Eccentric Communications Engineering, Inc.
35786 Geosynchronous Circle
Washington, DC 20004

December 14, 2012

Det 8 AFRL/RVKVV
ATTN: Luisa A. Martinez-Medina
3550 Aberdeen Ave
Bldg 413, Rm. 160
Kirtland AFB, NM 87117-5776

Dear Ms. Martinez-Medina,

Attached you will find our proposal in response to the AFRL/RV's broad agency announcement W/V-Band Satellite Communications Experiment – Phase 1 (BAA-RV-12-06). ECE takes no exception to any of the design criteria put forth in the BAA, and in several areas the proposed design meets or exceeds the objective requirements. ECE's many years of experience in high frequency satellite communications makes us the right choice to partner with your organization in this endeavor. ECE is excited to begin the technical period of performance as soon as we receive authorization to proceed.

Sincerely,

Colin McEwen
Vice President, Research Programs,
Eccentric Communications Engineering, Inc.

ECCENTRIC COMMUNICATIONS ENGINEERING, INC.

W/V-Band Satellite Communications Experiment – Phase 1

ECE6390 Fall 2012 Final Project

Colin McEwen

12/14/2012

This proposal includes data that shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed—in whole or in part—for any purpose other than to evaluate this proposal. If, however, a contract is awarded to this offeror as a result of—or in connection with—the submission of this data, the Government shall have the right to duplicate, use, or disclose the data to the extent provided in the resulting contract. This restriction does not limit the Government's right to use information contained in this data if it is obtained from another source without restriction. The data subject to this restriction are contained in sheets 1 through 18.

1. Executive Summary

Eccentric Communications Engineering, Inc. (ECE) is submitting this proposal in response to the Air Force Research Laboratory Space Vehicles Directorate (AFRL/RV) Broad Agency Announcement BAA-RV-12-06 W/V-Band Satellite Communications Experiment (WSCE) – Phase 1. By submitting this proposal, ECE is offering to perform the full scope of work defined by the BAA, as outlined by the contractor's statement of work included in Section 4, with no exception to any of the experiment design criteria.

The WSCE program, in support of two technical objectives, requires experimental measurements sufficient to statistically characterize atmospheric propagation physics at 71-76 GHz and 81-86 GHz to support systems engineering, assessment, and design of future operational military satellite communication architectures and systems. ECE's scope for Phase 1 of the experiment is intended to fully develop the concepts required in support of both the primary and secondary technical objectives outlined by the BAA to a level of maturity sufficient to complete the Preliminary Design Review (PDR) milestone.

ECE's proposal focuses on a risk-averse experiment design that maximizes the scientific benefits of the program while minimizing the cost and technical risk to AFRL/RV. The ECE experiment design makes use of commercial off-the-shelf (COTS) ground hardware and COTS spaceflight qualified hardware where available, minimizing the cost and schedule associated with developing new hardware. All threshold requirements are met by the proposed ECE experiment design and, where practical, several of the objective requirements are satisfied. The proposed program plan includes multiple off-ramp opportunities in the event that the program office chooses to re-evaluate any objective requirements in favor of threshold requirements to maintain programmatic and technical risk within an acceptable level.

2. Program Description

2.1. Overall Program Description

While Ka-band satellite communication technology has been proliferating over the past decade, the W/V-band portion of the radiofrequency (RF) spectrum remains generally unused. Before government and industry are able to make full use of these bands, the knowledge gap must first be filled with respect to the atmospheric propagation physics at such high frequencies. The W/V-Band Satellite Communications Experiment is intended to address these technical unknowns.

The primary technical objective of the WSCE program is to statistically characterize and model V-band propagation phenomena (signal attenuation, phase distortion, and depolarization) and correlate to atmospheric and meteorological parameters. The approach to meet the primary technical objective is to operate a beacon at a geostationary orbit over the continental United States (CONUS) that emits a narrowband reference signal that is then measured by multiple, disparate, ground data measurement receivers. Channel propagation effects can be assessed by comparing the received signal to the transmitted reference signal. As outlined in the BAA, the beacon experiment design criteria are summarized in Table 1.

Table 1. Beacon Experiment Design Criteria

Duration of data collection	Threshold: 36 months; Objective: 60

	months
Ground data collection sites	Multiple – exact number to be determined
Clear-day link margin	Threshold: 30 dB; Objective: 36 dB
Signal	Threshold: single tone at 73.5 GHz; Objective: three tones (e.g., at 71 GHz, 73.5 GHz, and 76 GHz)
Supplemental K-band beacon	Threshold: not included; Objective: Included
Transmit power	Design parameter to be determined
Transmit aperture size	Design parameter to be determined
Receive aperture	Design parameter to be determined

The secondary technical objective of this program is to develop and validate communication link models over the 71-76 GHz and 81-86 GHz frequency bandwidths. This technical objective necessitates a higher level of sophistication as bi-directional, modulated data signal measurements are required. Key measurements include bit-error-rate, link margin, and availability. As outlined in the BAA, the transponder experiment design criteria are summarized in Table 2.

Table 2. Transponder Experiment Design Criteria

Duration of data collection	Threshold: 36 months; Objective: 60 months – both intermittently (~10% duty cycle)
Ground sites	Threshold: single transceiver station; Objective: multiple transceiver stations (potentially using existing ground stations / antenna)
Clear-day link margin	Design parameter to be determined
Signal bandwidth / data rate	Threshold: bandwidth and signal-to-noise to support at least 19.2 kbps data rate; Objective: bandwidth and signal-to-noise to support at least 10 Mbps data rates
Number of carrier frequencies	Threshold: a single carrier frequency in the W-band (uplink) and a single carrier frequency in the V-band (downlink); Objective: three carriers in the W-band (uplink) (e.g., 81 GHz, 84.5 GHz, and 86 GHz), and a single V-band (downlink) carrier
Transmit power	Design parameter to be determined
Transmit aperture size	Design parameter to be determined
Receive aperture	Design parameter to be determined

For both objectives it is assumed that the flight unit will be a hosted payload on a primary spacecraft/bus to be determined by the Government, which will be positioned in a geostationary orbit (GEO) over CONUS (~100 deg West longitude). As directed by the BAA, the size, weight, and power are not considered to be limiting design requirements. It is assumed that the flight unit command, control, health and status will be accomplished through a communications link to the host spacecraft bus and that power will be provided by the host spacecraft.

The WSCE is planned to be accomplished in five program phases, as delineated in Table 3. ECE’s proposed approach for Phase 1 is presented in the Section 2.2.

Table 3. WSCE Planned Program Phases

Phase 1	Concept development to the Preliminary Design Review milestone
Phase 2	System design development to the Critical Design Review milestone; will include laboratory demonstrations for concept / design validation
Phase 3	Development and delivery of the engineering demonstration unit, the flight-ready system, and ground data collection systems
Phase 4	Pre-launch assembly, integration, and test support of the flight hardware
Phase 5	On-orbit experiment support

2.2. Phase 1 Program Description

In Phase 1 of the WSCE, ECE will further develop the experimental design concepts to a PDR level of maturity. This phase will culminate with a PDR milestone and technical report. The primary technical deliverables for Phase 1 are listed in Table 4. Draft and final versions of these documents will be delivered in accordance with the contract data requirements list (CDRL).

Table 4. Phase 1 Technical Deliverables

System Design Description
Experiment Plan
Interface Definition
Environment Definition

With fee it is estimated that ECE could perform Phase 1 at a cost of roughly $2,600,000. For more details on the cost and schedule estimates, see Section 3.2.

2.3. Approach

2.3.1. Beacon Experiment Design

The primary technical objective will be accomplished by operating a beacon from GEO that emits a narrowband reference signal that is then measured by multiple, disparate, ground data measurement receivers. Channel propagation effects can be assessed by comparing the received signal to the transmitted reference signal.

The proposed beacon architecture is illustrated in Figure 1, and is comprised of a K-band beacon and a V-band beacon. Since the K-band is well characterized in literature[1], it makes a good choice for an experiment reference that can be used to normalize any variations in the flight unit output. Both beacons will have a single linear polarization.

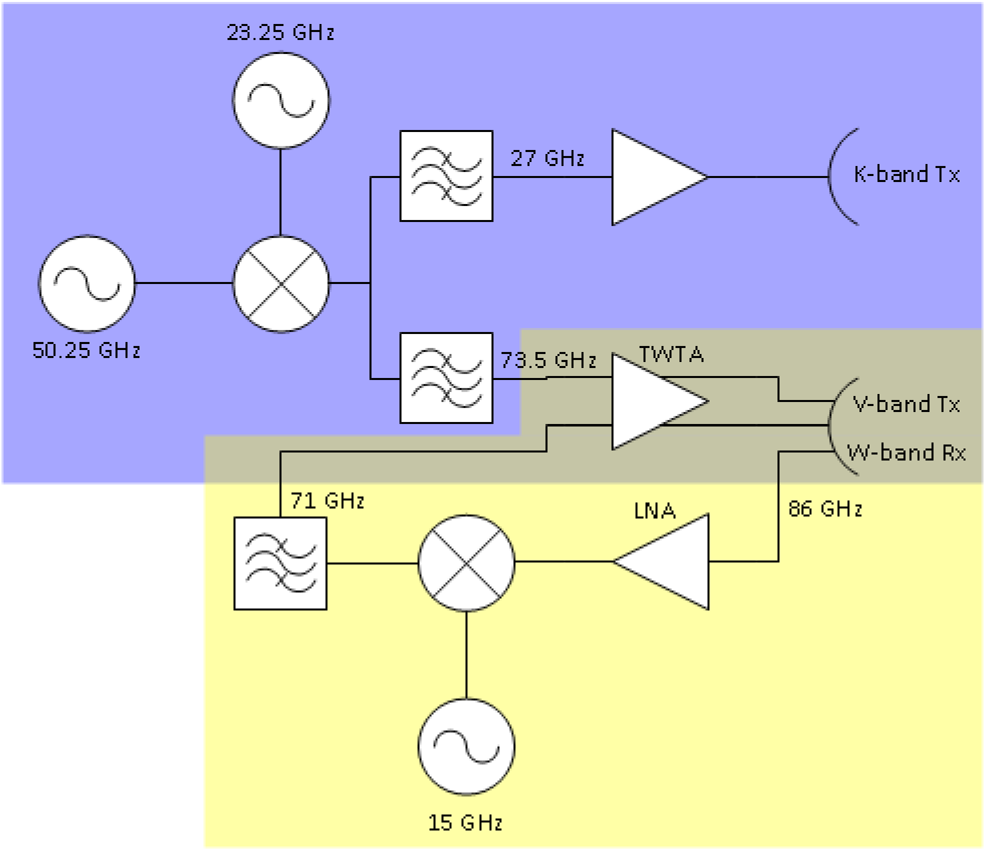

Figure 1. Satellite Payload Architecture where Blue Area is Beacon Experiment Hardware, Yellow Area is Transponder Experiment Hardware, and Green Area is Shared Hardware

The proposed ground station configuration is illustrated in Figure 2, and is comprised of a K-band receiver string, a V-band receiver string, and a V-band radiometer. While the V-band beacon is broadcast on a single linear polarization, the V-band receiver string consists of two perpendicularly oriented polarization feeds, which allows for the collection of depolarization measurements[2]. Also, a radiometer is used to avoid nonlinear losses in the receiver LNA[3]. Phase distortion is measured by comparison of the received K-band and V-band signals after compensating for known atmospheric K-band phase distortion[4]. And finally, signal attenuation is measured by comparison of the radiometer measurements to the theoretical output of the V-band beacon.

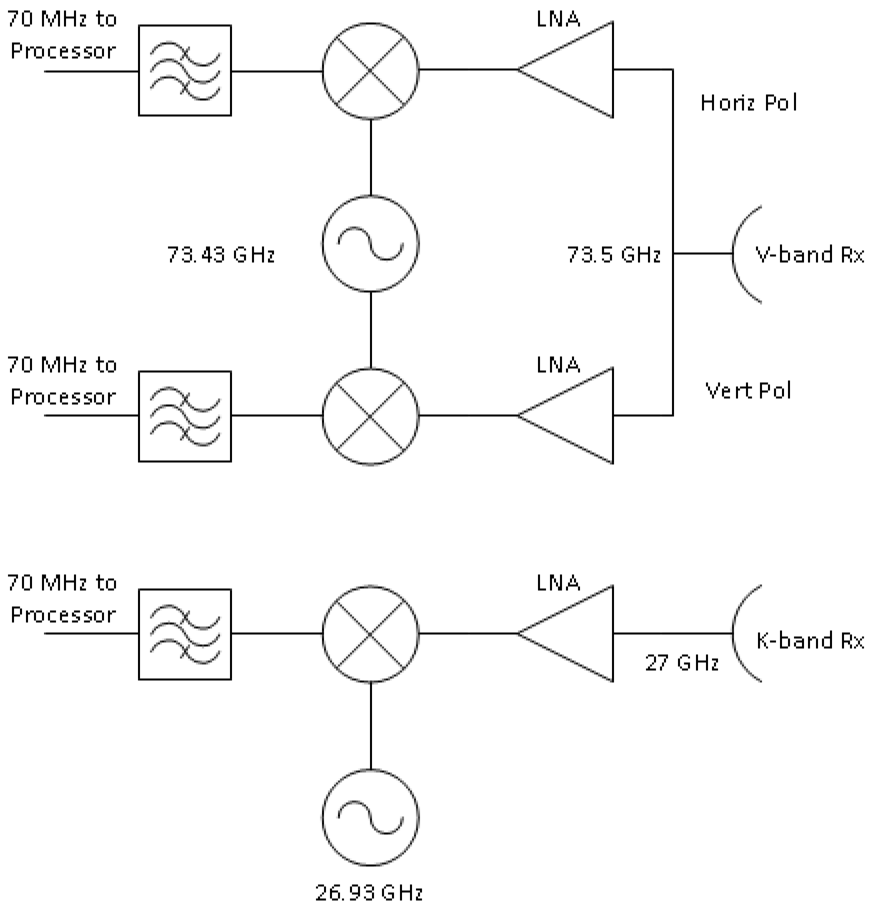

Figure 2. Beacon Experiment Ground Station Architecture

The beacon experiment design link budget is presented in Table 5. Assuming a GEO orbital slot of 100 deg West longitude, the design exceeds the objective requirement of 36 dB clear-air link margin to any point in the CONUS. Also, the system is designed to have a small receiver antenna in order to make feasible measurements in different rain attenuation regions across the CONUS (see Section 2.6). All three objective tones can be achieved with this design, but the system is designed to broadcast a single V-band tone at any given time.

The LNA gain and LNA noise figure are estimates of what is likely achievable at reasonable cost. A slightly lower frequency LNA was developed by a company in 2003, which was specified to have 30 dB of gain and a noise figure of 1.5 dB or less[5]. The HPA used for the basis of this analysis is a space-qualified 75 W V-band TWTA built by L-3 Communications Electron Technologies Inc[6].

The path length used in the link budget is the distance from a GEO satellite at 100 deg West longitude to the northeast corner of the CONUS, which is the longest distance from that orbital slot to CONUS.

Table 5. Beacon Experiment Design Link Budget

Miscellaneous Parameters		
Speed of Light	3.00E+08 m/s	3.00E+08 m/s
Boltzman's Constant	1.38E-23 J/K	1.38E-23 J/K
Link Characteristics		
	V-band Beacon	**K-band Beacon**
Downlink Frequency	73.5 GHz	27 GHz
Downlink Wavelength	4.08E-03 m	1.11E-02 m
Path Length	39720 km	39720 km
Satellite Transmit		
Tx Power (75 W - V, 1 W - K)	18.8 dBW	0.0 dBW
Tx Antenna Efficiency	60 %	60 %
Tx Antenna Gain	30.4 dB	30.4 dB
Downlink		
Path Loss	221.7 dB	213.0 dB
Miscellaneous Losses	3 dB	3 dB
Ground Receive		
Rx Antenna Efficiency	60 %	60 %
Rx Antenna Gain	45.3 dB	36.6 dB
LNA Noise Figure	3.0	3.0
System Noise Temp	870 K	870 K
Noise Bandwidth	0.7 MHz	0.7 MHz
Thermal Noise	-140.8 dB	-140.8 dB
LNA Gain	24.0 dB	24.0 dB
C/N @ Receiver	34.4 dB	15.7 dB
Required Clear-Air Link Margin	36.0 dB	0.0 dB
Receiver C/N Requirement	-1.6 dB	15.7 dB

2.3.2. Transponder Experiment Design

The secondary technical objective will be accomplished by operating a transponder in orbit that will receive (uplink) signals from a ground transceiver in the 81-86 GHz frequency band and retransmit (downlink) signals to the ground transceiver in the 71-76 GHz frequency band.

The flight unit is shown in Figure 2 and the ground unit is illustrated in Figure 3. An uncoded binary phase shift keying (BPSK) modulated signal is broadcast from the ground station to the flight unit, where it is received, down-converted directly from W-band to V-band, amplified, and retransmitted to the ground. All three objective uplink frequencies can be achieved with this design, but the system is intended to be operated on a single W-band uplink at any given time.

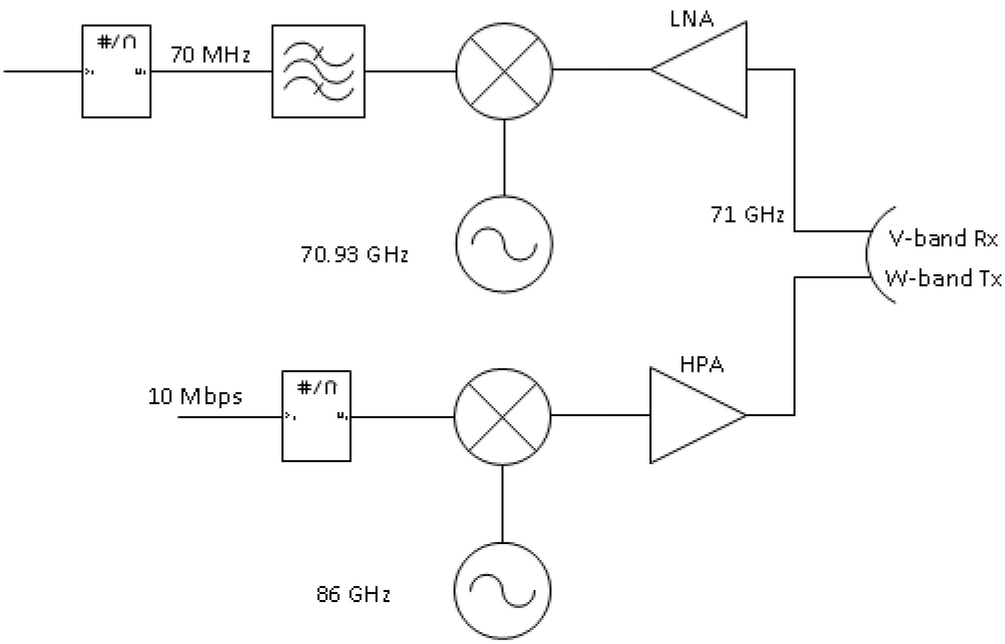

Figure 3. Transponder Experiment Ground Station Architecture

Bit error rate will be measured by comparing the received signal at the ground station to the known phrase that was transmitted to the satellite. Link margin will be measured by determining the signal-to-noise ratio at the receiver. It is expected that there will be negative link margin during periods of moderate to heavy precipitation, and the point at which this occurs will be used to analyze the link availability versus ITU Rain Region (see Section 2.6).

The transponder experiment design link budget is presented in Table 6. The design achieves at least 18.7 dB clear-air link margin to any point in the CONUS while minimizing hardware complexity.

Table 6. Transponder Experiment Design Link Budget

Miscellaneous Parameters		
Speed of Light	3.00E+08	m/s
Boltzman's Constant	1.38E-23	J/K
Link Characteristics		
Data Capacity	10	Mbps
Bandwidth	5	MHz
Modulation Type	BPSK	
# of Quantization Bits	1	
Symbol Rate	10	Mbaud
Uplink Frequency	86	GHz
Uplink Wavelength	3.49E-03	m
Downlink Frequency	71	GHz
Downlink Wavelength	4.23E-03	m

Path Length	39720	km
Ground Transmit		
SNR @ Quantization	6	dB
Tx Power (50 W)	17.0	dBW
Tx Antenna Efficiency	60	%
Tx Antenna Gain	48.9	dB
Uplink		
Path Loss	223.1	dB
Miscellaneous Losses	3	dB
Satellite Receive		
Rx Antenna Efficiency	60	%
Rx Antenna Gain	30.4	dB
LNA Noise Figure	3.0	
System Noise Temp	870	K
Noise Bandwidth	5.00E+09	Hz
Thermal Noise	-102.2	dB
LNA Gain	24	dB
Satellite Transmit		
HPA Gain	18.8	dB
Tx Antenna Efficiency	60	%
Tx Antenna Gain	30.4	dB
Downlink		
Path Loss	221.4	dB
Miscellaneous Losses	3	dB
Ground Receive		
Rx Antenna Efficiency	60	%
Rx Antenna Gain	48.9	dB
System Noise Temp	870	K
Noise Bandwidth	5	MHz
Thermal Noise	-132.2	dB
LNA Gain	24.0	dB
C/N @ Receiver	32.3	dB
E_b/N_0 Required for BER $\leq 10^{-6}$	10.5	dB
Required C/N @ Rx	13.5	dB
Clear-Air Link Margin	18.7	dB

2.4. Design Trades

While a variety of antenna designs could be selected to support this experiment, ECE has preliminarily chosen four paraboloidal reflector antennas. A one foot-diameter dish is intended to be used for receiving both the V-band and K-band beacons. While this design choice results in a less than optimal gain in for the K-band signal, there is still more than 15 dB of clear-air link margin. Similarly, on the satellite the W- and V-band signals for both experiments share a single dish antenna. The W/V-band paraboloidal reflector is designed to have a 3 dB beamwidth that spans the entire CONUS (3 deg x 6 deg). In order to ensure full CONUS coverage for the K-band beacon, a separate K-band antenna is implemented onboard the satellite. Finally, there is a reflector antenna at the transponder experiment ground station that is dedicated to transmitting the modulated W-band signal and receiving the modulated V-band signal. This antenna is designed to have a 3 dB beamwidth of 0.5 deg in order to minimize interference to/from satellites located near the experiment's host satellite.

The type of modulation ECE has chosen for the transponder experiment design is BPSK. QPSK was also considered, which would have decreased the bandwidth required to achieve a 10 Mbps link, but, since a wideband, high-power TWTA was selected in order to support the full extent of the V-band, QPSK modulation was found to be unnecessary. By selecting BPSK, the ground hardware architecture is simplified and the performance measurements will be easier to collect.

2.5. Risk Management

As shown in Section 2.3, the ECE design is inherently risk averse. Procuring a spaceflight-qualified LNA capable of the performance required by this experiment is the main hardware risk. This risk is mitigated, however, by the design decision to maintain only a single W-band uplink carrier at any time. The second highest risk is the availability of a receiver capable of measuring the phase distortion and depolarization of the V-band beacon with a receive C/N of -1.6 dB. However, this risk could be mitigated by procuring a larger receive antenna.

2.6. Systems Engineering

It is expected that moisture in the atmosphere, including rain and rain rate, will play a major role in the propagation physics in the W- and V-bands, as illustrated in Figure 4[7]. By selecting, for the beacon flight unit, a V-band antenna that is capable of providing a 3 dB beamwidth that covers the entire CONUS, ECE will be able to collect measurements in any or all of the six rain climatic zones that make up the CONUS (see Figure 5 and Table 7). This approach is also aided by the flight TWTA selection, which allows for all of the experiment design requirements to be met with a relatively simple-to-manufacture 1-ft diameter ground antenna.

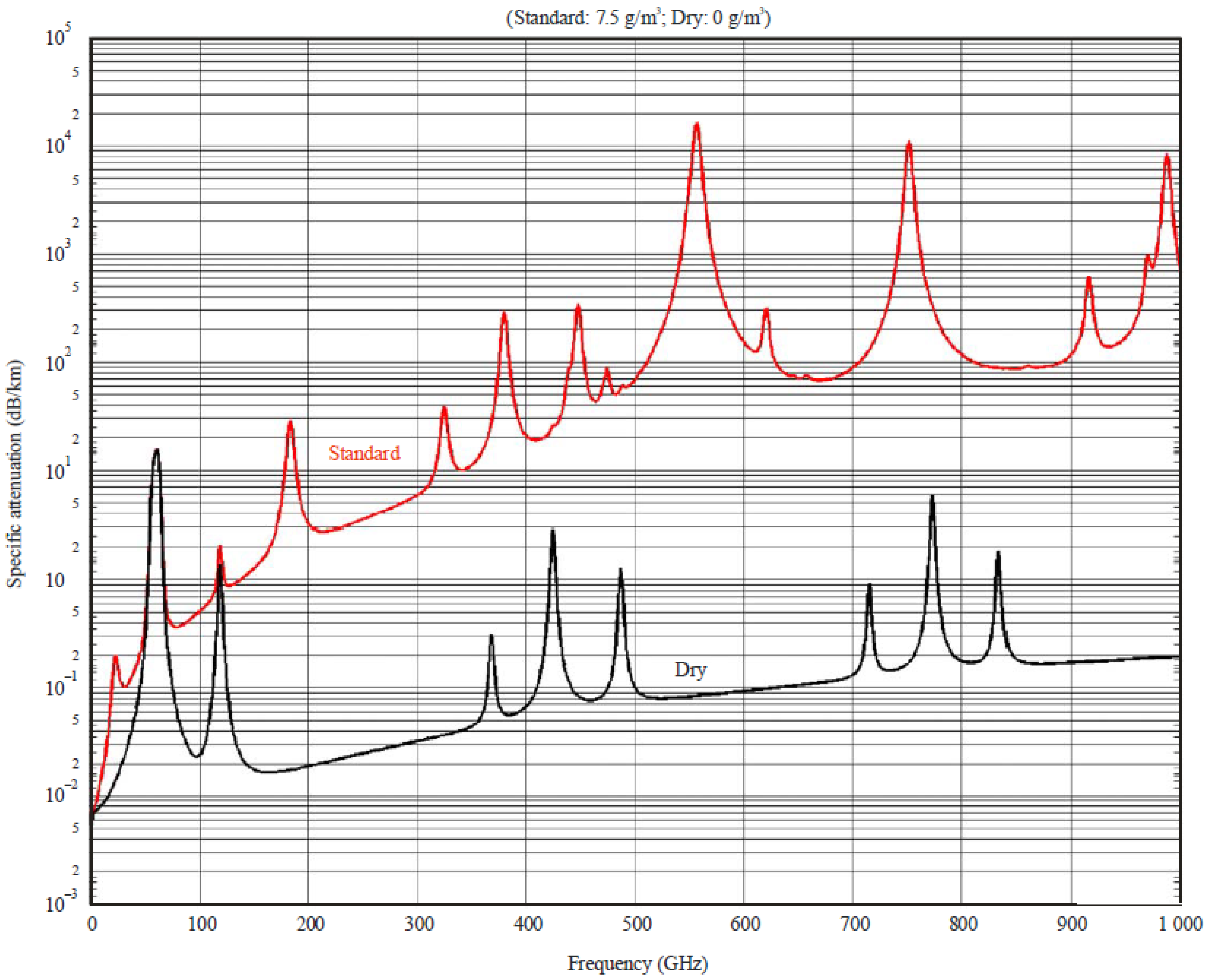

Figure 4. Specific Attenuation due to Atmospheric Gases (Source: ITU)

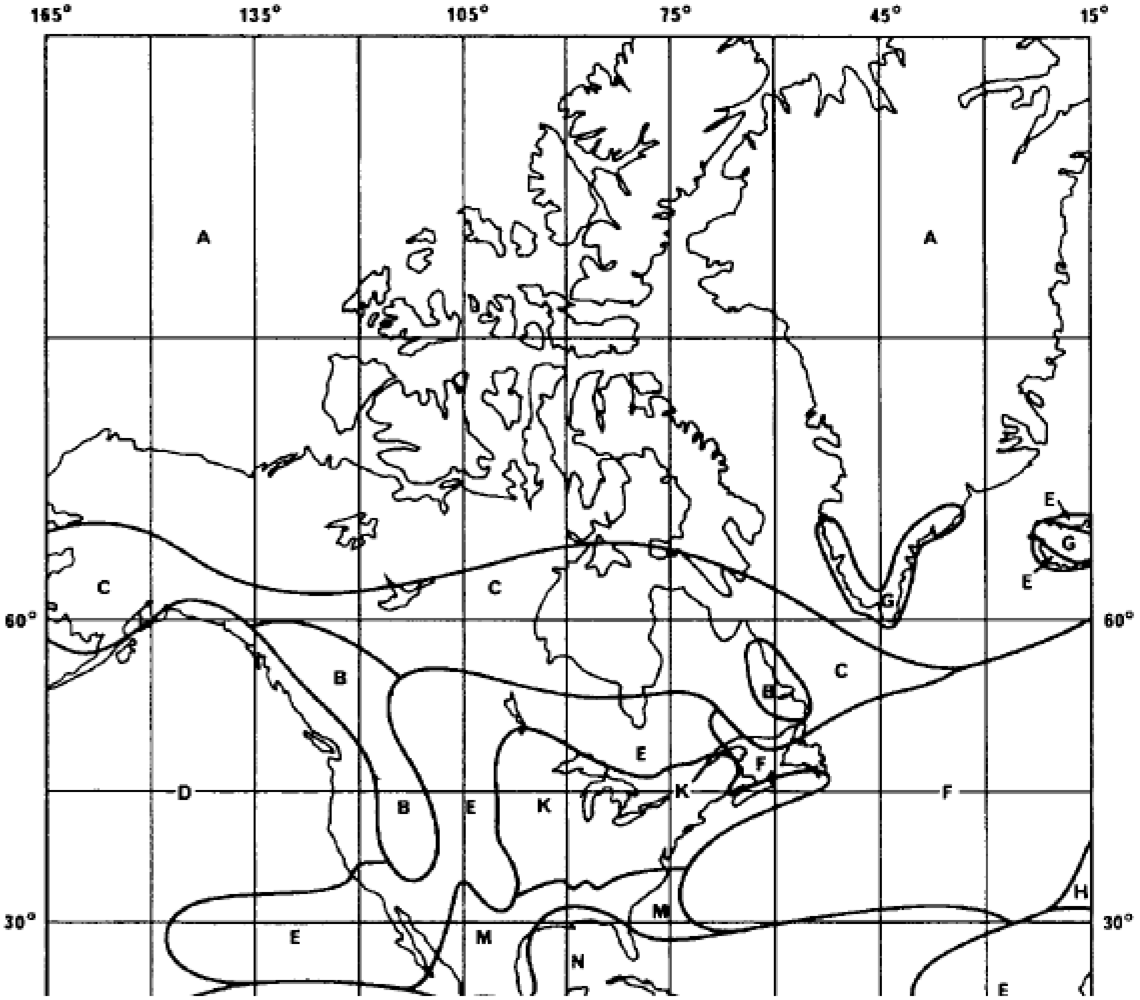

Figure 5. Rain Climatic Zones for CONUS (Source: ITU)

Table 7. Rainfall Intensity Exceeded (mm/hr) (Source: ITU)

Percentage of Time (%)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**J**	**K**	**L**	**M**	**N**	**P**	**Q**
1	<0.1	0.5	0.7	2.1	0.6	1.7	3	2	8	1.5	2	4	5	12	24
0.3	0.8	2	2.8	4.5	2.4	4.5	7	4	13	4.2	7	11	15	34	49
0.1	2	3	5	8	6	8	12	10	20	12	15	22	35	65	72
0.03	5	6	9	13	12	15	20	18	28	23	33	40	65	105	96
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145	115
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250	170

3. Program Plan

3.1. Overall Program Plan

Phase 1 of the program plan is explained in detail in the Section 3.2.

In Phase 2 of the program, ECE will perform full reliability and availability analyses for the system in order to ensure a mean mission duration that supports at least the threshold requirement of 36 months (assuming 100% duty cycle for the beacon unit and 10% duty cycle for the transponder unit). In addition to this, laboratory simulations will be done to show that the circuit design closes. The system requirements and verification plans will be finalized in Phase 2, to include the host interface requirements. All hardware selections will be made and all analyses completed in order to support a critical design review.

In Phase 3, an engineering development unit will be built and utilized for flight-like testing and high fidelity simulation and analysis. Finally, the flight-ready system and ground data collection systems will be provided.

In Phase 4, ECE will support pre-launch assembly, integration, and testing of the flight hardware, including end-to-end testing between the host command interface and the ground station hardware.

In Phase 5, ECE will provide on-orbit experiment support, to include data collection and processing.

3.2. Phase 1 Program Plan

The proposed period of performance (PoP) for Phase 1 is 52 weeks. The technical performance period is the first 36 weeks. An FTE breakdown is provided in Table 8 and an IMS is shown in Figure 6 through Figure 8. With fee it is estimated that ECE could perform Phase 1 at a cost of roughly $2,600,000.

Table 8. FTE Breakdown for Full Period of Performance

Position	**FTE over Full PoP**
Program Manager	0.5
RF Engineer III	0.5
RF Engineer II	1.35
Systems Engineer II	1.5
Technical Writer	0.4
Total	4.25

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Program Management																																																				
Program Management	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Risk Management	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■													
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Figure 6. Program Management Phase 1 Schedule.

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RF Engineering																																																				
Define Hardware Needs	■	■	■																																																	
Modeling & Simulation	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																				
Experiment Planning & Definition	■	■	■	■	■	■	■	■	■	■	■	■	■																																							
Get Hardware Quotes			■	■	■																																															
Support to Subsystem Design Definition				■	■	■	■	■	■	■	■	■																																								
Finalize Prelim Link Budget					■	■	■																																													
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Figure 7. RF Engineering Phase 1 Schedule

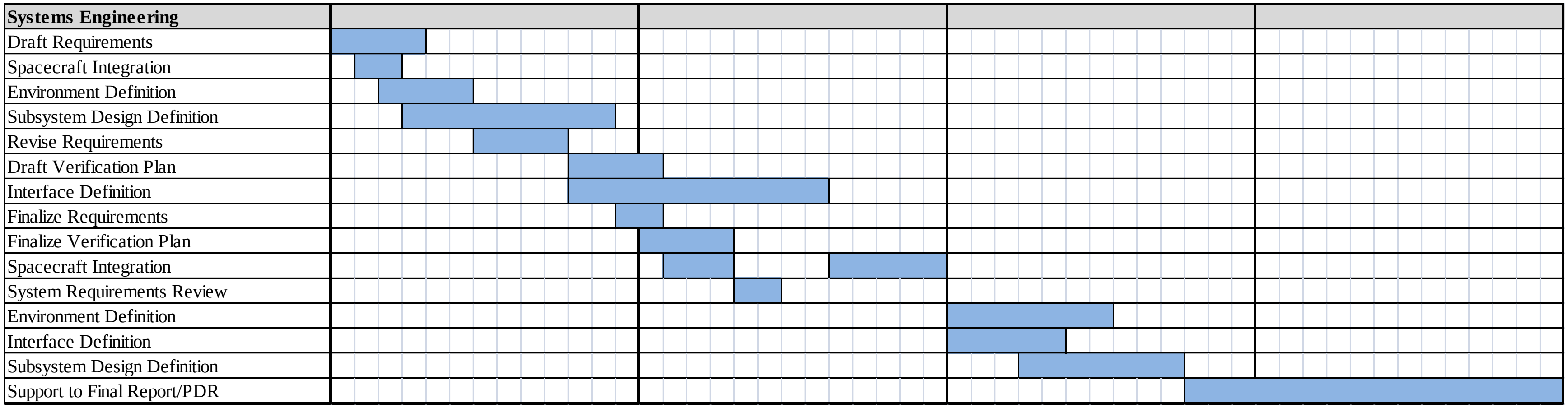

Figure 8. Systems Engineering Phase 1 Schedule

4. Contractor's Statement of Work (C-SOW)

The preliminary C-SOW is listed in Table 9.

Table 9. Contractor's Statement of Work

1.1	The contractor shall provide copies of presentation materials (slides) to the Government for all program meeting and program reviews to include the kick-off meeting, quarterly review meetings, technical interchange meetings, and design reviews, in accordance with CDRL A001.
1.2	The contractor shall deliver monthly status and execution reports in accordance with CDRL A002.
1.3	The contractor shall deliver the Scientific and Technical Report in accordance with CDRL A003.
1.4	The contractor shall deliver an updated IMS in accordance with CDRL A004.
1.5	The contractor shall deliver an updated Risk Assessment and Management Plan in accordance with CDRL A005.
1.6	The contractor shall deliver a draft System Design Description document in accordance with CDRL A006.
1.7	The contractor shall deliver a draft Experiment Plan document in accordance with CDRL A007.
1.8	The contractor shall deliver a draft Interface Definition document in accordance with CDRL A008.
1.9	The contractor shall deliver a draft Environment Definition document in accordance with CDRL A009.
2.1	The contractor shall hold a system requirements review with entry and exit criteria to be defined after ATP.
2.2	The contractor shall perform modeling and simulation to demonstrate that the proposed concept is feasible and will meet mission requirements (propagation channel, link, RF systems, size, weight, power requirements)
2.3	The contractor shall deliver sub-system design descriptions (space segment, ground segment, hardware, software)
2.4	The contractor shall analyze the experiment design's interface to a potential host satellite, to include thermal, power, command and telemetry, and EMI/EMC considerations.
2.5	The contractor shall hold a preliminary design review with entry and exit criteria to be defined after ATP.

5. Acronyms

AFRL/RV	Air Force Research Laboratory/Space Vehicles Directorate
ATP	Authorization to Proceed
BAA	Broad Agency Announcement
BPSK	binary phase shift keying
BER	bit error rate
bps	bits per second
C/N	Carrier-to-Noise Ratio
C-SOW	Contractor’s Statement of Work
CDRL	Contract Data Requirements List
CONUS	Continental United States
COTS	Commercial off-the-shelf
dB	decibel
deg	degree
E_b	Energy per bit
ECE	Eccentric Communications Engineering, Inc.
EMI/EMC	Electromagnetic Interference, Compatibility
FTE	Full Time Equivalent
G	Giga-
GEO	Geosynchronous Orbit
HPA	High Power Amplifier
hr	hour
Hz	Hertz
IMS	Integrated Master Schedule
ITU	International Telecommunication Union
J	Joule
k	kilo-
K	Kelvin
LNA	Low-Noise Amplifier
m	meter
M	Mega-
mm	millimeter
N_0	Noise power spectral density
PoP	Period of Performance
QPSK	quadrature phase shift keying
PDR	Preliminary Design Review
Rx	Receive
s	second
SNR	Signal-to-Noise Ratio
TWTA	Traveling Wave Tube Amplifier
Tx	Transmit
W	Watt
WSCE	W/V-Band Satellite Communications Experiment

6. References

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[1] Bauer, R. (n.d). Ka-band propagation measurements: An opportunity with the advanced communications technology satellite (ACTS). *Proceedings Of The IEEE, 85*(6), 853-862.

[2] Davies, K. K., Fritz, R. B., Grubb, R. N., & Jones, J. E. (1975). Some early results from the ATS-6 radio beacon experiment. *Radio Science, 10*(8), 785-799.

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