of frequencies for ground testing.

1.3 APPROACH

This report was based on several previous JSC analyses. First, the potential impact between the Predator datalinks and 4400 – 4940, 5250 – 5850, 14400 – 14830, and 15150 – 15350-MHz legacy equipment was determined.[1-1] Second, the potential for electromagnetic compatibility (EMC) between the Predator datalinks and unlicensed 5-GHz devices was analyzed to assess future issues as use of 5-GHz devices proliferates.[1-2,1-3] Third, a frequency band study was conducted to evaluate spectrum supportability of

[1-1] S. Bonter, Y. Kim, J. Timko, and T. Luu, *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*, JSC-PR-03-024, Annapolis, MD: DoD Joint Spectrum Center, November 2003.
[1-2] S. Bonter and C. Price, *Predator UAV C-Band Data Link EMC with 5-GHz CFR 47 Part 15 and Part 90 Devices*, JSC-PR-03-026, Annapolis, MD: DoD Joint Spectrum Center, November 2003.
[1-3] S. Bonter, *Predator UAV C-band Data Link Site-Independent EMC with 5-GHz 47 C.F.R. Part 15 and Part 90 Devices*, JSC-PR-04-009, Annapolis, MD: DoD Joint Spectrum Center, May 2004.

UAV datalinks in the 4400 – 4940, 5250 – 5850, and 14400 – 15350-MHz frequency bands.[1-4] Finally, a datalink system test was performed to determine technical parameters.[1-5]

The test data was analyzed to develop operational considerations including ground data terminal (GDT) placement, intra-platform and inter-platform adjacent-channel operation restrictions, UAV adjacent-channel return link frequency restrictions, antenna pattern shading, receiver dynamic range, and angular separation.

Seven scenarios, some with several variations, representing alternative approaches to satisfying the objective were identified and analyzed.

Scenario 1 considered the existing datalink design and the use of dual take-off and landing return link frequencies and a single long-range return link frequency.
Scenario 2 considered adding a medium-power mode to the return link and using dual take-off and landing return link frequencies and a single long-range return link frequency.
Scenario 3 modified the diplexer frequency bands to enlarge the return link band.
Scenario 4 improved diplexer filtering to enlarge the return link band.
Scenario 5 considered adding a new 4400 – 4940-MHz datalink to be used in addition to the existing C-band datalink.
Scenario 6 considered adding a new tactical common data link (TCDL) to be used in addition to the existing C-band datalink.
Scenario 7 considered adding a new K_u-band analog datalink to be used in addition to the existing C-band datalink.

Details of the previously published EMC analyses are listed below.

1.3.1 EMC Analysis for the ISAFAF Operating Environment

The JSC conducted an EMC analysis (Reference 1-1) to determine the potential for electromagnetic interference (EMI) between the Predator UAV LOS datalink terminal and the communications-electronics (C-E) environment near the ISAFAF for four candidate frequency bands: 4400 – 4940, 5250 – 5850, 14400 – 14830, and 15150 – 15350 MHz. Since the integration of the TCDL terminals into the UAV and GDT is anticipated, this analysis also considered the potential for EMI between the

[1-4] S. Bonter, D. Dunty, and J. Gillis, *C-band and Ku-band Line-of-Sight Unmanned Aerial Vehicle Frequency Band Study*, JSC-PR-04-014, Annapolis, MD: DoD Joint Spectrum Center, June 2004.
[1-5] S. Bonter, J. Smith, and Y. Kim, *Predator Line-of-Sight Data Link Terminal Radio Frequency Test Plan*, JSC-CR-03-062, Annapolis, MD: DoD Joint Spectrum Center, August 2003.

TCDL-configured Predator and the C-E environment near the ISAFAF for the 14400 – 14830 and 15150 –15350-MHz frequency bands.

For six Department of Justice fixed microwave links that use the upper portion of the 4400 – 4940-MHz band, it was recommended that there be a minimum frequency separation of 11 MHz between the return link transmitter and the fixed microwave links, and that the return link functions be located in the lower portion of this band (below 4749 MHz). For radio astronomy systems, either a 20-MHz frequency separation was required to preclude interference to the very-long baseline array at the Owens Valley Radio Observatory, Owens Valley, CA, or return link functions were required to be located in the lower portion of this band (below 4580 MHz). No interactions involving radar systems, telemetry systems, or satellite downlink systems resulted in predicted EMI.

Analysis of the 14400 – 14800-MHz return link frequency band indicated that the return link transmitter may cause interference to select transportable microwave links. It was recommended that K_u-band return link transmitter operations be coordinated with the Department of Energy (DOE).

No potential EMI issues were identified for the 5250 – 5850-MHz and 15150 – 15350-MHz frequency bands.

1.3.2 EMC Analyses for Unlicensed Devices

Two analyses were conducted to assess potential EMI between the 5150 – 5350-MHz and 5725 – 5925-MHz band unlicensed devices and the Predator datalinks operating in the 5250 – 5850-MHz band. The scope of the first analysis (Reference 1-2) was ISAFAF site-specific. The scope of the second analysis (Reference 1-3) was site-independent.

The ISAFAF site-specific analysis predicted no EMI issues. However, the Air Force plans to install unlicensed devices on hangar doors to facilitate wireless barcode readers used for maintenance purposes.[1-6] **Note:** This is one example of Part 15 device on-base applications. Although this particular example is in the 2400 – 2483-MHz band, it is reasonable to assume that there may also be an application where the 5150 – 5350-MHz and 5725 – 5925-MHz bands will be utilized.

The site-independent analysis predicted EMI issues and provided EMI mitigation guidance in the form of frequency-distance curves. Predicted command link (CL) EMI issues included point-to-point microwave, video surveillance, dedicated short-range communications (DSRC), and unlicensed national

[1-6] Corey Wilcox, OO-ALC/LCEA, e-mail to Fred Nelson, Joint Spectrum Center, Subject: *EMI/EMC and Bluetooth Technology,* Hill Air Force Base, UT: 10 March 2004.

information infrastructure (U-NII) victims. The command link frequency-distance curves are shown in Figures 1-1 and 1-2. Predicted return link (RL) EMI issues included radio local area network (RLAN) and U-NII victims. The return link frequency-distance curves are shown in Figure 1-3.

It was recommended that the use of unlicensed 5-GHz devices be restricted during periods when Predator UAVs operate. The results found in Reference 1-3 indicated that the interference power was higher than the interference power threshold in many cases, and higher than the signal-to-noise power ratio (S/N) threshold in six cases. Frequency management alone will not permit use of the command link frequency band and reduces the width of the available return link frequency band from 225 MHz to 86 MHz. Electromagnetic control in the vicinity of the GDT site would require enforcing substantial separation distances from unlicensed 5-GHz devices. Utilization of both frequency management and electromagnetic control of the region will likely result in substantial frequency range loss, depending on the size of the region that can be controlled.

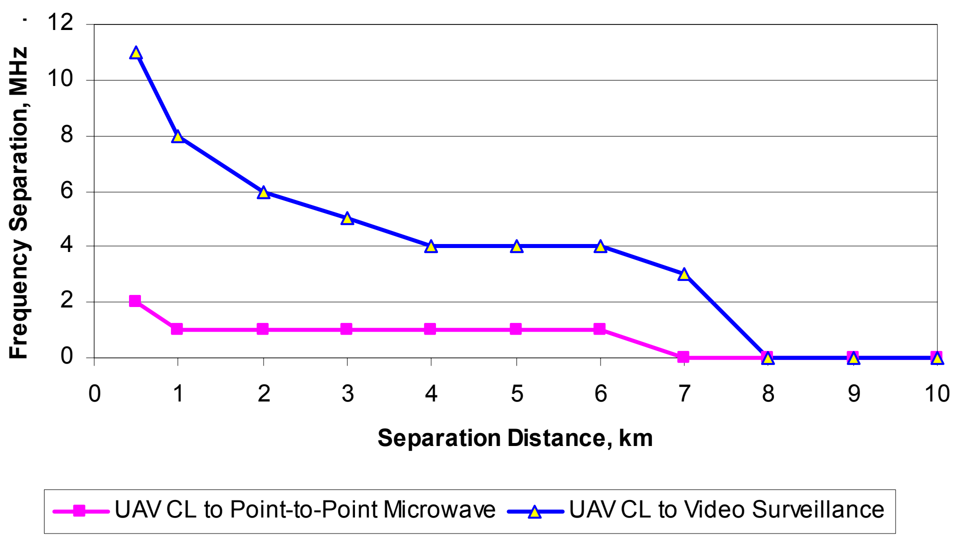


Figure 1-1. UAV Command Link to Point-to-Point Microwave and Video Surveillance Frequency-Distance Curves

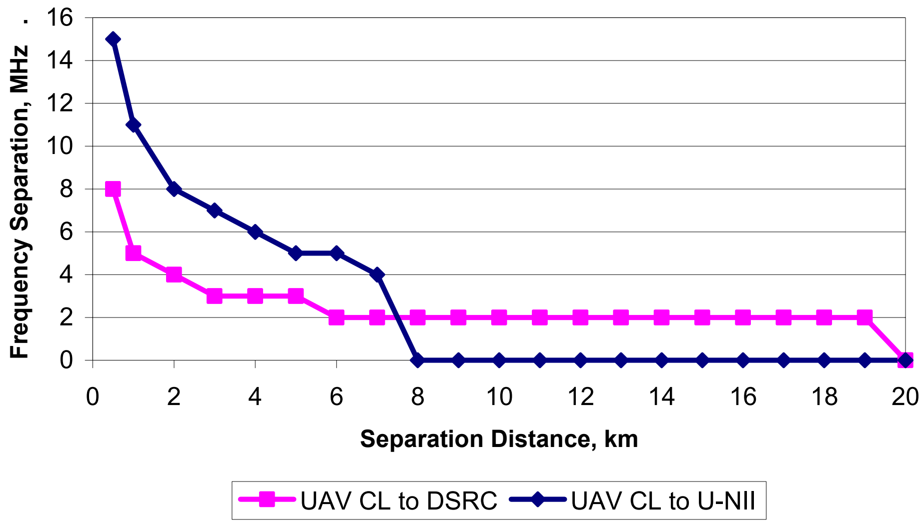


Figure 1-2. UAV Command Link to DSRC and U-NII Frequency-Distance Curves

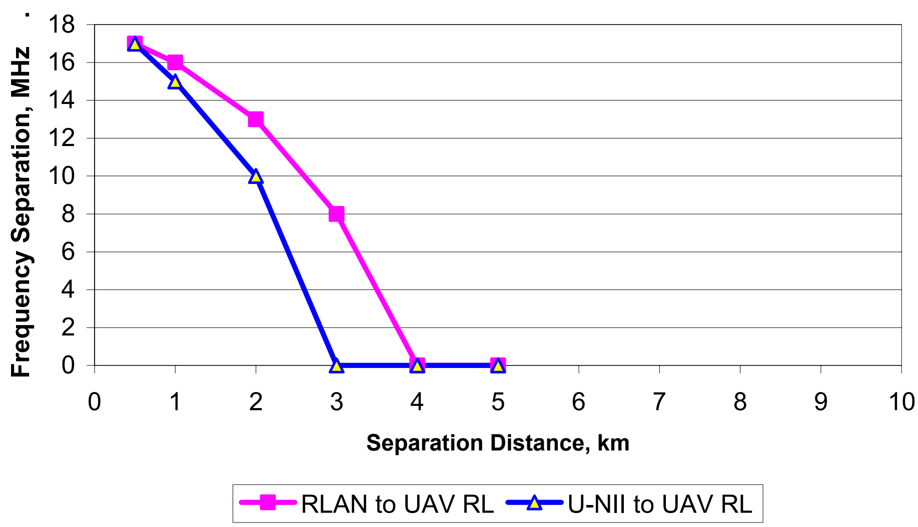


Figure 1-3. RLAN and U-NII to UAV Return Link Frequency-Distance Curves

1.3.3 UAV Frequency Band Study

The JSC conducted a C-band and K_u-band frequency band study (Reference 1-4) to evaluate spectrum supportability of UAV datalinks in the 4400 – 4940, 5250 – 5850, and 14400 – 15350-MHz bands. The recommended frequency bands are listed in Table 1-1.

Table 1-1. Recommended Frequency Bands

	United States & Possessions
Command Link	4400 – 4825 MHz 4835 – 4940 MHz 14500 – 15350 MHz
Return Link	4400 – 4825 MHz 4835 – 4940 MHz 14500 – 15136.5 MHz

1.3.4 Tests to Determine EMC Parameters

The JSC, with support from ASI, performed measurements of the datalink terminals in the Predator systems integration laboratory from 26 to 30 July 2004. The tests were conducted using the procedures defined in the established test plan (Reference 1-5).

The test results[1-7] provided the technical characteristics used in this document. Emission bandwidth, transmitter spurious emissions, diplexer attenuation, receiver sensitivity, receiver selectivity, system receiver gain compression, received power to SSI performance, and adjacent-signal performance were measured. SSI is a calibrated DC output voltage of the automatic gain control (AGC) circuit. Emission bandwidths are listed in Tables 1-2 through 1-5. Transmitter spurious emission frequencies and attenuations are listed in Tables 1-6 and 1-7. Diplexer frequencies and attenuations are listed in Table 1-8. Receiver sensitivity and gain compression results are listed Table 1-9. Received power correlated to SSI as a function of emission type are shown in Figure 1-4. Receiver selectivity curves are shown in Figures 1-5 and 1-6. Command link and return link adjacent-signal rejection are shown in Figures 1-7 and 1-8, respectively.

Table 1-2. Transmitter Emission Spectrum Results – High Power – Average

Emission Type	-3 dBc, kHz	-20 dBc, kHz	-40 dBc, kHz	-60 dBc, kHz
Command Link (GDT-to-UAV)				
560KF1D	275.0	358.3	483.3	1066.7
88K3F1D	233.3	441.7	841.7	1366.7
Return Link (UAV-to-GDT)				
17M0F9F	2000.0	5666.7	21000.0	33166.7
4M72F1D	166.7	14,666.7	22,500.0	35,666.7

[1-7] S. Bonter, D. Dunty, J. Greene, and Dr. W. Duff, *Predator UAV Line of Sight Data Link Terminal Radio Frequency Test Report*, JSC-CR-04-066, Annapolis, MD: DoD Joint Spectrum Center, September 2004.

Table 1-3. Transmitter Emission Spectrum Results – High Power – Peak

Emission Type	-3 dBc, kHz	-20 dBc, kHz	-40 dBc, kHz	-60 dBc, kHz
Command Link (GDT-to-UAV)				
560KF1D	300.0	333.3	516.7	1050.0
88K3F1D	266.7	433.3	933.3	1450.0
Return Link (UAV-to-GDT)				
17M0F9F	2000.0	16,000.0	21,000.0	35,000.0
4M72F1D	2000.0	8166.7	23,000.0	46,333.3

Table 1-4. Transmitter Emission Spectrum Results – Low Power – Average

Emission Type	-3 dBc, kHz	-20 dBc, kHz	-40 dBc, kHz	-60 dBc, kHz
Command Link (GDT-to-UAV)				
560KF1D	253.3	333.3	720.0	960.0
88K3F1D	226.7	440.0	973.3	1293.3
Return Link (UAV-to-GDT)				
17M0F9F	166.7	15,000.0	15,333.3	29,833.3
4M72F1D	333.3	14,666.7	28,333.3	34,666.7

Table 1-5. Transmitter Emission Spectrum Results – Low Power – Peak

Emission Type	-3 dBc, kHz	-20 dBc, kHz	-40 dBc, kHz	-60 dBc, kHz
Command Link (GDT-to-UAV)				
560KF1D	280.0	333.3	573.3	973.3
88K3F1D	260.0	466.7	873.3	1373.3
Return Link (UAV-to-GDT)				
17M0F9F	166.7	15,000.0	15,833.3	30,666.7
4M72F1D	2000.0	14,333.3	27,500.0	34,666.7

Table 1-6. Command Link Spurious Emission Values

Transmitter-Tuned Frequency, MHz	Spurious Emission Frequency, MHz	Spurious Level 560KF1D LOS, dBc	Spurious Level 88K3F1D DLOS, dBc
5625	5832	-98.3	-98.7
	5760	-98.2	-102.3
	5761	-98.2	Not Measured
5850	5653	Not Measured	-110.5
	5669	-104.6	-108.1
	5672	-105.3	-105.7
	5685	Not Measured	-110.1
	5760	-100.0	Not Measured
	5761	-101.5	Not Measured
	5762	Not Measured	-105.7
DLOS – digital line-of-sight LOS – line of sight			

Table 1-7. Return Link Spurious Emission Values

Transmitter-Tuned Frequency, MHz	Spurious Emission Frequency, MHz	Spurious Level 17M0F9F LOS, dBc	Spurious Level 4M72F1D DLOS, dBc
5250	5363	-73.7	-73.7
5475	5304	-89.7	Not Measured
	5305	-85.2	
	5307	-86.0	
	5311	-89.9	
	5333	-91.0	
DLOS – digital line-of-sight LOS – line of sight			

Table 1-8. Diplexer Sweep Test Results

Serial Number	Link	-60 dB, MHz	-40 dB, MHz	-20 dB, MHz	-3 dB, MHz	-3 dB, MHz	-20 dB, MHz	-40 dB, MHz	-60 dB, MHz
GDT Diplexers									
334003	Tx to Antenna	5040.0	5101.3	5160.0	5202.7	5504.0	5549.3	5600.0	5640.0
347003	Tx to Antenna	4978.7	5101.3	5101.3	5213.3	5510.7	5545.3	5582.7	5690.7
334003	Antenna to Rx	5537.0	5571.0	5592.0	5609.0	5918.0	5937.0	5966.0	6025.0
347003	Antenna to Rx	5512.0	5554.0	5581.0	5601.0	5907.0	5923.0	5950.0	6009.0
	UAV Diplexers								
346006 Tx to Antenna		5118.7	5174.7	5200.0	5214.7	5506.7	5526.7	5552.0	5585.3
346001 Tx to Antenna		5120.0	5173.3	5200.0	5221.3	5509.3	5526.7	5552.0	5592.0
346006 Antenna to Rx		5408.0	5526.7	5564.0	5596.0	5909.3	5949.3	6006.7	6117.3
346001 Antenna to Rx		5413.3	5536.0	5565.3	5596.0	5906.7	5948.0	6009.3	6136.0
Tx – Transmitter Rx – Receiver									

Table 1-9. Receiver Sensitivity and Gain Compression Results

Emission Link Type	Receiver Sensitivity, dBm	Receiver Gain Compression, dBm
560KF1D LOS Command	-105.4	-34.4
88K3F1D DLOS Command	-101.4	
17M0F9F LOS Return	-88.3	-28.3
4M72F1D DLOS Return	-84.3	
DLOS – digital line-of-sight LOS – line-of-sight		

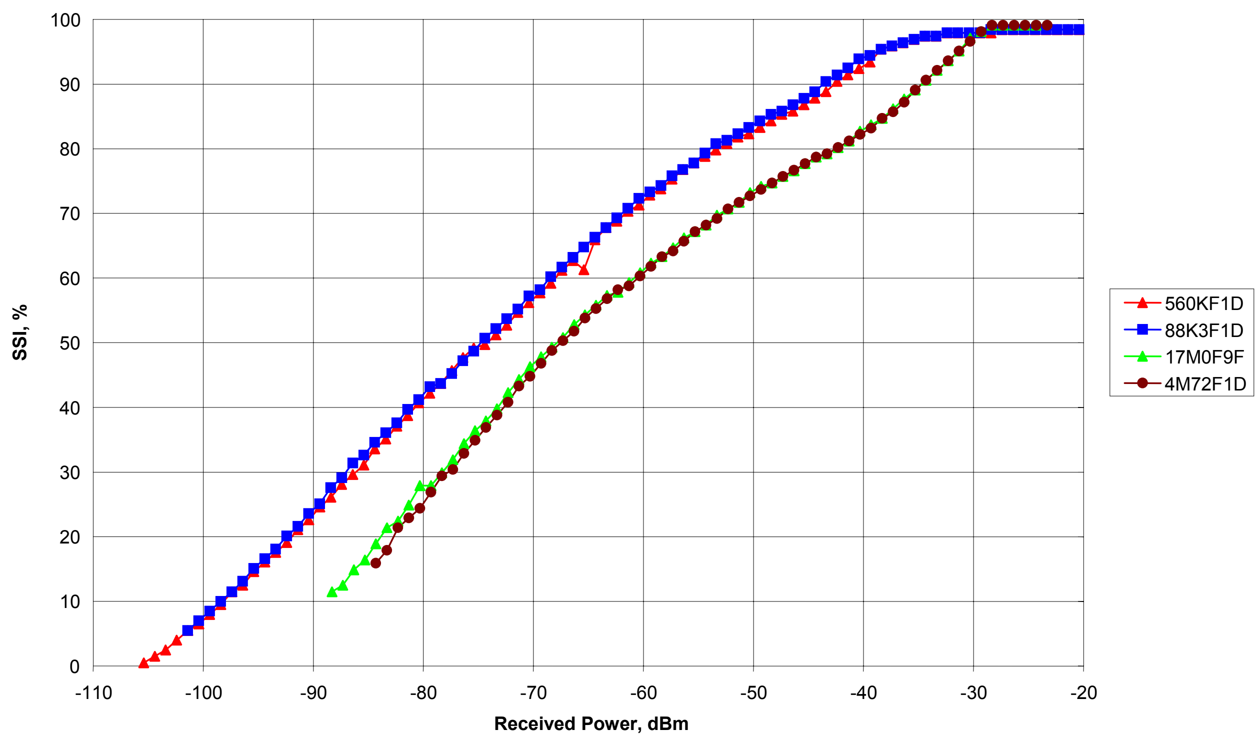


Figure 1-4. Received Power Correlated to SSI as a Function of Emission Type

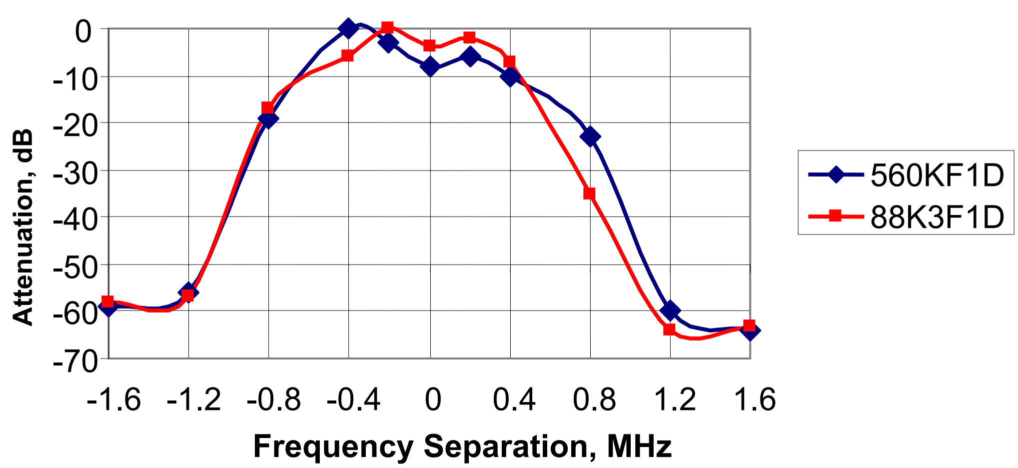


Figure 1-5. Command Link Receiver Selectivity Results

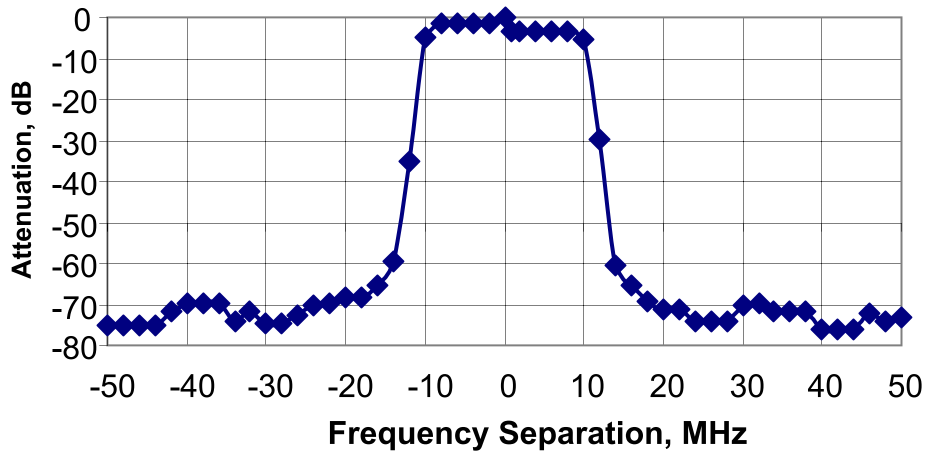


Figure 1-6. Return Link Receiver Selectivity Results

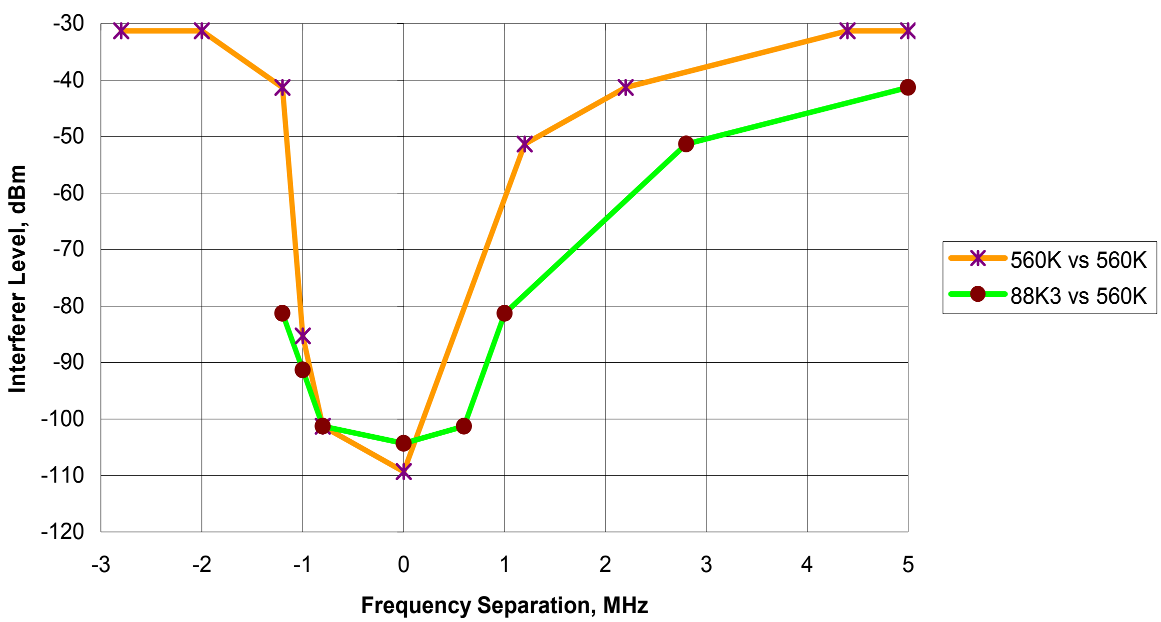


Figure 1-7. Command Link Adjacent-Signal Rejection

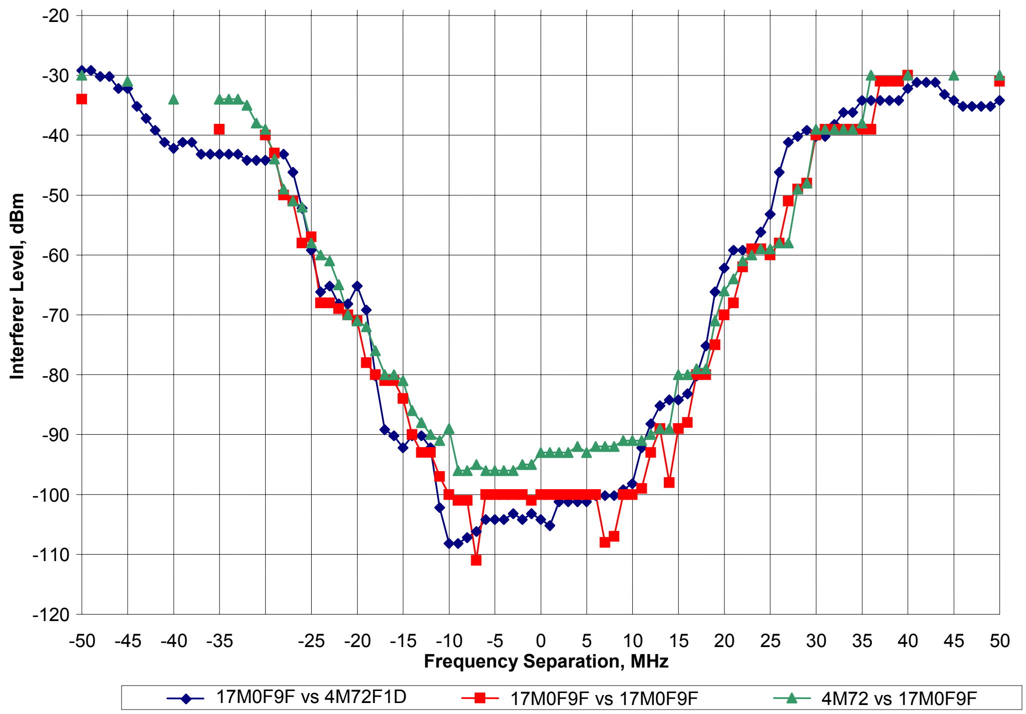


Figure 1-8. Return Link Adjacent-Signal Rejection

SECTION 2 – SYSTEM DESCRIPTION

The Predator datalink 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 command link. The payload data and status information is provided from the UAV to the GCS using the return link. The transmitter and receiver units can be software-configured to perform command link or return link functions. The Predator datalink utilizes two command links and two return links and uses 16-bit messages (15 information bits plus one parity bit).

The installed command link configured terminals can transfer randomized 15-bit non-return-to-zero data at 19.2 kbps and 200 kbps using frequency shift keyed (FSK) modulation. The installed return link configured terminals can transfer either National Television System Committee formatted video with a data subcarrier at 6.8 MHz or 7.5 MHz offset, or FSK data without subcarriers at 3.2 Mbps.

The TCDL command link transmitter utilizes binary phase-shift keying in both clear and direct-sequence spread-spectrum modes. The data rate for both modulations is 200 kbps.

The TCDL return link transmitter utilizes offset-quadrature phase-shift keying. The data rate planned for the Predator UAV is 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 a 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 system noise figure. The Predator system datalink radio frequency (RF) configuration is shown in Figure 2-1. The TCDL RF configuration is shown in Figure 2-2.

The dual-Predator UAV datalink system contains transmitters, receivers, a 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.

The Predator datalink component RF characteristics are listed in Table 2-1 for current terminals, and Table 2-2 for TCDL terminals.[2-1,2-2,2-3]

[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.
[2-2] *Source Control Drawing for 4' Diameter, High Gain Antenna*, SCD00069, San Diego, CA: Aeronautical Systems Incorporated, 19 August 1999.
[2-3] *Application for Equipment Frequency Allocation (DD Form 1494) for L3 Communications Tactical Common Data Link (TCDL)*, J/F 12/7834/1, Washington, DC: MCEB, 18 February 1999.

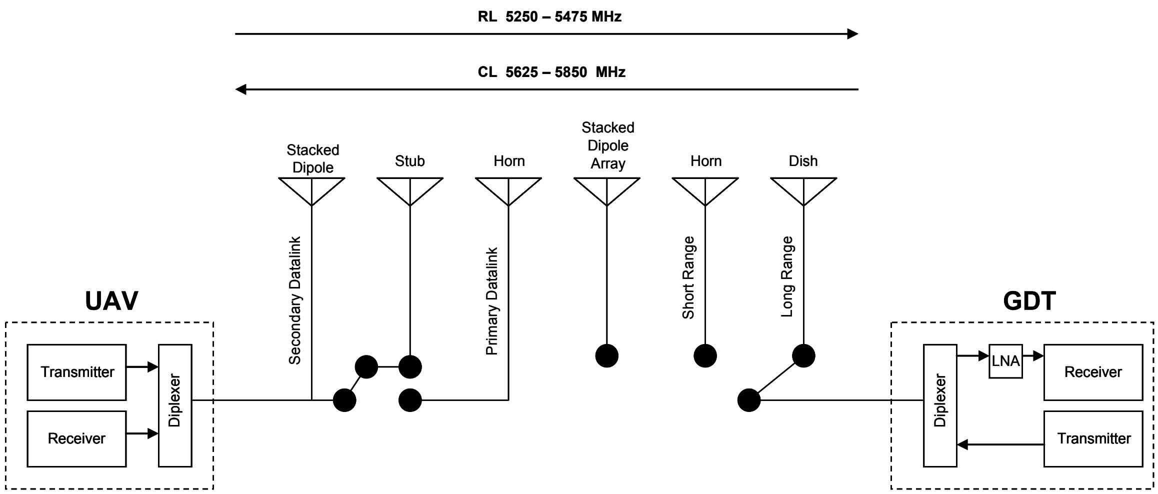


Figure 2-1. Predator System Datalink Configuration

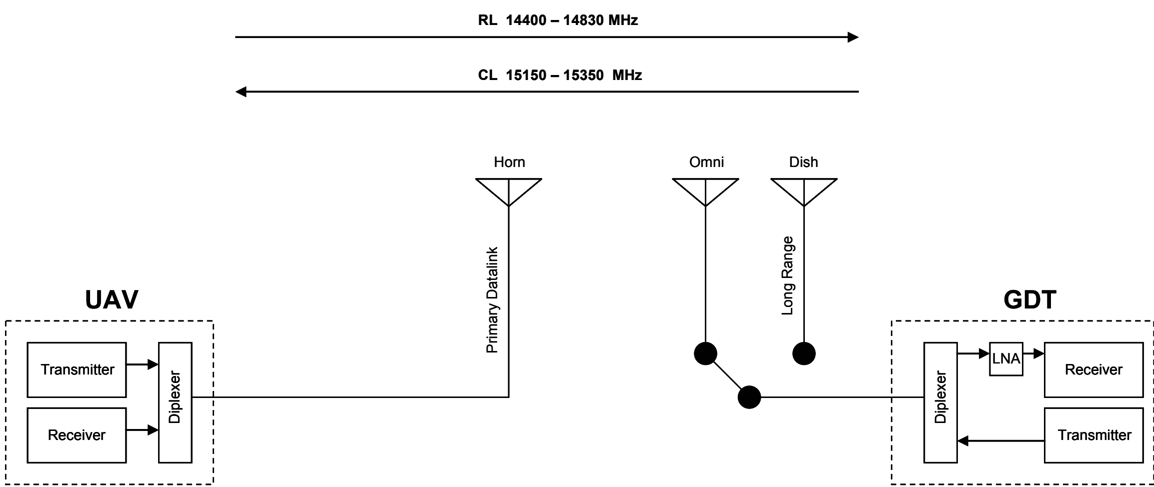


Figure 2-2. TCDL RF Configuration

Table 2-1. Predator Datalink 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 High-Power Mode Low-Power Mode	 40 0			
Spurious/Harmonic Attenuation, dB	65			
Link Type	Command Link		Return Link	
Emission Designators	560KF1D	88K3F1D	17M0F9F	4M72F1D
Emission Bandwidth, MHz -3 dB -20 dB -40 dB -60 dB	 0.34 0.42 NAvail 1.2	 0.063 0.088 0.219 0.671	 8.5 18.0 NAvail 46.2	 2.8 20.0 NAvail 66.0
Receiver				
Tuning Range, MHz	5250 – 5850			
Alternate Tuning Ranges in Consideration, MHz	4400 – 4940, 14400 – 14830 (RL only), and 15150 – 15350 (CL only)			
RF Selectivity, MHz -3 dB -20 dB -60 dB	 303 375 525			
1st IF Selectivity, MHz -3 dB -20 dB -60 dB	 35 55 115			
Link Type	Command Link		Return Link	
2nd IF Selectivity, MHz -3 dB -20 dB -60 dB	 1 3.2 4		 20 22.5 28	
Sensitivity, dBm	-98	-98	-84	-86
Sensitivity Criterion	$1x10^{-6}$ BER	$1x10^{-6}$ BER	23-dB S/N	$1x10^{-6}$ BER
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			

Table 2-1. Predator Datalink Technical Characteristics (continued)

UAV Horn	
Manufacturer	Technical Associates, Inc.
Model Number	11572
Gain, dBi	15.0
Beamwidth, degrees	30 azimuth, 30 elevation
Polarization	Vertical
UAV Stacked Dipole Array	
Manufacturer	TECOM Industries, Inc.
Model Number	702653-1
Gain, dBi	3.0
Beamwidth, degrees	360 azimuth, 25 elevation
Polarization	Vertical
UAV Stub	
Manufacturer	TECOM Industries, Inc.
Model Number	702-653-3
Gain, dBi	0.3
Beamwidth, degrees	360 azimuth, 55 elevation
Polarization	Vertical
GDT 4-Foot Diameter Dish	
Manufacturer	NAvail
Model Number	NAvail
Gain, dBi	≥ 29.0
Beamwidth, degrees	3.3 azimuth, csc^2 to 45 elevation
Polarization	Vertical
GDT Horn	
Manufacturer	Technical Associates, Inc.
Model Number	15921
Gain, dBi	15.0
Beamwidth, degrees	30 azimuth, 30 elevation
Polarization	Vertical
GDT Omni	
Manufacturer	Technical Associates, Inc.
Model Number	10171
Gain, dBi	6.0
Beamwidth, degrees	360 azimuth, 30 elevation
Polarization	Vertical

BER – bit error rate
csc – cosecant
IF – intermediate frequency
RF – radio frequency
S/N – signal-to-noise power ratio
NAvail – not available

Table 2-2. TCDL Technical Characteristics

Characteristic	Specifications			
Transmitter				
Tuning Range, MHz	14400 – 14830 Return Link and 15150 – 15350 Command Link			
Tuning Increment, MHz	5			
Transmitter Power, dBm	33			
Spurious/Harmonic Attenuation, dB	65			
Link Type	Return Link and Command Link			
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, MHz	14400 – 14830 (RL) and 15150 – 15350 (CL)			
Link Type	RL		CL	
RF Selectivity, MHz				
-3 dB	430		200	
-20 dB	500		410	
-60 dB	750		560	
Link Type	Return Link and Command Link			
1st IF Selectivity, MHz				
-3 dB	200			
-20 dB	450			
-60 dB	1500			
Link Type	Return Link and Command Link			
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			
GDT 1-Meter Diameter Dish				
Manufacturer	L3 Communications			
Model Number	NAvail			
Gain, dBi	40.0			
Beamwidth, degrees	1.7 azimuth, 1.7 elevation			
Polarization	Right-Hand Circular			
GDT Omni				
Manufacturer	L3 Communications			
Model Number	NAvail			
Gain, dBi	3.0			
Beamwidth, degrees	360 azimuth, 32 elevation			
Polarization	Vertical			

Table 2-2. TCDL Technical Characteristics (continued)

UAV Biconical Dipole	
Manufacturer	L3 Communications
Model Number	NAvail
Gain, dBi	3.0
Beamwidth, degrees	360 azimuth, 41 elevation
Polarization	Vertical
BER – bit error rate IF – intermediate frequency NAvail – not available RF – radio frequency	

SECTION – 3 ANALYSIS METHODOLOGY

The test report data was used to develop the operational parameters required to analyze alternative approaches to accommodate the simultaneous operation of seven Predator UAV frequency sets at the ISAFAF and to provide an additional set of frequencies for ground testing.

3.1 TEST DATA ANALYSIS

3.1.1 Transmitter Emission Spectrum

Average transmitter emission spectrum data from the transmitter high-power mode was used in the analysis. The widest of the two command link and two return link bandwidths were used, referenced at the -20-dB bandwidth. This data was used as a frequency-dependent calculation input and is listed in Table 3-1.

Table 3-1. Emission Bandwidth Values

Data Link Type	-3 dB, kHz	-20 dB, kHz	-40 dB, kHz	-60 dB, kHz
Command Link	233.3	441.7	841.7	1366.7
Return Link	166.7	14666.7	22500.0	35666.7

3.1.2 Transmitter Spurious Emission Attenuation

Spurious attenuation was measured and is listed in Table 1-6 for the command link emissions within the 5625 – 5850-MHz band and Table 1-7 for the return link emissions within the 5250 – 5475-MHz band. Test configuration limitations prevented command link measurements in the return link band and vice versa. It was assumed that command link spurious attenuation values are the same as the return link spurious attenuation values in the 5250 – 5475-MHz band, and that the return link spurious attenuation values are the same as the command link spurious attenuation values in the 5625 – 5850-MHz band since identical transmitters were used for both command and return links. For this analysis, worst case spurious attenuation values of 98.2 dB for the 5625 – 5850-MHz band and 73.7 dB for the 5250 – 5475-MHz band were used.

3.1.3 Diplexer Performance

The diplexers employ 11-pole transmitter-to-antenna port filters and 7-pole antenna-to-receiver port filters. The GDT diplexer is set up for command link transmitter-to-antenna port and return link antenna-to-receiver port functions, while the UAV diplexer is set up for return link transmitter-to-antenna port and return link antenna-to-receiver port functions. The diplexer sweep data is listed in Table 1-8.

Two GDT diplexers with large serial number differences (implying different manufacturing lots) were measured. The frequency responses were notably different; therefore, it was assumed that the more restrictive frequency response of the two GDT diplexers would represent the more restrictive fielded diplexers. The more restrictive GDT diplexer frequency responses are provided in Table 3-2.

Table 3-2. GDT Diplexer Frequency Response

Port Type	-60 dB, MHz	-40 dB, MHz	-20 dB, MHz	-3 dB, MHz	-3 dB, MHz	-20 dB, MHz	-40 dB, MHz	-60 dB, MHz
GDT Diplexer								
Transmitter to Antenna	5537.0	5571.0	5592.0	5609.0	5907.0	5923.0	5950.0	6009.0
Antenna to Receiver	4978.7	5101.3	5101.3	5213.3	5504.0	5549.3	5600.0	5640.0

Two UAV diplexers with small serial number differences (implying same manufacturing lots) were also measured. The frequency responses were nearly identical. In the absence of data to the contrary, it was assumed that the UAV diplexer frequency response was representative of the fielded diplexers. The more restrictive UAV diplexer frequency responses are provided in Table 3-3.

Table 3-3. UAV Diplexer Frequency Response

Emission Type	-60 dB, MHz	-40 dB, MHz	-20 dB, MHz	-3 dB, MHz	-3 dB, MHz	-20 dB, MHz	-40 dB, MHz	-60 dB, MHz
UAV Diplexer								
Transmitter to Antenna	5120.0	5173.3	5200.0	5221.3	5506.7	5526.7	5552.0	5585.3
Antenna to Receiver	5413.3	5536.0	5565.3	5596.0	5906.7	5948.0	6009.3	6136.0

The most restrictive GDT diplexer transmitter-to-antenna port and UAV diplexer antenna-to-receiver port frequency responses were extracted. Even though a -20 dB emission bandwidth is adequate to fit the emissions within the -3-dB bandwidth of the diplexer, a -40-dB emission bandwidth was used to provide a safety margin. The same process was followed for the UAV diplexer transmitter-to-antenna port; the most restrictive GDT diplexer antenna-to-receiver port frequency responses were extracted. The half -40-dB bandwidth for the command link and return link were 421 kHz and 11250 kHz, respectively. The resulting available command link and return link tuning ranges were 5610 – 5850 MHz and 5250 – 5492 MHz, respectively. The resulting diplexer crossover band and bandwidth were 5492 – 5610 MHz and 118 MHz, respectively. This is a considerable reduction in crossover bandwidth (from 150 MHz to 118-MHz), providing an additional 15-MHz command link bandwidth and 17-MHz return link bandwidth with no system modifications.

3.1.4 GDT-to-GDT Minimum Physical Separation Requirements

GDT-to-GDT physical separation requirements are driven by spurious emissions and spurious responses. Spurious emissions were discussed in Section 3.1.2. Spurious responses are generated by non-linear operations resulting from emissions from a neighboring GDT(s) injected into the GDT receiver front-end. Although spurious response attenuation was not measured, it was assumed to be -30 dB. This value is lower than typical receivers since there is no RF filter to provide protection to the receiver front-end. Equation 3-1 was used to calculate minimum separation distance. Calculation results are listed in Table 3-4.

$$MinDist = 10^{\left(\frac{P_T - A_{SE} + G_T + G_R - L_D - L_S - A_{SR} - I_T - 20\log f + 27.55}{20}\right)} \tag{3-1}$$

where MinDist = minimum GDT-to-GDT separation distance, in m
- P_T = transmitter power, 40.0 dBm
- A_{SE} = spurious emission attenuation, in dB
- G_T = transmitter antenna gain in the direction of the receiver antenna, in dBi
- G_R = receiver antenna gain in the direction of the transmitter antenna, in dBi
- L_D = diplexer loss, in dB
- L_S = total (transmitter and receiver) system losses, 3 dB
- A_{SR} = spurious response attenuation, in dB
- I_T = received interference power threshold, in dBm
- f = frequency, in MHz
- 27.55 = proportionality constant

Table 3-4. Minimum GDT-to-GDT Distance Separation Calculations

P_T, dBm	A_{SE}, dB	G_T, dBi	G_R, dBi	L_D, dB	L_S, dB	A_{SR}, dB	I_T, dBm	20logf, dB	Constant	MinDist, m
40.0	73.9	4.3	4.3	60.0	3.0	0.0	-108.4	74.8	27.6	0.0
40.0	0.0	4.3	4.3	60.0	3.0	30.0	-108.4	75.0	27.6	6.6

The received interference-power threshold, based on an interference-to-noise power ratio threshold of -9 dB, was determined to be -108.4 dBm using Equation 3-2.[3-1] The -3-dB receiver selectivity bandwidth value of 18 MHz was extrapolated from measured return link selectivity data.

$$I_T = -114 + 10\mathrm{Log}(B_{IF}) + NF + (I/N)_T \tag{3-2}$$

[3-1] M. Coleman-Ragland, L. McIntyre, et al., *EMC Analysis Handbook*, JSC-CR-97-010, Annapolis, MD: DoD Joint Spectrum Center, March 1997.

where B_{IF} = -3-dB bandwidth of the intermediate frequency (IF) amplifier, 18.0 MHz
NF = receiver noise figure, 2.0 dB
$(I/N)_T$ = interference-to-noise power ratio threshold, -9 dB

and all other terms are as previously defined.

The JSC Statistical Antenna Gain model[3-2] was utilized to estimate off-axis antenna gain. The gain of the transmitter antenna in the direction of the receiver antenna, and the gain of the receiver antenna in the direction of the transmitter antenna, was calculated using the assumption that 77.6 percent of the time both antenna mainbeams would be off-axis to each other by more than 41 degrees. This correlates to a 95th-percentile mutual coupling. The gains of the GDT dish and horn antennas at 41 degrees off-axis were estimated to be -1.82 and +4.25 dBi, respectively.

3.1.5 Received Power vs. SSI % Correlation

As the SSI drops below 37 %, the air vehicle operator datalink SSI display characters change from green to yellow. The air vehicle operator typically switches to a higher-gain antenna or limits the UAV to this range.

Return link received power vs. SSI % was similar for both the 17M0F9F and 4M72F1D modulations, as shown in Figure 1-4. For the return link waveforms, 37 % SSI corresponds to -74.2-dBm received power.

Command link received power vs. SSI % was similar for both the 560KF1D and 88K3F1D modulations, as shown in Figure 1-4. For the command link waveforms, 37 % SSI corresponds to -82.5 dBm received power.

For the same datalink system, or the command and return links associated with same GDT and UAV, the minimum SSI % was driven by the return link. The command link SSI was 50 % when the return link SSI was 37 %. For the purpose of this analysis, received power for both the command and return links was assumed to be -74.2 dBm.

Note: According to ASI, received power vs. SSI % may vary from GCS to GCS; however, -74.2 dBm was considered valid since the variance would most likely be sufficiently small.

[3-2] W.R. Klocko, T.L. Strickland, *Environmental Analysis System (EASY) Statistical Antenna Gain Model for Fixed-Azimuth Antennas*, ECAC-TN-85-023, Annapolis, MD: DoD ECAC (now DoD JSC), February 1986.

3.1.6 Receiver Sensitivity

Command link and return link sensitivity values are shown in Figure 1-4 and listed in Table 1-9. However, aside from normalization of the adjacent-signal performance curves, shown in Figures 1-7 and 1-8 and discussed in Section 3.1.10, sensitivity was not used in this analysis as a minimum received power because this analysis was interference-limited, not noise-limited. This analysis used a datalink minimum desired received power of -74.2 dBm.

3.1.7 Datalink Range vs. Antenna Configuration

Equation 3-3 was used to determine the maximum range for each antenna configuration, while maintaining 37 % SSI for high- and low-power modes. As a potential solution for UAV taxi and test functions, a range for a "medium-power" transmitter mode of 20 dBm was calculated. The maximum range vs. antenna configuration is listed in Table 3-5.

$$\text{Range} = 10^{\left(\frac{P_T + G_T + G_R - L_S - P_R - 20\log f - 37.8}{20}\right)} \quad (3\text{-}3)$$

where Range = communications range, in nmi

P_R = received power, -74.2 dBm

37.8 = proportionality constant

and all other terms are as defined previously.

Table 3-5. Datalink Range vs. Antenna Configuration for 37 % SSI, High Power

UAV Antenna	GDT Antenna	Calculated Communications Range					
		High Power		Low Power		Medium Power*	
		nmi	km	nmi	km	nmi	km
Horn	Dish	LOS-Limited		1.4	2.5	13.5	25.1
Omni	Dish	34.0	63.0	0.3	0.6	3.4	6.3
Horn	Horn	27.0	50.0	0.3	0.5	2.7	5.0
Omni	Horn	6.8	12.6	0.1	0.1	0.7	1.3
Horn	Omni	9.6	17.7	0.1	0.2	1.0	1.8
Omni	Omni	2.4	4.5	0.0	0.0	0.2	0.4
*Not a current capability; limited to Scenario 2 option.							

3.1.8 Receiver Gain Compression

Command link gain compression points were consistent for both the 560KF1D and 88K3F1D modulations. Return link gain compression points were consistent for both the 17M0F9F and 4M72F1D modulations. The measured command and return link gain compression points were -34.4 dBm and -28.3 dBm, respectively.

3.1.9 Receiver Intermodulation Products

Receiver intermodulation (IM) products, or spurious responses, can be generated when two or more signals at frequencies other than the intended receive frequency are inputted into a non-linear device. Third-order IM products are of primary concern since the power is greater than that of higher-order IM products.

Two-signal, third-order IM product frequencies can be determined by $\pm 2p \pm q$ and $\pm 2q \pm p$ where p and q are frequencies of the first and second signals. As an example, if p and q were 5350 MHz and 5375 MHz, then the positive third order IM products would be 16,075, 5325, 16,100, and 5400 MHz. Of these, 5325 and 5400 MHz would be of particular concern since they are potential return link frequencies.

Three-signal, third-order IM products are a concern because they will produce more in-band frequencies. For three-signal IM products, the third-order IM product frequencies can be determined by $\pm p \pm q \pm r$ where p, q, and r are frequencies of the first, second, and third signals. For example, if p, q, and r were 5250 MHz, 5275 MHz, and 5375 MHz, then the positive third-order IM products would be 15,900, 5150, 5350, and 5400 MHz. Of these, 5150, 5350, and 5400 MHz would be of particular concern since they are potential return link frequencies.

Two-signal, third-order IM product power can be determined by calculating p and q signal input power and determining the third-order IM output product power using Figure 3-1. The third-order IM output product power was referenced to third-order IM input product power by subtracting the LNA gain of 18.0 dB. For example, if the input power is -30.0 dBm, the third-order IM product output power is -70.0 dBm, and, referencing to the LNA input, the third-order IM product input power is -88.0 dBm.

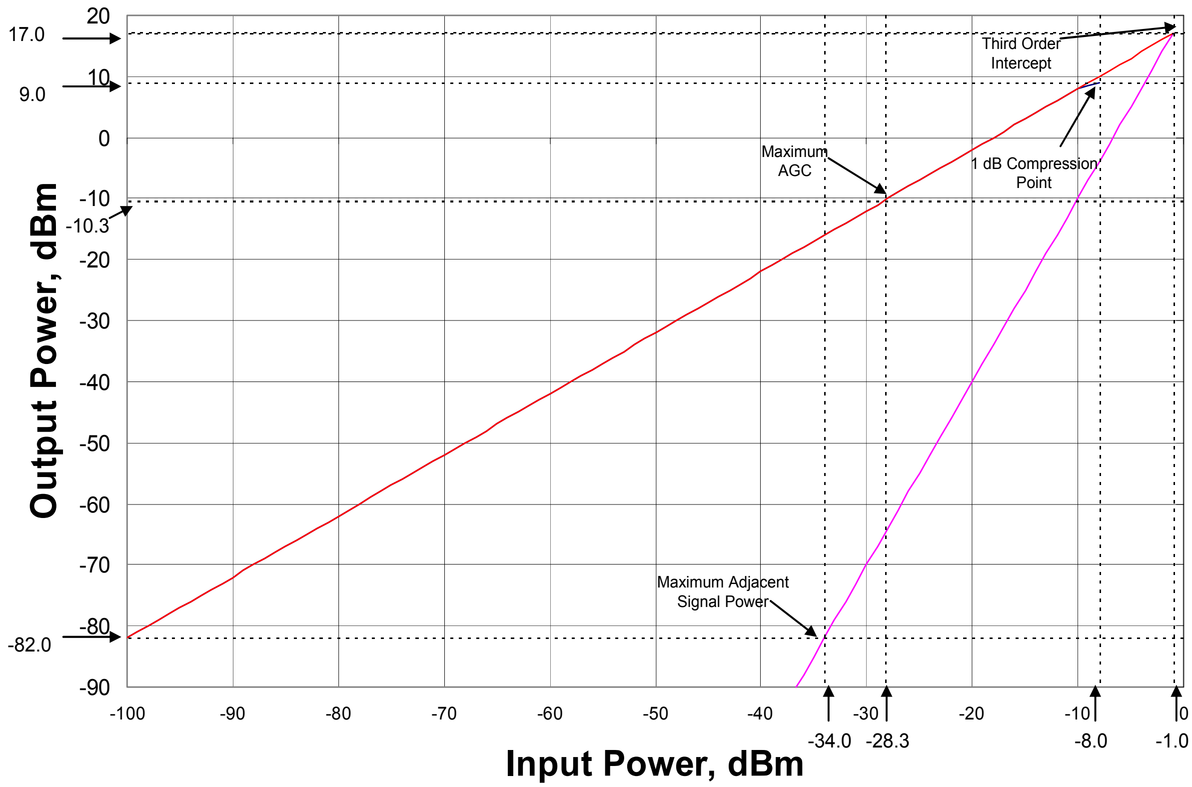


Figure 3-1. LNA IM Product Power Curve

Based on the non-linear power series expansion for IM product, the three-signal, third-order IM product power is 6-dB greater than that of two-signal, third-order IM product. Because of the two-to-one slope differential between the third-order and the first-order lines shown in Figure 3-1, the maximum return link input power is reduced by 3-dB. Therefore, the maximum return link power to preclude three-signal, third-order IM interference should be -37 dBm.

Randomizing the return link frequency spacing is not recommended as a solution. Randomization through frequency planning is not feasible because of the large number of IM product frequencies produced by three-signal IM products. The lack of spectrum bandwidth is also a constraining issue. Reduction of maximum received power is offered as an alternative solution and is investigated in this section.

Figure 3-2 illustrates that on-tune signals at levels of -100 dBm and weaker will not produce interference effects. Figure 3-1 illustrates that the LNA output power for a -100 dBm input signal is -82 dBm. Figure 3-1 also illustrates that a -82 dBm two-signal, third-order IM product is produced when two -34 dBm extraneous signals are present at the LNA input. Therefore, the maximum return link input power (two extraneous signals) at the LNA input should be -34 dBm or weaker to preclude two-signal, third-order IM product interference.

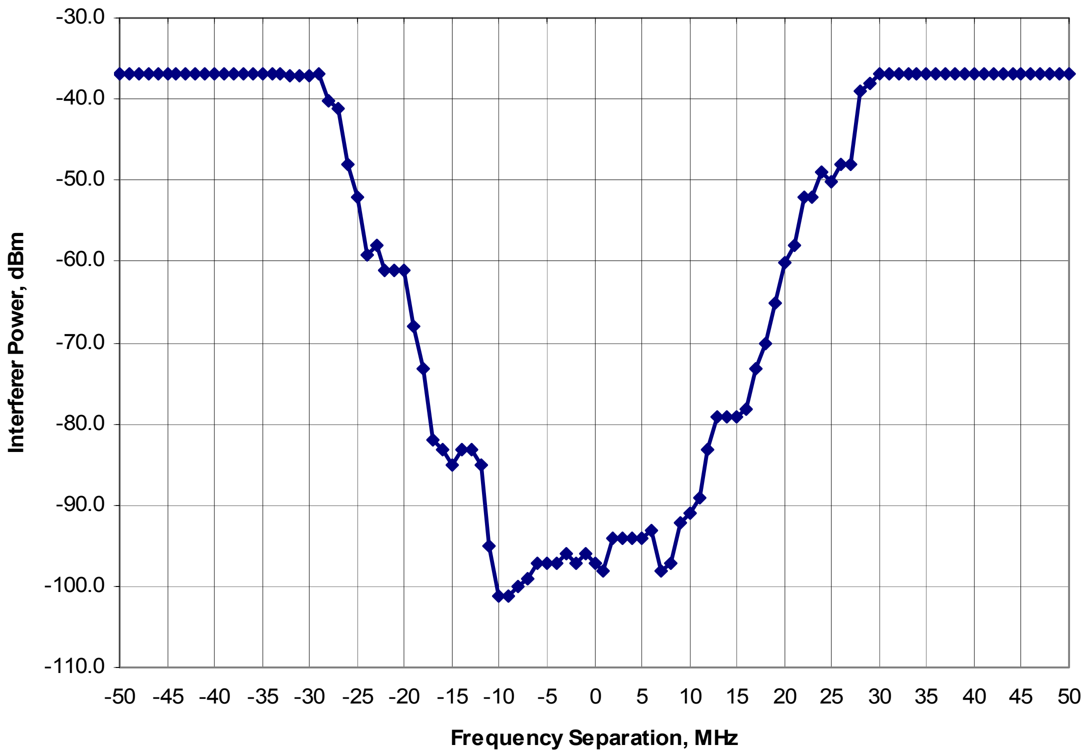


Figure 3-2. Return Link Adjacent-Signal Performance

The three-signal, third-order IM product power is -6-dB greater than that of two-signal, third-order IM products. Therefore, the maximum return link input power to preclude three-signal, third-order IM interference should be -37 dBm.

Command link maximum return link input power should be -34.4 dBm.

3.1.10 Adjacent-Signal Performance

The adjacent-signal performance curves shown in Figures 1-7 and 1-8 were measured using minimum discernable signal plus 3-dB received power. This corresponds to -102.3, -85.3, and -81.3 dBm for 560KF1D, 17M0F9F, and 4M72F1D, respectively. The curves were referenced to -74.2 dBm received power by maintaining a constant S/I and raising the curves 28.1, 11.1, and 7.1 dB for 560KF1D, 17M0F9F, and 4M72F1D, respectively. The high interference power limit was then flat-lined at the receiver gain-compression powers of -34.4 dBm for the command link and -28.3 dBm for the return link. Finally, the command and return link worst-case envelopes were generated. It should be noted that the command link values were adjusted to smooth the data. The resulting adjacent-signal performance curves are shown in Figures 3-2 and 3-3, with the data listed in Tables 3-6 and 3-7.

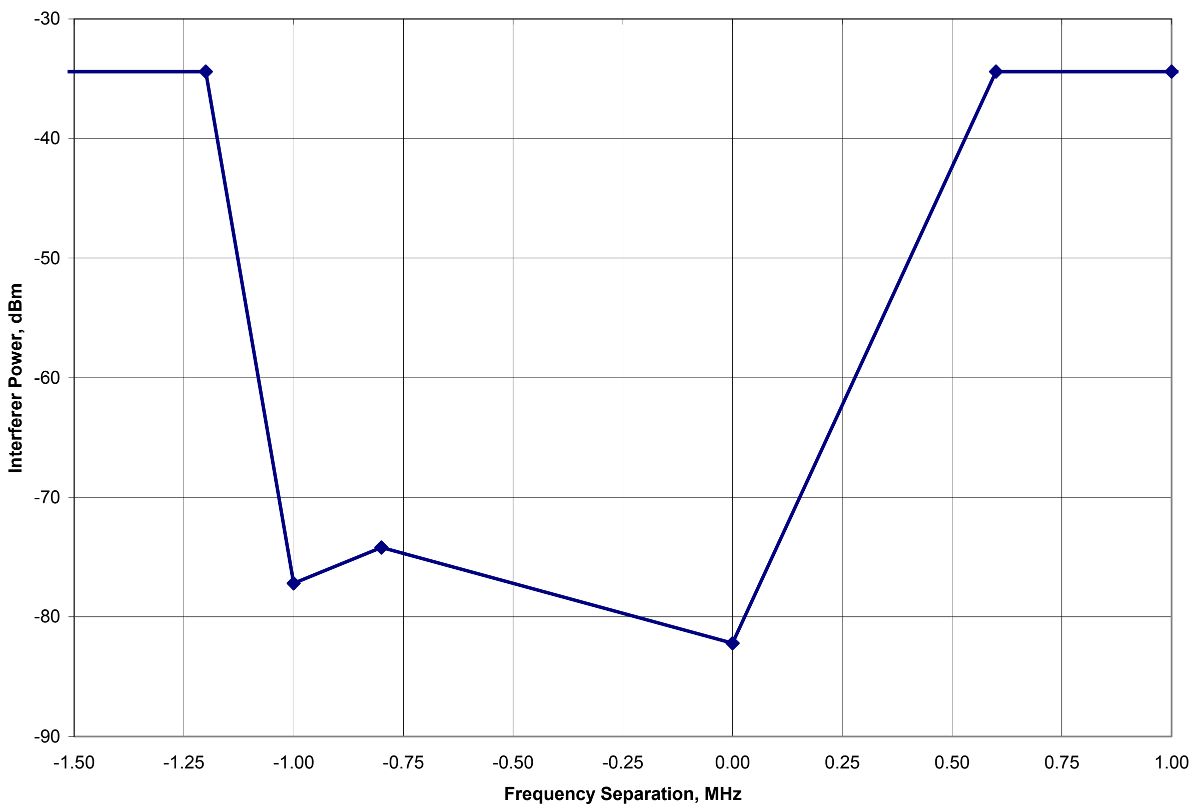


Figure 3-3. Command Link Adjacent-Signal Performance

Table 3-6. Return Link Adjacent-Signal Performance

Frequency Separation, MHz	I_T, dBm	Frequency Separation, MHz	I_T, dBm	Frequency Separation, MHz	I_T, dBm	Frequency Separation, MHz	I_T, dBm
-50	-37.0	-24	-59.1	2	-94.1	28	-39.1
-49	-37.0	-23	-58.1	3	-94.1	29	-38.1
-48	-37.0	-22	-61.1	4	-94.1	30	-37.0
-47	-37.0	-21	-61.1	5	-94.1	31	-37.0
-46	-37.0	-20	-61.1	6	-93.1	32	-37.0
-45	-37.0	-19	-68.1	7	-98.1	33	-37.0
-44	-37.0	-18	-73.1	8	-97.1	34	-37.0
-43	-37.0	-17	-82.1	9	-92.1	35	-37.0
-42	-37.0	-16	-83.1	10	-91.1	36	-37.0
-41	-37.0	-15	-85.1	11	-89.1	37	-37.0
-40	-37.0	-14	-83.1	12	-83.1	38	-37.0
-39	-37.0	-13	-83.1	13	-79.1	39	-37.0
-38	-37.0	-12	-85.1	14	-79.1	40	-37.0
-37	-37.0	-11	-95.1	15	-79.1	41	-37.0
-36	-37.0	-10	-101.1	16	-78.1	42	-37.0
-35	-37.0	-9	-101.1	17	-73.1	43	-37.0
-34	-37.0	-8	-100.1	18	-70.1	44	-37.0
-33	-37.0	-7	-99.1	19	-65.1	45	-37.0
-32	-37.1	-6	-97.1	20	-60.1	46	-37.0
-31	-37.1	-5	-97.1	21	-58.1	47	-37.0
-30	-37.1	-4	-97.1	22	-52.1	48	-37.0
-29	-37.0	-3	-96.1	23	-52.1	49	-37.0
-28	-40.1	-2	-97.1	24	-49.1	50	-37.0
-27	-41.1	-1	-96.1	25	-50.1		
-26	-48.1	0	-97.1	26	-48.1		
-25	-52.1	1	-98.1	27	-48.1		

Table 3-7. Command Link Adjacent-Signal Performance

Frequency Separation, MHz	I_T, dBm
-2.0	-34.4
-1.2	-34.4
-1.0	-77.2
-0.8	-74.2
0	-82.2
0.6	-34.4
1.0	-34.4

3.1.11 Operational Dynamic Range

Operational dynamic range was calculated assuming the air vehicle operator maintains an SSI above 37%. The command link operational dynamic range of 39.8 dB was calculated by subtracting received power (-74.2 dBm) from the gain compression received power value. The return link operational dynamic range of 37.2 dB was calculated by subtracting received power from the maximum return link input power for three-signal, third-order IM products.

3.1.12 Receiver Selectivity

The command link receiver selectivity curves for the 560KF1D and 88K3F1D modulations were combined to generate a worst case selectivity curve. The resulting command link values are listed in Table 3-8. The return link values are listed in Table 3-9.

Table 3-8. Command Link Receiver Selectivity Data

Frequency Separation, MHz	Attenuation, dB
-1.6	58
-1.2	56
-0.8	17
-0.4	0
-0.2	0
0	4
0.2	2
0.4	7
0.8	23
1.2	60
1.6	63

Table 3-9. Return Link Receiver Selectivity Data

Frequency Separation, MHz	Attenuation, dB	Frequency Separation, MHz	Attenuation, dB	Frequency Separation, MHz	Attenuation, dB
-50	75.0	-14	59.5	20	71.4
-48	75.0	-12	35.2	22	71.4
-46	75.0	-10	5.1	24	74.0
-44	75.0	-8	1.5	26	74.0
-42	71.6	-6	1.5	28	74.0
-40	69.9	-4	1.5	30	70.0
-38	69.9	-2	1.5	32	69.8
-36	69.9	0	0	34	71.6
-34	74.0	1	3.4	36	71.6
-32	71.7	2	3.5	38	71.6
-30	74.5	4	3.5	40	76.0
-28	74.5	6	3.6	42	76.0
-26	72.8	8	3.6	44	76.0
-24	70.4	10	5.3	46	72.0
-22	69.7	12	29.7	48	74.1
-20	68.5	14	60.3	50	73.0
-18	68.5	16	65.3		
-16	65.2	18	69.3		

3.1.13 Two-UAV Return Link Distance and Frequency Separation Requirements

Equation 3-1 was used to convert the I_T data (listed in the adjacent-signal performance data provided in Table 3-6) to minimum distances. The calculated minimum distance values are shown in Figure 3-4 and listed in Table 3-10. The distance separations listed in Table 3-10 can be used to prevent EMI for 95 % of all possible coupling conditions. Reviewing the planned layout shown in Figure 3-5, the existing towers are 335 m from runway 08/26 and 242 m from the south end of 13/31. The planned towers are 1185 m from runway 08/26 and 562 m from runway 13/31. Frequency separations based on the physical layout and high-power mode interferer transmitter are provided in Table 3-11.

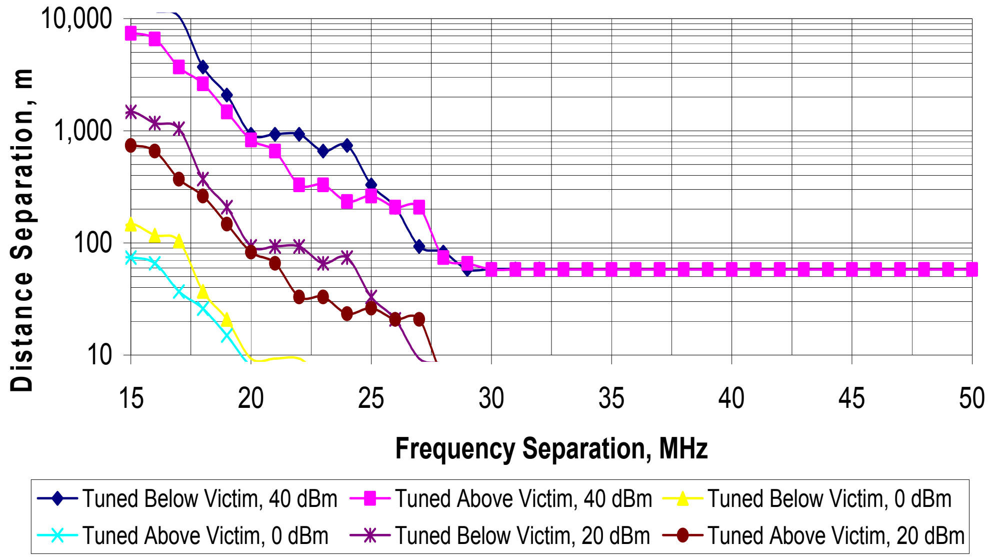


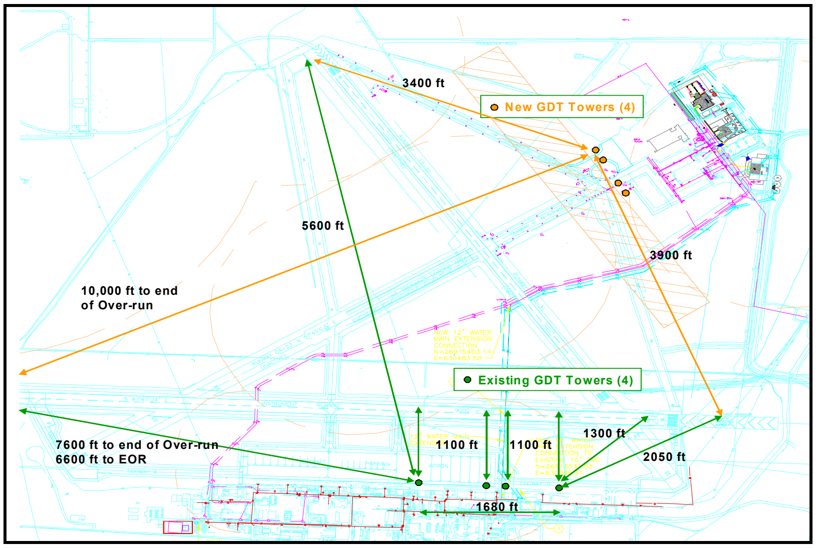
Figure 3-4. UAV-to-GDT Frequency-Distance Separation Requirements

Table 3-10. UAV-to-GDT Frequency-Distance Separation Requirements

Frequency Separation, MHz	Distance Separation, m					
	High-Power Mode		Low-Power Mode		Medium-Power Mode	
	Tuned Below Victim	Tuned Above Victim	Tuned Below Victim	Tuned Above Victim	Tuned Below Victim	Tuned Above Victim
50	58	58	1	1	6	6
49	58	58	1	1	6	6
48	58	58	1	1	6	6
47	58	58	1	1	6	6
46	58	58	1	1	6	6
45	58	58	1	1	6	6
44	58	58	1	1	6	6
43	58	58	1	1	6	6
42	58	58	1	1	6	6
41	58	58	1	1	6	6
40	58	58	1	1	6	6
39	58	58	1	1	6	6
38	58	58	1	1	6	6
37	58	58	1	1	6	6
36	58	58	1	1	6	6
35	58	58	1	1	6	6
34	58	58	1	1	6	6
33	58	58	1	1	6	6
32	59	58	1	1	6	6
31	59	58	1	1	6	6

Table 3-10. UAV-to-GDT Frequency-Distance Separation Requirements (continued)

Frequency Separation, MHz	Distance Separation, m					
	High-Power Mode		Low-Power Mode		Medium-Power Mode	
	Tuned Below Victim	Tuned Above Victim	Tuned Below Victim	Tuned Above Victim	Tuned Below Victim	Tuned Above Victim
30	59	58	1	1	6	6
29	58	66	1	1	6	7
28	83	74	1	1	8	7
27	93	209	1	2	9	21
26	209	209	2	2	21	21
25	330	262	3	3	33	26
24	740	234	7	2	74	23
23	659	330	7	3	66	33
22	931	330	9	3	93	33
21	931	659	9	7	93	66
20	931	830	9	8	93	83
19	2,085	1,476	21	15	209	148
18	3,708	2,625	37	26	371	262
17	10,450	3,708	104	37	1,045	371
16	11,725	6,593	117	66	1,173	659
15	14,761	7,398	148	74	1,476	740
14	11,725	7,398	117	74	1,173	740
13	11,725	7,398	117	74	1,173	740
12	14,761	11,725	148	117	1,476	1,173
11	46,678	23,395	467	234	4,668	2,339
10	93,136	29,452	931	295	9,314	2,945
9	93,136	33,046	931	330	9,314	3,305
8	83,007	58,765	830	588	8,301	5,876
7	73,980	65,935	740	659	7,398	6,593
6	58,765	37,078	588	371	5,876	3,708
5	58,765	41,602	588	416	5,876	4,160
4	58,765	41,602	588	416	5,876	4,160
3	52,374	41,602	524	416	5,237	4,160
2	58,765	41,602	588	416	5,876	4,160
1	52,374	65,935	524	659	5,237	6,593
0	58,765	58,765	588	588	5,876	5,876



Ft	m
1100	335
1300	396
1680	512
2050	625
3400	1036
3900	1189
5600	1707
6600	2012
7600	2317
10000	3048

Figure 3-5. Proposed GDT Locations

Table 3-11. Frequency Separation Requirements

Existing/Proposed Towers	Runway	Frequency Separation, MHz					
		High Power		Low Power		Medium Power	
		Tuned Below Victim	Tuned Above Victim	Tuned Below Victim	Tuned Above Victim	Tuned Below Victim	Tuned Above Victim
Existing	08/26	24	21	11	8	18	17
Existing	13/31	25	23	11	10	18	18
Proposed	08/26	19	19	10	7	15	11
Proposed	13/31	24	21	10	8	17	16

3.1.14 Same UAV Return Link Frequency Separation Requirements

Frequency separation requirements for two return links on the same UAV are based on the received-power difference from the primary to the secondary link. The primary link usually utilizes the UAV horn antenna, while the secondary link utilizes the stacked-dipole antenna. There is a 12-dB difference in antenna gains. A conservative 20-dB wing propagation blockage was assumed for the secondary link. This results in a worst case power differential of 32 dB.

Assuming the secondary link SSI is 37 % (-74.2 dBm received power), the primary link received power must be -42.2 dBm or more, as calculated using Equation 3-4. Setting I_T equal to -42.2 dBm and using Table 3-6, the required frequency separation for the primary link tuned below the secondary link is 28 MHz, and for the primary link tuned above the secondary link is 29 MHz.

$$P_{R1} = P_{R2} + 32.0 \tag{3-4}$$

where P_{R1} = primary link received power, in dBm
P_{R2} = secondary link received power, in dBm

3.1.15 Command Link Frequency Separation Requirements

Command link interference power thresholds are listed in Table 3-7 and shown in Figure 3-3. Using Equation 3-4 and Table 3-7, the command link frequency separation requirement for the primary command link tuned either below or above the secondary link is 2 MHz.

3.2 SCENARIO 1: OPERATE WITH NO EQUIPMENT MODIFICATIONS

The objective is to compatibly operate eight datalink systems, seven for full-use and one for ground-use only. Frequency separation requirements identified in Table 3-11 and Sections 3.1.3, 3.1.14, and 3.1.15 were reviewed to develop a frequency plan to optimize use of the available bandwidth.

It is recommended that the use of unlicensed 5-GHz devices be restricted during periods when 5250 – 5850-MHz configured Predator UAVs are operating. This issue is discussed in Section 1.3.2 and in detail in Reference 1-3.

There is 240 MHz of bandwidth available (5610 – 5850 MHz) for command link use. The command link frequency separation requirements are 2 MHz. Sixteen frequencies are required to support eight full datalink systems. The total required command link frequency band is 32 MHz, including 1-MHz guard bands above and below. The software default test and maintenance frequency set is fixed at 5800 and 5850 MHz. The requirements are easily met with 240 MHz of bandwidth available.
There is 242 MHz of bandwidth available (5250 – 5492 MHz) for return link use. The return link frequency separation requirements are listed in Table 3-11 and Section 3.1.14. The existing tower has greater frequency separation requirements than the proposed tower, due to the close proximity of the existing tower to the runways.

The software default test and maintenance frequency set is fixed at 5300 and 5350 MHz. If 5300 and 5350 MHz are restricted to high-power mode, required frequency separation to preclude EMI to adjacent-channel receivers is 25 MHz both above and below 5300 and 5350 MHz.

The optimized frequency layout without operational changes is listed in Table 3-12.

Table 3-12. Proposed Frequency Plan Without Operational Changes

Frequency Set Number	Frequency, MHz	Tower Location	Purpose
1	5250	Proposed	High-Power Flight, Launch, Recovery, and Taxi
1	5325		
2	5275		
2	5375		
3	5400	Either	
3	5450		
4	5425		
4	5475		
Test	5300	Either	Low-Power Test and Maintenance, High-Power Taxi
Test	5350		

Two operational changes were investigated without an increase in the number of available frequency sets. The first was to move test frequencies so they are adjacent and at one end of the frequency band. The second was to use existing towers for launch, recovery, and taxi functions and use proposed towers for range operations.

A third operational change was to use a single primary return link when at long range. This would entail one test frequency set, two proposed tower frequency sets, and four single-channels for use with either the proposed or existing towers. This plan permits seven datalink systems; two for full use, four for long- range use, and one for ground-based tests. This plan will require occasional datalink hand-off between the existing and proposed GDT towers. A potential frequency plan is listed in Table 3-13.

Table 3-13. Proposed Frequency Plan With Single Long-Range Return Links

Frequency Set Number	Frequency, MHz	Tower Location	Purpose
1	5250	Proposed	High-Power Flight, Launch, Recovery, and Taxi
1	5325		
2	5275		
2	5375		
3	5400	Either	High-Power Flight
4	5450		
5	5425		
6	5475		
Test	5300	Either	Low-Power Test and Maintenance, High-Power Taxi
Test	5350		

3.3 SCENARIO 2: MODIFY RETURN LINK TRANSMITTERS TO ADD MEDIUM-POWER MODE

Scenario 2 modifies the return link transmitter system to include a medium-power mode (20 dBm) with the existing low- (0 dBm) and high- (40 dBm) power modes.

The objective is to compatibly operate eight datalink systems; seven for full use and one for ground-use only. Frequency separation requirements identified in Table 3-11 and Sections 3.1.3, 3.1.14, and 3.1.15 were reviewed to develop a frequency plan to optimize use of the available bandwidth.

It is recommended that the use of unlicensed 5-GHz devices be restricted during periods when 5250 – 5850-MHz configured Predator UAVs are operating. This issue is discussed in Section 1.3.2 and in detail in Reference 1-3.

Since there were no command link issues, no command link changes were proposed.

There is 242 MHz of bandwidth available (5250 – 5492 MHz) for return link use. The return link frequency separation requirements are listed in Table 3-11 and Section 3.1.14. The existing tower has greater frequency separation requirements than the proposed tower due to the close proximity to the runways of the existing tower.

The software default test and maintenance frequency set is fixed at 5300 and 5350 MHz. If 5300 and 5350 MHz are restricted to high-power mode, required frequency separation to preclude EMI to adjacent-channel receivers is 25 MHz both above and below 5300 and 5350 MHz.

Moving test frequencies to 5250 and 5275 MHz did not increase the number of frequency sets. A potential frequency plan using a medium-power mode and the test frequency defaults is listed in Table 3-14. This plan permits five datalink systems; two for full use with proposed GDT tower use, two for close-in operations, and one for ground-based test. This plan will require occasional datalink hand-off between the existing and proposed GDT towers.

Table 3-14. Proposed Frequency Plan With Medium-Power Mode and Test-Frequency Defaults

Frequency Set Number	Frequency, MHz	Tower Location	Purpose
1	5250	Either	Medium-Power Launch and Recovery, High-Power Taxi
1	5325		
2	5275		
2	5375		
3	5400	Proposed	High-Power Flight, Launch, Recovery, and Taxi
3	5448		
4	5424		
4	5472		
Test	5300	Either	Low-Power Test and Maintenance, High-Power Taxi
Test	5350		

An additional operational change option was to use a single primary return link when at long range. This would entail one test frequency set, two medium power mode tower frequency sets, and four single channels for use with either the proposed or existing towers, for a total of seven links. This plan will require occasional datalink hand-off between the existing and proposed GDT towers. A potential frequency plan is listed in Table 3-15. This option is not recommended due to operational complexities.

Table 3-15. Proposed Frequency Plan With Medium-Power Mode and Single Long-Range Return Link Modifications

Frequency Set Number	Frequency, MHz	Tower Location	Purpose
1	5250	Either	Medium-Power Launch and Recovery, High-Power Taxi
1	5325		
2	5275		
2	5375		
3	5400	Proposed	High-Power Long-Range Flight Operations
4	5424		
5	5448		
6	5472		
Test	5300	Either	Low-Power Test and Maintenance, High-Power Taxi
Test	5350		

3.4 SCENARIO 3: MODIFY DIPLEXER FREQUENCY BANDS TO ENLARGE RETURN LINK BAND

The objective is to compatibly operate eight datalink systems; seven for full use and one for ground use only. Frequency separation requirements identified in Table 3-11 and Sections 3.1.3, 3.1.14, and 3.1.15 were reviewed to develop a frequency plan to optimize use of the available bandwidth.

It is recommended that the use of unlicensed 5-GHz devices be restricted during periods when 5250 – 5850-MHz configured Predator UAVs are operating. This issue is discussed in Section 1.3.2 and in detail in Reference 1-3.

Scenario 3 modifies the return link transmitter system to enlarge the diplexer return link pass band. If the command link frequency requirements and the 5800/5850-MHz test default frequencies are maintained, command link operations can be contained within the 5798 – 5850-MHz band. Subtracting the current 118-MHz diplexer crossover band provides a remaining return link band of 5250 – 5680 MHz.

There is 430 MHz of bandwidth available (5250 – 5680 MHz) for return link use. The return link frequency separation requirements are listed in Table 3-11 and Section 3.1.14. The existing tower has greater frequency separation requirements than the proposed tower due to the close proximity of the existing tower to the runways.

The software default test and maintenance frequency set is fixed at 5300 and 5350 MHz. If the 5300 and 5350 MHz are restricted to high-power mode, required frequency separation to preclude EMI to adjacent-channel receivers is 25 MHz both above and below 5300 and 5350 MHz.

Scenario 3 permits eight datalink systems; three for full use with proposed GDT tower use, four for close-in operations, and one for ground-based test. This scenario will require occasional datalink hand-off between the existing and proposed GDT towers.

The optimized frequency layout with an enlarged return link diplexer passband is listed in Table 3-16. This scenario achieves the goal of eight frequency sets, including one test frequency set.

Table 3-16. Proposed Frequency Plan With Enlarged Return Link Diplexer Passband

Frequency Set Number	Frequency, MHz	Tower Location	Purpose
1	5250	Proposed	High-Power Flight, Launch, Recovery, and Taxi
1	5325		
2	5275		
2	5399		
3	5375		
3	5423		
4	5448	Either	
4	5498		
5	5473		
5	5548		
6	5523		
6	5598		
7	5573		
7	5623		
Test	5300	Either	Low-Power Test and Maintenance, High-Power Taxi
Test	5350		

3.5 SCENARIO 4: IMPROVE DIPLEXER FILTERING TO ENLARGE RETURN LINK BAND

Scenario 4 entails improved diplexer filtering to enlarge the available bandwidth without moving the passbands. The current diplexers have a 118-MHz crossover band that enables return links in the 5250 – 5492-MHz band and command links in the 5610 – 5850-MHz band. The operationally used value is a 150-MHz crossover band, enabling return links in the 5250 – 5475-MHz band and command links in the 5625 – 5850-MHz band. The current diplexers each have 11-pole transmitter-to-antenna port bandpass filters and 7-pole antenna-to-receiver port bandpass filters. Insertion loss for the transmitter-to-antenna path is approximately 0.7 dB and for the antenna-to-receiver path is approximately 0.4 dB. The total insertion loss for a datalink path is 1.1 dB.

It is recommended that the use of unlicensed 5-GHz devices be restricted during periods when 5250 – 5850-MHz configured Predator UAVs are operating. This issue is discussed in Section 1.3.2 and in detail in Reference 1-3.

Throughout this document the available return link has been based on measurements, rather than operationally recognized values. Any further improvement will require either a change in the type of filter or increasing the number of filter poles.

The current transmitter-to-antenna bandpass and antenna-to-receiver bandpass design could be replaced by a highpass/lowpass design. This would minimize crossover band size at the cost of EMI immunity from adjacent-band environmental transmitters. The antenna-to-receiver diplexer filter protects the receiver front-end. There is no RF preselector filter implemented in this receiver. For that reason, this option is not recommended.

Increasing the number of poles in each filter will increase the insertion loss, thereby decreasing communications range. The system designer has optimized this diplexer to attain the best filtering vs. insertion-loss tradeoff; therefore, this option is also not recommended.

3.6 SCENARIO 5: ADD 4400 – 4940-MHz DATALINK TO EXISTING SCENARIO 1 DATALINK CONFIGURATION

The Scenario 1 analysis resulted in two all-purpose frequency sets for use with the proposed towers, two all-purpose frequency sets for use with either proposed or existing towers, and one low-power test frequency set. The requirement is for at least seven all-purpose sets and one low-power test frequency set, so three additional frequency sets are needed.

Several frequency band restrictions were identified by the environmental and frequency band studies. The environmental study detailed in Section 1.3.1 recommended that return link operations be restricted to the 4400 – 4580-MHz band. The frequency band study detailed in Section 1.3.3 recommended no command link operations in the 4825 – 4835-MHz band. Based on the aforementioned restrictions, the return link frequency band should be contained within the 4400 – 4580-MHz band and the command link band could be contained within the 4835 – 4940-MHz to eliminate known frequency coordination issues. However, frequency coordination is possible and the designed return link frequency band can be 4400 – 4782 MHz and the command link frequency band can be 4900 – 4940 MHz. This would reserve 382 MHz for return link and 40 MHz for command link operations. An advantage to this option was that the datalink performance would be similar to the existing operations. The only difference that the air vehicle operators might notice would be the frequency numbers on the display.

Scenario 5 requires different transmitters, diplexers, receivers, and potentially LNAs and antennas. The Predator UAV design originally included either 4400 – 4940-MHz or 5250 – 5850-MHz frequency band operation, so much of the design effort has been completed.

The Predator squadrons could be set up so that one squadron has the 4400 – 4940-MHz design, while the other has the 5250 – 5850-MHz design. This would eliminate much of the current frequency scheduling requirements. Assuming the measured datalink performance for the 5250 – 5850-MHz band is the same as that in the 4400 – 4940-MHz band and does not change due to frequency coordination constraints. The proposed frequency sets are listed in Table 3-17.

Table 3-17. Proposed 4400 – 4782-MHz Return Link Frequency Plan

Frequency Set Number	Frequency, MHz	Tower Location	Purpose
1	4400	Either	High-Power Flight, Launch, Recovery, and Taxi
1	4450		
2	4425		
2	4500		
3	4475		
3	4550		
4	4525		
4	4600		
5	4575		
5	4650		
6	4625		
6	4700		
7	4675		
7	4750		
8	4725		
8	4775		

Scenario 5 is recommended since utilization of both the 4400 – 4940-MHz and 5250 – 5850-MHz frequency bands exceeds the requirements by provision for 12 all-use frequency sets and one test set.

3.7 SCENARIO 6: ADD TCDL TO EXISTING SCENARIO 1 DATALINK CONFIGURATION

The Scenario 1 analysis resulted in two all-purpose frequency sets for use with the proposed towers, two all-purpose frequency sets for use with either proposed or existing towers, and one low-power test frequency set. The requirement is for at least seven all-purpose sets and one low-power test frequency set, so three additional frequency sets are needed.

Several frequency band restrictions were identified by the environmental and frequency band studies. The environmental study detailed in Section 1.3.1 recommended that return link operations be coordinated with the DOE in the 14400 – 14800-MHz frequency band. The frequency band study detailed in Section 1.3.3 recommended no datalink operations in the 14400 – 14500-MHz band and no return link operations in the 15136.5 – 15350-MHz band. Based on the aforementioned restrictions, the return link frequency band should be contained within the 14500 – 14830-MHz portion of the

14400 – 14830-MHz standard operating band for the TCDL and the command link frequency band should be contained within the 15150 – 15350-MHz standard operating band for the TCDL.
An advantage to this option was that the return datalink could be integrated into the global information grid with less effort than the existing system, since the data is already packaged and digitized.

Scenario 6 requires resolution of the following issues:

- complete change of transmitters, diplexers, receivers, low-noise amplifiers and antennas
- reduced communications range, unless a directional antenna is integrated
- directional antenna beamwidth would decrease, requiring alternate pointing algorithms and lost-link procedures
- datalink does not maintain synchronization during outages.

The Predator squadrons could be set up so that one squadron has the 14500 – 15350-MHz design while the other has the 5250 – 5850-MHz design. This would eliminate much of the current frequency scheduling requirements. Equation 3-1 was used to recalculate distance separation based on the higher frequencies. The F-D separation requirements were evaluated based on the recalculated distances. The frequency separation requirements were determined to be 27 MHz and 25 MHz for the existing and new towers, respectively. Assuming the measured datalink performance for the 5250 – 5850-MHz band is the same in the 14500 – 15350-MHz band and the datalink performance is comparable to the measured datalink, the proposed frequency sets are listed in Table 3-18.

Table 3-18. Proposed 14500 – 14830-MHz Return Link Frequency Plan

Frequency Set Number	Frequency, MHz	Tower Location	Purpose
1	14500	Either	High-Power Flight, Launch, Recovery, and Taxi
1	14550		
2	14525		
2	14600		
3	14575		
3	14650		
4	14625		
4	14700		
5	14675		
5	14750		
6	14725		
6	14800		
7	14775		
7	14825		

This scenario is recommended, once the previously-mentioned TCDL issues are worked out. Operating in both the 14500 – 15350-MHz and 5250 – 5850-MHz frequency bands would permit exceeding the requirement by providing for 11 all-use frequency sets and one test set.

3.8 SCENARIO 7: ADD K_u-BAND ANALOG DATALINK TO EXISTING SCENARIO 1 DATALINK CONFIGURATION

The Scenario 1 analysis resulted in two all-purpose frequency sets for use with the proposed towers, two all-purpose frequency sets for use with either proposed or existing towers, and one low-power test frequency set. The requirement is for at least seven all purpose sets and one low power test frequency set, so three additional frequency sets are needed.

Several frequency band restrictions were identified by the environmental and frequency band studies. The environmental study detailed in Section 1.3.1 recommended that return link operations be coordinated with the DOE in the 14400 – 14800-MHz frequency band. The frequency band study detailed in Section 1.3.3 recommended no datalink operations in the 14400 – 14500-MHz band and no return link operations in the 15136.5 – 15350-MHz band. Based on the aforementioned restrictions, the return link frequency band should be contained within the 14500 – 14830-MHz portion of the 14400 – 14830-MHz standard operating band for the TCDL and the command link frequency band should be contained within the 15150 – 15350-MHz standard operating band for the TCDL.

Advantages to this option were that the return datalink is analog and, therefore, will not lose synchronization during outages. Since the design is not finalized, the return link tuning range could be expanded from 14500 – 14830 MHz to 14500 – 15000 MHz with the command link using 15300 – 15350 MHz. This frequency plan would provide 500 MHz for return link operation.

Scenario 7 requires resolution of the following issues:

- complete change of transmitters, diplexers, receivers, low-noise amplifiers and antennas
- reduced communications range, unless a directional antenna is integrated
- directional antenna beamwidth would decrease, requiring alternate pointing algorithms and lost-link procedures

The Predator squadrons could be set up so that one squadron has the 14500 – 15350-MHz design while the other has the 5250 – 5850-MHz design. This would eliminate much of the current frequency scheduling requirements. Assuming the measured datalink performance for the 5250 – 5850-MHz band is the same in the 14500 – 15350-MHz band and the datalink performance is comparable to the measured datalink, the proposed frequency sets are listed in Table 3-19.

Table 3-19. Proposed 14500 – 15000-MHz Return Link Frequency Plan

Frequency Set Number	Frequency, MHz	Tower Location	Purpose
1	14500	Either	High-Power Flight, Launch, Recovery, and Taxi
1	14550		
2	14525		
2	14600		
3	14575		
3	14650		
4	14625		
4	14700		
5	14675		
5	14750		
6	14725		
6	14800		
7	14775		
7	14850		
8	14825		
8	14900		
9	14875		
9	14950		
10	14925		
10	14975		

Scenario 7 is recommended, once the previously mentioned K_u-band analog issues are worked out. Operation in both the 14500 – 15350-MHz and 5250 – 5850-MHz frequency bands would permit exceeding the requirement by providing 14 all-use frequency sets and one test set.

SECTION 4 – RESULTS AND RECOMMENDATIONS

Seven scenarios representing different approaches to satisfy the objectives of this task were identified. Each scenario was analyzed to determine its effectiveness in terms of satisfying the overall requirement for the simultaneous operation of eight Predator frequency sets at ISAFAF.

Four of the seven scenarios are recommended: Scenarios 3, 5, 6, and 7, which are discussed in detail in Sections 3.4, 3.6, 3.7, and 3.8, respectively.

The four recommended scenarios are presented below:

- Scenario 3 modifies the diplexer frequency bands to enlarge the return link band. Results showed that frequency requirements can be met with unrestricted operations. This option is recommended.

- Scenario 5 considers adding a new 4400 – 4940-MHz datalink to be used in addition to the existing C-band datalink. This option provides more frequency sets than are required.

- Scenario 6 considers adding a new TCDL datalink to be used in addition to the existing C-band datalink. This option provides more frequency sets than are required and is recommended with reservations.

- Scenario 7 considers adding a new K_U-band analog datalink to be used in addition to the existing C-band datalink. This option provides more frequency sets than are required and is recommended with reservations.

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