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ELECTROMAGNETIC INTERFERENCE IMPACT OF THE PROPOSED EMITTERS FOR THE HIGH FREQUENCY ACTIVE AURORAL RESEARCH PROGRAM (HAARP)

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14 May 1993

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The proposed HAARP emitters at the Gakona (Alaska) preferred site and at the Clear AFS (Alaska) alternative site are the Ionospheric Research Instrument (IRI), the Incoherent Scatter Radar (ISR), and the Vertical Incidence Sounder (VIS). The electromagnetic interference (EMI) impact of those emitters on receiving systems in the vicinity of the sites is estimated in this study. The results are intended for use as an input to the Air Force Environmental Impact Statement as part of the Environmental Impact Analysis Process.

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SECTION 1

INTRODUCTION

The objectives of the High Frequency Active Auroral Research Program (HAARP) are to identify, investigate, and if feasible, control ionospheric processes and phenomena that might serve to enhance future Department of Defense (DoD) Command, Control and Communications capabilities. For example, research areas that will be explored include generation of very low and extremely low frequency waves, generation of geomagnetic field-aligned irregularities, electron acceleration, and investigation of upper atmospheric processes.

The heart of the proposed research facility is a powerful world class radio wave transmitter that will operate between 2.8 and 10.0 MHz. This powerful transmitter is called the Ionospheric Research Instrument (IRI).

The IRI itself will not be capable of diagnosing the impact of the radio wave energy upon the ionosphere. For this reason a number of diagnostic instruments will become part of the overall HAARP research facility.

A primary diagnostic instrument will be an ultra-high frequency (UHF) (approximately 445 MHz) incoherent scatter radar (ISR) that will define electron density profiles, atmospheric temperatures, and electric fields. A vertical incidence sounder (VIS) will be used for IRI frequency management as well as a diagnostic instrument for defining the large scale ionospheric structures and motions. The VIS will transmit and receive nominally between 1 and 15 MHz. The diagnostic instrumentation will also include an imaging riometer, several optical imagers (including an infrared imager), and a magnetometer.

The IRI will be developed in three stages: the Development Prototype, the Limited IRI, and the full IRI. In its final configuration, the IRI will have an effective radiated power in excess of 1 gigawatt. It will be capable of rapidly scanning a narrow beam (approximately 5° beamwidth) over a cone angle of 60° centered on the zenith. It will transmit in continuous

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wave (CW) and pulsed modes. It is expected that the final configuration will be completed by 1997.

The preferential site for the proposed HAARP emitters is at Gakona (Alaska) and the alternative site is at Clear AFS (Alaska).

The proposed HAARP facility will have in-band emissions at 1-15 megahertz (MHz) and 440-450 MHz of the electromagnetic spectrum. These in-band emissions, together with out-of-band emissions from harmonics and spurious emissions, may impact user receiving systems for public domain activities (such as communications, airborne navigation, emergency and public services) that are dependent upon the transmission and reception of information via the electromagnetic spectrum (frequencies from hundreds of kilohertz (kHz) to tens of gigahertz (GHz).

The purpose of this study is to estimate the electromagnetic interference (EMI) impact of these emitters on receiving systems in the vicinity of the Gakona and Clear sites. The study also includes an assessment of HAARP impact on electro-explosive devices (EEDs) and cardiac pacemakers at these sites. The approach used is a conservative analysis providing an upper bound on the level of interference that could occur from HAARP's addition to the electromagnetic environment. The results of this study are intended for use as an input to the Air Force Environmental Impact Statement as part of the Environmental Impact Analysis Process.

The user receiving systems are identified in section 2, including their sensitivities (appendix A) and nearest distances to the HAARP emitters (appendix C). The characteristics of the HAARP emitters are presented in section 3, including their power densities at the nearest user receiving systems (appendix B). An assessment of the projected electromagnetic impact is given in section 4. Mitigation approaches and considerations are discussed in section 5. Section 6 presents the conclusions.

SECTION 2

CHARACTERISTICS OF THE USER RECEIVING SYSTEMS

2.1 LOCATIONS

Two locations have been identified as HAARP study areas for the purpose of the Environmental Impact Analysis Process. The Government's preferred location is at the abandoned over-the-horizon backscatter (OTH-B) radar transmit site near Gakona, Alaska. An alternative location for the IRI is at Clear AFS, and for the ISR and the VIS at Bear Creek, Alaska, approximately 10 nautical miles south-southwest of Clear AFS. The site layouts relative to existing roads, facilities, and geographical features are shown in figures C-1, C-2 (Gakona), C-3 (Clear AFS), and C-4 (Bear Creek) of Appendix C.

User receiving systems at these sites are defined to include systems that are intended to receive electromagnetic energy in the same portions of the electromagnetic spectrum as those of the HAARP emissions as well as those systems that are not intended to receive electromagnetic energy. Examples of the former are high-frequency (HF) communications, radio, television, and radio-navigation systems. Examples of the latter are cardiac pacemakers and EEDs.

Assessments have been made for the following eighteen families of receiving systems:

- Cellular Telephone
- Satellite Television
- Television Broadcast
- Frequency Modulation (FM) Radio Broadcast
- Cardiac Pacemakers
- Mobile VHF Radio
- Citizen Band Radio
- HAARP Scintillation Receiver
- Pipeline Systems
- HAARP Riometer
- HF Communications
- Amplitude Modulation (AM) Radio Broadcast
- Avionics
- Electro-Explosive Devices
- Wildlife Trackers
- Handheld Transceivers
- Radio Telephone
- Terrestrial Microwave

The closest ranges are summarized in tables C-1 (Gakona study area) and C-2 (Clear AFS study area) of appendix C. The closest ranges are distances from the HAARP emitters to locations and facilities where one or more of the eighteen user system families might be employed.

2.2 SENSITIVITIES

The sensitivities of the user receiving systems are discussed in appendix A. The receiving system sensitivities are expressed in terms of the receiving system noise available power density referenced to the terminals of the equivalent lossless receiving antenna. Nominal values of the receiving system sensitivities and parameters for the eighteen user families are given in table A-2.

SECTION 3

CHARACTERISTICS OF THE HAARP EMISSIONS

Operation of the three primary HAARP emitters (IRI, ISR, and VIS) would change the electromagnetic environment, over their frequency bands of operation and their out-of-band harmonic frequencies and spurious emissions, within the physical space their energy reaches.

Civilian use of the radio spectrum is under control of the Federal Communications Commission (FCC); government use is under the control of the National Telecommunications and Information Administration (NTIA). Because HAARP is a DoD research and development program, an application for experimental spectrum support has been made through Air Force channels to the Interdepartmental Radio Advisory Committee (IRAC) of NTIA, which will consider and authorize, as appropriate, the operation of the HAARP emitters.

The HAARP IRI would transmit in portions of the electromagnetic spectrum from 2.8 to 10.0 MHz. These transmissions would be in the HF band. An important characteristic of radio signals within this frequency band is that they can be refracted and reflected by layers of naturally occurring ionization at heights above approximately 50 kilometers (km). The refraction and reflection results in these radio signals returning to Earth over a broad area. This is referred to as skywave propagation. HAARP radio wave energy is also transmitted by tropospheric wave propagation and groundwave propagation. The HF band at the IRI frequencies is shared with radars (operational and experimental), radio systems for air-to-ground and ship-to-shore communications, systems for standard time and frequency broadcasts, the Amateur Radio Service, Citizens Band radio and others. In addition, similar ionospheric research instruments are operated, for example, in Norway, Puerto Rico, and Russia.

The HAARP VIS transmits in the 1.0 to 15.0 MHz portion of the HF band. The VIS operates at much lower power than the IRI and is used to aid in selecting frequencies for operating the IRI and as a diagnostic instrument to assess the background ionosphere and changes induced by the IRI. The HAARP VIS is a common instrument used to monitor the ionosphere at many world locations.

The HAARP ISR transmits in the 440- to 450-MHz portion of the ultra high frequency (UHF) band. This band is shared with radars such as the Ballistic Missile Early Warning System (BMEWS). The ISR is a primary diagnostic instrument used for detailed assessments of the background ionosphere and the changes induced by the IRI. The majority of the radio frequency (RF) energy from the ISR travels through the ionosphere and escapes into space.

The specific portions of the HF band within which the HAARP IRI will transmit are those bands also employed by transmitters of the Fixed Service and the Broadcast Service. The Fixed Service provides fixed (i.e., not mobile) point-to-point links of the transmission of data or information from one part of the globe to another. Before the advent of communication satellites, the U.S. Armed Forces were major users of the Fixed Service bands — operating large transmitting and receiving systems in Hawaii, California, and other locations worldwide. The Broadcast Service transmitters are also located throughout the world, broadcasting for example news, music, and religious programs. The Broadcast Services use the HF bands because the skywave allows them to propagate their programming to areas at great distances from the transmitter, reaching audiences they could not otherwise reach. Among these transmitters are Radio Moscow, the Voice of America, and the British Broadcasting Corporation; there are many others. The listeners to the Broadcast Services are located throughout the world.

The HAARP IRI would operate on a number of channels of various widths within the frequency range of 2.78 to 10.0 MHz. The IRI would have the capability to illuminate the ionosphere within a maximum cone angle of 60°, centered on the zenith. The IRI may or may not change frequency each time it switches its beam to illuminate a different portion of the ionosphere within the 60° cone angle. Ionospheric conditions, which change with solar activity, time-of-day, and season of the year dictate the particular range of frequencies that will be used to investigate ionospheric processes and their interaction with radiowave energy.

Although the function of the HAARP emitters is to provide RF energy to investigate ionospheric processes above approximately 50-km altitude, some of the energy will remain near the ground and propagate by what is termed the groundwave. The groundwave signal is attenuated relatively rapidly as it propagates away from the emitter sources. Some of the energy will also propagate through the troposphere (the lower atmosphere) without reaching the ionosphere. The skywave combined with the tropospheric wave is called the spacewave.

Not all of the RF energy transmitted by the HAARP emitters enters the main beams. Much smaller concentrations of power appear in the sidelobes of the emitter antennas. The peak power in the sidelobes is approximately 1/20th of the peak power in the main beams.

The HAARP emitters will produce signals on frequencies other than the intended ones, but at much lower power levels. This is a characteristic of all RF emitters. Care will be taken in the HAARP system designs to minimize such signals because they both are a waste of transmitter power and a potential source of interference to other user systems. Some of the out-of-band frequencies are integer multiples of the intended, or fundamental, frequency and are termed harmonics. Others are less clearly related to the fundamental frequency, and are called spurious emissions. Generally, harmonic and spurious signals will not be propagated by skywave. Furthermore, their associated groundwaves are negligible or will be attenuated rapidly.

When a radiowave transmitter emits a modulated signal in its desired frequency band, it also emits some energy in the directly adjacent portions of the spectrum. These emissions are close enough in frequency to propagate along with the desired signal and to create the possibility of adjacent-channel interference. The possibility of adjacent channel interference is why television channels, such as 9 and 10, are not used in the same community. The modulation of the HAARP emitters will be designed and built to minimize the out-of-band RF energy; the transmitted signals will have good spectral purity.

In addition to the three primary, aforementioned HAARP emitters, HAARP will employ the following auxiliary transmitting systems:

a. Very-high frequency (VHF) or UHF land mobile radio systems to support intrasite maintenance and security activities. These will be standard, commercially available transceivers such as those used by police, fire departments, and the Forest Service. These vehicle-mounted or hand-carried systems will operate on frequencies assigned by NTIA through the IRAC so as to avoid interference to other users of the land mobile frequency bands. Emissions from these HAARP auxiliary emitters will not be discussed further as they are commonly used, of low power, and will operate on frequency bands assigned for this purpose.

b. Data links for the operation and control of off-site diagnostic instrumentation and for transmission of diagnostic data to the main HAARP site where it will be collected, analyzed, and displayed for use by all experimenters. Commercial telephone lines and/or a microwave radio system will be employed as data links. These commercial systems are used throughout Alaska and are licensed and administered by Federal and State agencies.

The IRI is the primary HAARP emitter and a one-of-a-kind device. For this reason, the HAARP IRI emitter characteristics are discussed in some detail. The reader is referred to appendix B for a further discussion of the characteristics of the HAARP ISR and VIS.

3.1 TRANSMITTED WAVEFORMS

The HAARP IRI will be capable of generating single frequency (CW), amplitude (AM), frequency (FM), and pulsed modulated waveforms. A standard waveform library will be available that will include sinusoidal, triangular, ramp, sawtooth, and pulse. The capability will also exist to tailor a waveform for specific experiments. The AM frequency range will be from zero to 30 kHz with an amplitude depth of zero to 100%. The FM will have a similar range from zero to 30 kHz and a maximum frequency deviation of 100 kHz. The pulse modulation will have a rise/fall time of less than one microsecond between the 10%

and 90% points. The minimum pulse width will be 5 microseconds with a pulse repetition rate of zero to 100 kHz.

3.2 HARMONIC AND SPURIOUS OUTPUTS

The HAARP IRI system specification requires all harmonics, at frequencies less than or equal to 45 MHz, to be at least 80 dB down (reduced by a factor of 100,000,000) from the levels of the fundamental signal when the transmitter is operating at its maximum output power level. All harmonics above 45 MHz, except at 88 MHz to 200 MHz, shall be at least 120 dB down (reduced by a factor of 1,000,000,000,000) from the fundamental signal level when the transmitter is operating at maximum power output. At 88 MHz to 200 MHz, the specified level is -150 dB (reduced by a factor of 1,000,000,000,000,000). This does not imply that radiated harmonics will be only 80 to 150 dB down from the radiated fundamental; they will be considerably weaker because the antenna system will not provide high gain at the harmonic frequencies. This is discussed in further detail in appendix B. The IRI will have 360 transmitters each supplying power to a corresponding single dipole of the 360-element antenna array. The system forms a high gain, relatively narrow beam by timing the transmitter output signals so that precise phase relationships exist between the signal emitted between each of the 360 dipole elements. This careful timing must account for the electrical length of the transmission line between the transmitter and the antenna, which may be different for each of the 360 transmitter/dipole pairs. The antenna elements are also placed so that certain phase relationships exist between the signal radiated by each dipole element and those reflected from the groundscreen and the adjacent antenna elements. The harmonic signals radiated by the antenna system elements (and reflected from the groundscreen and adjacent antenna elements) will be randomly phased. The phase relationships, that produce a high gain, narrow beam at the fundamental frequency, will not exist at the harmonic frequencies.

At maximum transmitter power and without waveform modulation (CW mode), the transmitter spurious output will meet the following requirements, where the spurious output is given in dB relative to the output at the fundamental frequency:

a. Non-harmonic energy will be suppressed to a level 80 dB down (reduced by a factor of 100,000,000) at 20 kHz or more from the carrier (fundamental) frequency.

b. Spurious output energy from the transmitters will be suppressed to a level 120 dB down (reduced by a factor of 1,000,000,000,000) above 45 MHz, except at 88 MHz to 200 MHz. At 88 MHz to 200 MHz, spurious output energy will be suppressed to a level 150 dB down (reduced by a factor of 1,000,000,000,000,000).

c. Detectable subharmonics (energy output at a frequency one-half, one-third, ... of the fundamental frequency) will not be generated.

3.3 SIGNALS PROPAGATED BY SPACEWAVE

The HAARP IRI will transmit a significant fraction of its RF energy skyward via a skywave whose main beam varies between a six and twenty degree cone angle. The IRI, from 2.8 to 8.0 MHz, will be able to steer this relatively narrow beam within a 60° cone angle centered on the zenith. Above 8.0 MHz, the beam steering capability will decrease from a 60° cone angle to a 20° cone angle at 10.0 MHz.

Experience with similar facilities (e.g., Arecibo and Tromso) suggest that 80-90% of the experiments will employ the IRI in skywave modes that will transmit fundamental radio frequency energy to the ionosphere which refracts and reflects energy Earthward. This refracted and reflected RF energy will illuminate a broader area on the ground and will in turn be reflected and scattered skyward. The process will be repeated until the radiowave escapes into space, due to spatial differences in the refractive and reflective properties of the ionosphere, or ionospheric absorption and ground scattering reduce the signal to background noise levels. The lower ionosphere (50-100 km) is most absorptive in daytime or beneath an active morning sector (approximately midnight to 6:00 am local time) aurora. In these absorptive situations, the radial distance to which the skywave will illuminate the Earth is reduced.

The specific harmonics and spurious signals that propagate depend on the ionospheric conditions that vary with local time, season, time within the sunspot cycle, and solar/auroral disturbance level. However, only those frequencies below approximately 40 MHz would ever propagate by skywave. Harmonic and spurious signals, above approximately 40 MHz, are lost to space and would not propagate via skywave to distant regions.

IRI energy will also be transmitted to Earth via the tropospheric wave. This energy is contained primarily within the far sidelobes of the IRI antenna pattern. At frequencies at HF or below, most of the IRI far-sidelobe energy will propagate via the skywave rather than the tropospheric wave. However, most of the IRI electromagnetic interference above the HF band that impacts upon receiving systems in the vicinity of the Gakona and Clear sites will be from far sidelobe energy propagated via the tropospheric wave. Tropospheric wave propagation loss is a function of the troposphere's refractive index and the Earth's terrain, vegetation, and permittivity. Line-of-sight free-space propagation loss is assumed in the study as a worse case of EMI impact.

3.4 SIGNALS PROPAGATED BY GROUNDWAVE

Some of the RF energy radiated by the IRI antenna system is expected to remain near the Earth's surface where it propagates by groundwave, becoming attenuated as a function of distance from the IRI more rapidly than the spacewave. Several first-order factors govern the efficiency of groundwave propagation. The horizontal dipoles comprising the IRI array couple poorly to the groundwave mode. Hilly and mountainous terrain attenuate groundwaves. Ground conductivity is the third factor; frozen soil or permafrost is a relatively poor conductor.

The strength of the groundwave is of most interest close to the site; however, as discussed in page B-25 of appendix B, the strength of the line-of-sight tropospheric wave is greater than the groundwave at distances beyond approximately 1,000 ft. Additionally, the research objectives will often dictate that the IRI operate to produce skywave reception in areas adjacent to the HAARP study areas and extending radially 100s of kilometers. Reception of the IRI groundwave signal beyond distances of approximately 50 to 100 km is of reduced interest because the skywave received signal strength will dominate. Areas shadowed from line-of-sight tropospheric wave IRI signals, and within approximately 50-km radial distance, may experience groundwave signals of greater strength than the skywave.

3.5 OPERATING FREQUENCIES AND THEIR SELECTION

The radio frequencies that the IRI employs is a partial basis for defining HAARP's addition to the electromagnetic environment. This section summarizes the frequencies that are projected to be available for operation of the HAARP IRI and then discusses a concept for selecting the specific frequency(ies) that the IRI will employ for a specific experiment or test.

The NTIA is expected to authorize the HAARP IRI to operate on a "clear channel, noninterference basis" within specific bands of the HF portion of the radio spectrum. The expected specific bands are those shared with users of the Fixed and Broadcast Services.

All other portions of the HF band, including the bands occupied by the Aeronautical Mobile and Marine Mobile Services, Amateur Radio Service (i.e., the Hams), and the standard frequencies will be forbidden to the HAARP IRI. The first two services are used for communication between and among aircraft, ships, and shore or ground stations. The Hams are hobbyists who communicate with other Hams throughout the world using the HF bands. The Standard Frequency bands support, for example, the transmission of precise time and frequency information, as well as propagation predictions, solar and geophysical data. The Standard Frequency stations are operated by national government agencies and include WWV in Colorado, CHU in Ontario, and JJY near Tokyo. Table B-3 of appendix B is a summary listing of the distress, calling, and guarded frequencies that the IRI must avoid.

Figure 3-1 summarizes the concept for HAARP IRI frequency selection. From the list of frequency bands that have been authorized for HAARP use on a clear channel noninterference basis, a specific, narrow (up to 200 kHz) frequency band is selected. The selected band is chosen on the basis of observed ionospheric and auroral conditions, research objectives, noninterference with other radio spectrum users, and avoidance of the forbidden

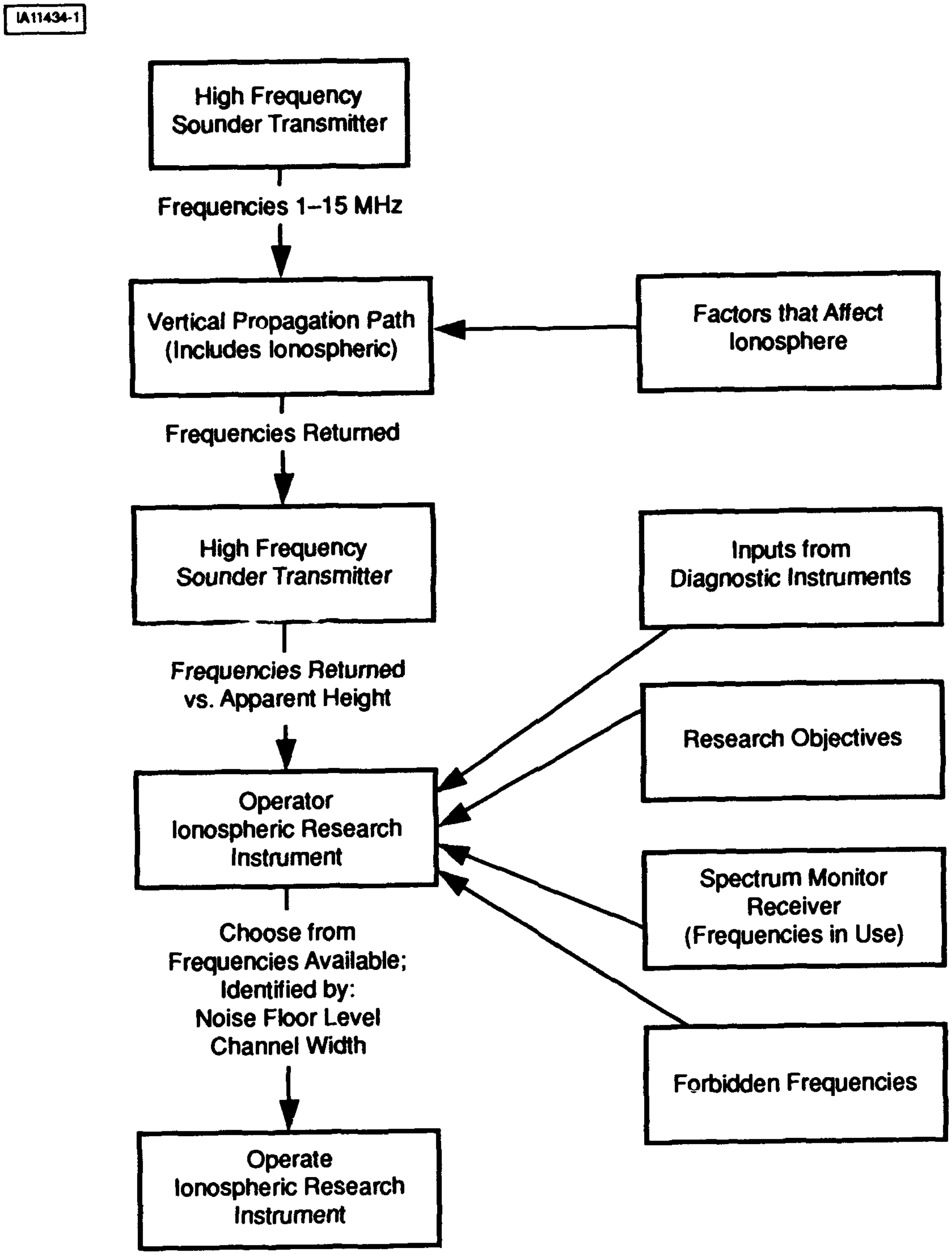

Figure 3-1. Concept for HAARP IRI Frequency Selection

frequencies. The ionospheric conditions are determined from the VIS that provides information on the electron density variation with altitude. Auroral conditions are determined primarily from the optical and the infrared imagers and the magnetometer, the off-site imaging riometer and from other space environmental diagnostics that may be available from, for example, the University of Alaska and/or the National Space Environmental Support Center cooperatively operated by the USAF and the National Oceanographic and Atmospheric Administration. A spectrum monitor scans the frequency bands (outside the forbidden frequencies) that will meet the research objectives and determines the noise floor level and the channel width. From the results of the spectrum monitor scan, the operator selects (or confirms an automated frequency selection) a frequency(ies) and begins/continues the IRI operation. The IRI will have the capability to operate simultaneously on any two distinct frequencies within its operating range.

3.6 IRI, ISR, AND VIS EMITTER POWER DENSITIES

The approach and techniques used to estimate the IRI, ISR, and VIS emitter power densities are described in appendix B. Numerical values of the power densities are given in table B-1 of appendix B.

SECTION 4

ASSESSMENT OF PROJECTED EMI IMPACT

4.1 APPROACH

The objective of this section is to identify user systems that potentially could be impacted by the HAARP emitters. Reliable predictions of HAARP emitter impacts on user systems in real-world, specific environments is difficult. Rather the reader is encouraged to evaluate the appıoach being employed and to look at the assessments made as an indicator of potential interference scenarios. The details of actual interference occurrences will depend on many factors not considered in this assessment. These factors include, for example, topography, vegetation, structures, conditions and age (technology employed) of the receiving systems, and atmospheric conditions.

An existing or potential user of the electromagnetic spectrum would like to know if the addition of the HAARP emitters will impact the performance of an existing or proposed system. To answer this question requires information on where the user system might be employed, the frequencies of the user systems, the nature of the user receiving antennas, and the sensitivity of the user receivers.

In general, the closer the user is to the HAARP emitters, the greater the potential impact. For this reason, nearby, line-of-sight locations have been assumed for the employment of user systems. These locations are summarized in appendix C.

The characteristics (antenna and receiver sensitivity) of the user receiving system population, even though from a single family (e.g., AM or VHF mobile radios,, may differ markedly by manufacturer, age (technology employed), and condition of the system. However, an approach has been taken to model representative characteristics of user receiving system families. The model is described in appendix A. Appendix A also defines a "receiving system sensitivity" (expressed in power per unit area, i.e., Watts per square meter) for each family of user systems. This receiving system sensitivity (for users of the electromagnetic spectrum) is the predicted incident, plane-wave power density (referred to the input terminals of an equivalent lossless receiving antenna) that the receiving system would experience in the absence of the HAARP emitters. For systems that could be affected by the electromagnetic environment, such as EEDs or pacemakers, the receiving system sensitivity, is the threshold below which safe operation occurs. The HAARP emitters' addition to the electromagnetic environment has been estimated in appendix B at the frequency and location of the user systems analyzed. The approach and techniques used to estimate the HAARP emitter power densities are described in appendix B.

4.2 NUMERICAL RESULTS

Estimates of the impact on user systems are given by the ratios of the HAARP emitter estimated power densities evaluated in appendix B to the receiving system sensitivities evaluated in appendix A. These ratios are given in tables 4-1 and 4-2 for the Gakona and Clear AFS study areas, respectively. Tables 4-1 and 4-2 summarize the receiving system sensitivities, HAARP emitter incident power densities, and the predicted interference-to-noise ratios for each family of systems that may be employed or inadvertently affected in the HAARP study areas. If the interference-to-noise ratio is one or less, no impact is expected. If the ratio is much greater than one, a significant impact may occur.

4.3 ASSUMPTIONS

To fully appreciate tables 4-1 and 4-2, it is important to understand the assumptions that were used. Since tables 4-1 and 4-2 follow directly from the work summarized in appendices A, B, and C, it is appropriate to provide the assumptions used to develop the information contained in the appendices.

Appendix A Assumptions

a. Receiving system sensitivities are for the spacewave only (tropospheric wave plus the skywave) and does not include the groundwave.

Table 4-1. EMI Impact of HAARP Emitters on Receiving Systems in the Vicinity of Gakona

Notation: $aEb \equiv a \times 10^b$

Receiving System		Sensitivity, n_o (W/m^2)	HAARP Emitter Incident Power Density, s_o (W/m^2)			Interference/Noise, s_o/n_o (numeric)		
No.	Name		(1) IRI 2.8-10 MHz	(2) ISR 444-446 MHz	(3) VIS 1-15 MHz	(1) IRI	(2) ISR	(3) VIS
1	Cellular Telephone 870-890 MHz	9.9E-16	3.5E-14	4.8E-15	1.0E-15	3.5E+01	4.8E+0	1.0E+0
2	HAARP Riometer 38.2 MHz	3.2E-18	1.0E-16	negligible[1]	2.6E-19	3.1E+01	<<1	8.1E-02
3	Satellite Television a. 5925-6875 MHz b. 12,500-12,750 MHz	1.4E-14 9.6E-15	6.8E-21 1.2E-21	6.0E-22 negligible[1]	1.4E-23 6.3E-25	4.9E-07 1.2E-07	4.3E-08 <<1	1.0E-09 6.6E-11
4	HF Communications 2.1-10 MHz 10-30 MHz	9.1E-17 1.1E-17	1.7E-03 1.7E-11	negligible[1] negligible[1]	2.3E-10 3.8E-11	1.9E+13 1.5E+06	<<1 <<1	2.5E+06 3.5E+06
5	Television Broadcast 54-88 MHz, 200-216 MHz 88-200 MHz	5.9E-15 5.9E-15	5.6E-15 5.6E-18	negligible[1] negligible[1]	5.9E-13 5.9E-13	1.0E+00 1.0E-03	<<1 <<1	1.0E+02 1.0E+02
6	AM Radio Broadcast 0.535-1.0 MHz 1.0-1.7 MHz	1.6E-16 1.6E-16	negligible[1] negligible[1]	negligible[1] negligible[1]	negligible[1] 4.7E-12	<<1	<<1	<<1 2.9E+04
7	FM Radio Broadcast 92.9-106.7 MHz	4.3E-17	5.6E-18	negligible[1]	2.3E-17	1.3E-01	<<1	5.0E-01

1. Interference from subharmonics is negligible. However, interference from receiver saturation is possible.

Table 4-1. EMI Impact of HAARP Emitters on Receiving Systems in the Vicinity of Gakona (Continued)

Receiving System		Sensitivity, n_o (W/m^2)	HAARP Emitter Incident Power Density, s_o (W/m^2)			Interference/Noise, s_o/n_o (numeric)		
No.	Name		(1) IRI 2.8-10 MHz	(2) ISR 444-446 MHz	(3) VIS 1-15 MHz	(1) IRI	(2) ISR	(3) VIS
8	Avionics							
	a. GPS 1227, 1575 MHz	7.0E-13	2.9E+1 m ***	1.5E+2 m ***	<<1.0E+3 m ***	1.0	1.0	1.0
	b. VHF Radio 118-137 MHz	8.9E-18	2.5E+3 m ***	in mainbeam[2]	5.1E+4 m ***	1.0	<<1	1.0
	c. UHF Radio 960-1125 MHz	6.0E-16	9.8E+3 m ***	4.0E+3 m ***	4.8E+3 m ***	1.0	1.0	1.0
	d. VOR 115-116 MHz	5.8E-17	1.0E+3 m ***	in mainbeam[2]	3.2E+4 m ***	1.0	<<1	1.0
	e. ADF 0.25-0.40 MHz	2.2E-16	in mainbeam[2]	in mainbeam[2]	in mainbeam[2] ***	<<1	<<1	1.0
9	Cardiac Pacemakers							
	a. Incident Pulsed	1.0E+2*	3.4E-05	6.9E-05	2.1E-11	3.4E-07	6.9E-07	2.1E-13
	b. Incident CW	>>1.0E+2*	3.4E-05	6.9E-05	2.1E-11	<<3.4E-07	<<6.9E-07	<<2.1E-13
10	Electro-Explosive Devices							
	a. Exposed	1.0E-2**	3.4E-05	6.9E-05	2.1E-11	3.4E-03	6.9E-03	2.1E-09
	b. In Metal Container	1.0E+2**	3.4E-05	6.9E-05	2.1E-11	3.4E-07	3.0E-07	2.1E-13
11	Mobile VHF Radio							
	38-45 MHz	4.2E-18	3.5E-10	negligible[1]	6.6E-12	8.3E+07	<<1	1.6E+06
	45-88 MHz	1.7E-17	3.5E-14	negligible[1]	6.6E-12	2.1E+03	<<1	3.9E+05
	88-166 MHz	1.7E-17	3.5E-17	negligible[1]	6.6E-12	2.1E+00	<<1	3.9E+05
12	Wildlife Trackers							
	30-45 MHz	1.3E-18	3.5E-10	negligible[1]	1.7E-13	2.7E+08	<<1	1.3E+05
	45-88 MHz	2.6E-18	3.5E-14	negligible[1]	1.7E-13	1.3E+04	<<1	6.5E+04
	88-200 MHz	2.6E-18	3.5E-17	negligible[1]	1.7E-13	1.3E+01	<<1	6.5E+04
	200-222 MHz	2.6E-18	3.5E-14	negligible[1]	1.7E-13	1.3E+04	<<1	6.5E+04

*Design Susceptibility Threshold
**Safe-Exposure Limit
***Nearest Distance of Aircraft for $s_o/n_o = 1$

1. Interference from subharmonics is negligible. However, interference from receiver saturation is possible.
2. Nearest distance to aircraft to prevent receiver saturation. Interference from subharmonics is negligible.

Table 4-1. EMI Impact of HAARP Emitters on Receiving Systems in the Vicinity of Gakona (Concluded)

Receiving System		Sensitivity, n_o (W/m^2)	HAARP Emitter Incident Power Density, s_o (W/m^2)			Interference/Noise, s_o/n_o (numeric)		
No.	Name		(1) IRI 2.8-10 MHz	(2) ISR 444-446 MHz	(3) VIS 1-15 MHz	(1) IRI	(2) ISR	(3) VIS
13	Citizen Band Radio 26.9-27.4 MHz	2.0E-17	3.5E-10	negligible[1]	2.1E-13	1.8E+07	<<1	6.0E-04
14	Handheld Transceivers							
	a. VHF 118-174 MHz	3.0E-18	3.5E-17	negligible[1]	1.3E-16	1.2E+01	<<1	4.3E+01
	b. UHF 403-470 MHz	4.7E-17	3.5E-14	4.2E-07	1.0E-16	7.4E+02	8.9E+09	2.1E+0
15	HAARP Scintillation Receiver 240-245 MHz	1.0E-19	5.6E-20	negligible[1]	2.2E-23	5.6E-01	<<1	2.2E-04
16	Radio Telephone							
	a. VHF 152-158 MHz	6.3E-18	2.8E-22	negligible[1]	9.1E-17	4.4E-05	<<1	1.4E+01
	b. UHF 454-460 MHz	2.7E-17	2.8E-19	1.5E-11	4.6E-20	1.0E-02	5.6E+05	1.7E-03
17	Pipeline Systems							
	a. Control 157, 162 MHz	1.1E-17	2.2E-22	negligible[1]	4.7E-17	2.0E-05	<<1	4.2E+0
	b. VHF Comm. 150-162 MHz	1.6E-17	2.2E-22	negligible[1]	3.7E-16	1.4E-05	<<1	2.3E+01
	c. UHF Comm. 450-460 MHz	1.3E-16	2.6E-20	4.5E-12	4.1E-17	2.0E-04	3.5E+04	3.2E-01
18	Terrestrial Microwave 5945-6094 MHz	5.4E-18	7.4E-21	3.9E-24	1.5E-23	1.4E-03	7.2E-07	2.9E-06

1. Interference from subharmonics is negligible. However, interference from receiver saturation is possible.

Table 4-2. EMI Impact of HAARP Emitters on Receiving Systems in the Vicinity of Clear

Notation: $aEb \equiv a \times 10^b$

Receiving System		Sensitivity, n_o (W/m^2)	HAARP Emitter Incident Power Density, s_o (W/m^2)			Interference/Noise, s_o/n_o (numeric)		
No.	Name		(1) IRI 2.8-10 MHz	(2) ISR 444-446 MHz	(3) VIS 1-15 MHz	(1) IRI	(2) ISR	(3) VIS
1	Cellular Telephone 870-890 MHz	9.9E-16	3.5E-14	2.7E-13	5.8E-14	3.5E+01	2.7E+02	5.9E+01
2	HAARP Riometer 38.2 MHz	3.2E-18	1.6E-16	negligible[1]	2.6E-19	3.1E+01	<<1	8.1E-02
3	Satellite Television a. 5925-6875 MHz b. 12,500-12,750 MHz	1.4E-14 9.6E-15	9.8E-19 1.7E-19	2.2E-20 negligible[1]	5.1E-22 2.3E-23	7.0E-05 1.8E-05	1.6E-06 <<1	3.6E-08 2.0E-09
4	HF Communications 2.1-10 MHz 10-30 MHz	9.1E-17 1.1E-17	1.7E-03 8.9E-10	negligible[1] negligible[1]	2.3E-10 3.8E-11	1.9E+13 8.1E+07	<<1 <<1	2.5E+06 3.5E+06
5	Television Broadcast 54-88 MHz, 200-216 MHz 88-200 MHz	5.9E-15 5.9E-15	8.9E-14 8.9E-17	negligible[1] negligible[1]	2.3E-12 2.3E-12	1.5E+01 1.5E-02	<<1 <<1	3.9E+02 3.9E+02
6	AM Radio Broadcast 0.535-1.0 MHz 1.0-1.7 MHz	1.6E-16 1.6E-16	negligible[1] negligible[1]	negligible[1] negligible[1]	negligible[1] 4.7E-12	<<1	<<1	<<1 2.9E+04
7	FM Radio Broadcast 92.9-106.7 MHz	4.3E-17	8.9E-17	negligible[1]	2.3E-13	2.1E+00	<<1	5.3E+03

1. Interference from subharmonics is negligible. However, interference from receiver saturation is possible.

Table 4-2. EMI Impact of HAARP Emitters on Receiving Systems in the Vicinity of Clear (Continued)

Receiving System		Sensitivity, n_o (W/m^2)	HAARP Emitter Incident Power Density, s_o (W/m^2)			Interference/Noise, s_o/n_o (numeric)		
No.	Name		(1) IRI 2.8-10 MHz	(2) ISR 444-446 MHz	(3) VIS 1-15 MHz	(1) IRI	(2) ISR	(3) VIS
8	Avionics							
	a. GPS 1227, 1575 MHz	7.0E-13	2.9E+1 m ***	1.5E+2 m ***	<<1.0E+3 m ***	1.0	1.0	1.0
	b. VHF Radio 118-137 MHz	8.9E-18	2.5E+3 m ***	in mainbeam[2]	5.1E+4 m ***	1.0	<<1	1.0
	c. UHF Radio 960-1125 MHz	6.0E-16	9.8E+3 m ***	4.0E+3 m ***	4.8E+3 m ***	1.0	1.0	1.0
	d. VOR 115-116 MHz	5.8E-17	1.0E+3 m ***	in mainbeam[2]	3.2E+4 m ***	1.0	<<1	1.0
	e. ADF 0.25-0.40 MHz	2.2E-16	in mainbeam[2]	in mainbeam[2]	in mainbeam[2] ***	<<1	<<1	1.0
9	Cardiac Pacemakers							
	a. Incident Pulsed	1.0E+2*	1.4E-04	3.9E-03	1.0E-09	1.4E-06	3.9E-05	1.0E-11
	b. Incident CW	>>1.0E+2*	1.4E-04	3.9E-03	1.0E-09	<<1.4E-06	<<3.9E-05	<<1.0E-11
10	Electro-Explosive Devices							
	a. Exposed	1.0E-2**	3.4E-05	3.9E-03	1.0E-09	3.4E-03	3.9E-01	1.0E-07
	b. In Metal Container	1.0E+2**	3.4E-05	3.9E-03	1.0E-09	3.4E-07	3.9E-05	1.0E-11
11	Mobile VHF Radio							
	38-45 MHz	4.2E-18	3.5E-10	negligible[1]	2.3E-08	8.3E+07	<<1	5.5E+09
	45-88 MHz	1.7E-17	3.5E-14	negligible[1]	2.3E-08	2.1E+03	<<1	1.4E+09
	88-166 MHz	1.7E-17	3.5E-17	negligible[1]	2.3E-08	2.1E+00	<<1	1.4E+09
12	Wildlife Trackers							
	30-45 MHz	1.3E-18	3.5E-10	negligible[1]	5.0E-10	2.7E+08	<<1	3.8E+08
	45-88 MHz	2.6E-18	3.5E-14	negligible[1]	5.0E-10	1.3E+04	<<1	1.9E+08
	88-200 MHz	2.6E-18	3.5E-17	negligible[1]	5.0E-10	1.3E+01	<<1	1.9E+08
	200-220 MHz	2.6E-18	3.5E-14	negligible[1]	5.0E-10	1.3E+04	<<1	1.9E+08

*Design Susceptibility Threshold

**Safe-Exposure Limit

***Nearest Distance of Aircraft for $s_o/n_o = 1$

1. Interference from subharmonics is negligible. However, interference from receiver saturation is possible.
2. Nearest distance to aircraft to prevent receiver saturation. Interference from subharmonics is negligible.

Table 4-2. EMI Impact of HAARP Emitters on Receiving Systems in the Vicinity of Clear (Concluded)

Receiving System		Sensitivity, n_o (W/m^2)	HAARP Emitter Incident Power Density, s_o (W/m^2)			Interference/Noise, s_o/n_o (numeric)		
No.	Name		(1) IRI 2.8-10 MHz	(2) ISR 444-446 MHz	(3) VIS 1-15 MHz	(1) IRI	(2) ISR	(3) VIS
13	Citizen Band Radio 26.9-27.4 MHz	2.0E-17	3.5E-10	negligible[1]	5.9E-10	1.8E+07	<<1	3.0E+07
14	Handheld Transceivers a. VHF 118-174 MHz b. UHF 403-470 MHz	 3.0E-18 4.7E-17	 3.5E-17 3.5E-14	 negligible[1] 2.3E-05	 4.7E-13 3.7E-13	 1.2E+01 7.4E+02	 <<1 5.0E+11	 1.6E+05 7.9E+03
15	HAARP Scintillation Receiver 240-245 MHz	1.0E-19	5.6E-20	negligible[1]	1.2E-23	5.6E-01	<<1	1.2E-04
16	Radio Telephone a. VHF 152-158 MHz b. UHF 454-460 MHz	 6.3E-18 2.7E-17	 **** ****	 **** ****	 **** ****	 **** ****	 **** ****	 **** ****
17	Pipeline Systems a. Control 157, 162 MHz b. VHF Comm. 150-162 MHz c. UHF Comm. 450-460 MHz	 1.1E-17 1.6E-17 1.3E-16	 6.2E-24 6.2E-24 6.2E-21	 negligible[1] negligible[1] 8.6E-13	 1.4E-21 1.4E-21 4.4E-24	 5.6E-07 3.9E-07 4.7E-05	 <<1 <<1 6.6E+03	 1.3E-04 8.8E-05 3.4E-08
18	Terrestrial Microwave 2127-2177 MHz	5.4E-18	3.5E-20	1.3E-22	9.1E-23	6.5E-03	2.5E-05	1.7E-05

1. Interference from subharmonics is negligible. However, interference from receiver saturation is possible.

****Our survey has not located a radio telephone user within the Clear AFS area.

b. The HAARP emitters are in the far field of the receiving antennas. However, the receiving systems may be in the near field or far field of the HAARP emitters.

c. The ambient temperatures of the receive antenna circuit, matching network, and transmission line are equal to the noise factor reference temperature at 288 K.

d. The signal/noise processing factors of the receiving system are equal to unity.

e. The external system noise is equal to quiet-rural-noise.

f. The receive antenna directivities are equal to the peak directivities of the antennas for a worse-case sensitivity to EMI. Appendix B modifies these antenna directivities to account for the receive directivity in the direction of the HAARP emitters.

Appendix B Assumptions

a. IRI transmitter harmonics lie 80 dB below the carrier for frequencies below 45 MHz, 120 dB below the carrier for frequencies above 45 MHz to 88 MHz, 150 dB below the carrier for frequencies 88 MHz to 200 MHz, and 120 dB below the carriers for frequencies above 200 MHz.

b. ISR transmitter harmonics lie 80 dB below the carrier for frequencies below 1 GHz and lie 100 dB below the carrier for frequencies above 1 GHz.

c. IRI and ISR transmitter subharmonics are negligible.

d. Propagation loss is that of free space for line-of-sight paths.

e. A diffraction loss of 30 dB is applied to non-line-of-sight paths.

f. An absorption loss of 5 dB is applied to skywave (HF) paths.

g. The IRI waveform is CW.

h. The ISR waveform is pulsed, with a 0.5 MHz bandwidth.

i. The pattern of the IRI antenna well outside the HF band is random with no main beam or grating lobes, and the directivity is that of an isotropic radiator in the upper hemisphere (3 dBi).

j. The ISR pattern is that of a parabolic dish of 1000 m^2 aperture, as specified by a semi-empirical model.

k. IRI element efficiency above the HF band is -10 dB.

Appendix C Assumption

a. The closest ranges of the HAARP emitters to the user receiving systems are utilized to assess the worst cases of electromagnetic interference.

Summary of Assumptions

The EMI impact estimates in tables 1 and 2 are based largely on worst-case, line-of-sight (tropospheric) propagation. Such propagation to ground-based users is limited in range by the Earth's curvature. The strength of the received signal is also affected by intervening topography, structures, and vegetation.

For the user systems that operate above 10 MHz (the top frequency of the IRI) and remote from the HAARP study areas, potential interference from the IRI could occur only through harmonic and spurious emissions. It is quite likely that any IRI interference experienced by such users above 10 MHz will be via line-of-sight, tropospheric wave propagation. Skywave propagation, of IRI harmonic and spurious emissions, is less likely because the energy may be lost into space; may require lossy, "multi-hop" propagation between the ionosphere and the ground; and would originate from the IRI antenna that disperses the out-of-band RF energy over the upper hemisphere, rather than into a focused beam.

4.4 DISCUSSION

From tables 1 and 2, it is concluded that the systems that may be affected by the HAARP IRI are HF Communications, mobile VHF radios, wildlife trackers, citizen band radios, handheld transceivers, and avionics (VHF and UHF radio, VOR).

The HAARP incoherent scatter radar may affect the performance of UHF handheld transceivers, UHF radio telephone systems, and UHF communication pipeline systems.

The HAARP VIS is likely to affect similar systems to those affected by the IRI, as both systems operate in the lower one half of the HF band. However, certain things can be said to allay concerns for the interference potential of the VIS. The radiated power of the VIS is 60,000 times less than the IRI; the VIS HF antenna pattern has approximately 400 times less gain than the IRI antenna; the VIS HF antenna as an out-of-band emitter distributes the power over 10-15 elements into an inefficient spikey pattern; the VIS sweeps in frequency which means that if interference episodes do occur, they will be short-lived and when converted to audio frequencies will be a short buzz or click. Such sounders are operated on a noninterference basis throughout the world and in general are compatible with the shared use of the RF spectrum. These considerations suggest that the VIS will not be a significant source of interference. Nevertheless, the quantitative analysis has been completed and the VIS results are included in tables 1 and 2.

The HAARP emitters do not operate continuously. In the case of the IRI, a maximum of five campaigns per year, each of four-week duration with operations of eight hours per day are projected. On a long-term basis, the IRI may operate less than 13% of the time. The ISR may operate up to 12 hours per day for the same periods (approximately 19% on a long term basis); the VIS may collect data routinely for several minutes every half hour for periods when the IRI is not operating as well as operating 12 hours per day during the campaigns (approximately 25% on a long-term basis).

Optical instruments are expected to provide important diagnostics to characterize the background environmental conditions as well as to define the changes induced by operating the IRI. If optical measurements are needed to achieve the research objectives, the HAARP campaigns will occur primarily at night over the seasons of fall and winter (October through March).

SECTION 5

MITIGATION APPROACHES AND CONSIDERATIONS

At present, the western world's most powerful HF IRI is operated near Tromso, Norway. While the Norwegian IRI is approximately four times less powerful than planned for the HAARP, it is encouraging to note that broadcast radio and television and telecommunications operate successfully within close proximity to Tromso. Satellite television signals are received without interference on the roof of a building within 100 meters of the antenna array. Antenna arcing at times causes interference. This can be minimized by fabrication and construction techniques that ensure the long-term electrical integrity of the antenna and groundscreen and by periodic inspection of the antenna to spot loose connections and areas of corrosion that may prevent electrical continuity.

As another related example, the USAF has considerable experience in the clear channel, noninterference operation of large, powerful HF OTH-B radars. From more than a decade of development, testing, and operation of these radars, in a mode similar to that proposed for the HAARP IRI, there has been but one report of interference and none within the International Broadcast Bands.

The interference to noise ratios summarized in tables 4-1 and 4-2, provide insight as to those user systems most likely to be affected by the HAARP emitters. As mentioned earlier, reliable predictions of specific effects are difficult. The ratios presented in tables 4-1 and 4-2 are believed to be worst-case situations and not those likely to be experienced by the majority of the users within the HAARP study areas. Local topography, vegetation, structures, and receiving antenna nulls will contribute to make the real-world situation more benign than that suggested by tables 4-1 and 4-2. However, given that several of the predicted interference to noise ratios are significantly greater than one, it is appropriate to consider what initiatives the government could take to verify the predictions and what mitigation approaches could be taken if needed.

While the HAARP emitters are being developed and installed in Alaska, measurements of the radio noise environment could be made. These measurements would provide a baseline of the environment in the absence of the HAARP emitters. The measurements could also include the government operation of representative user systems in and near likely user locations.

To provide a procedure for reporting suspected EMI, HAARP could notify the community of RF spectrum users of a telephone number for filing reports. If the report would be filed while the suspected interference was occurring, steps could be taken by the operators of the HAARP emitters to isolate the conditions related to interference.

With the expected nature of the HAARP IRI frequency use authorization, and given a report of EMI, HAARP would be obligated to resolve the interference situation or cease operating on a specific frequency and/or mode that is a validated cause of interference.

Given a confirmed interference situation either as a result of government investigations or through user interference reports, specific mitigation approaches could be defined and employed.

Mitigation approaches used by fixed user installations might include:

a. Use of low sidelobe directional receive antennas. Such antennas could be employed to increase the desired signal strength (as received in the mainbeam of the antenna) and suppress the unwanted HAARP emitter signals.

b. Transmission of the desired signals over a coaxial or fiber optics cable. Coaxial and fiber optics cables are immune to RF interference. This approach might be appropriate for short-distance communications and/or situations where the interference is isolated to a limited area.

c. Change of user system frequency. This approach might be appropriate for a short link of a longer-haul communication system. The frequency could be changed to a node not affected by the HAARP emitters and the message relayed on an unaffected frequency through a limited area to another node where the original frequency system can operate effectively.

d. Use of a preselection filter. This approach could be employed for those situations where a nearby user experiences an out-of-band saturated receiver. This type of filter selectively suppresses the out-of-band interfering signal while simultaneously allowing the reception of the desired in-band signal. This approach is appropriate only for signals that are not co-channel.

e. Moving of a user system to a position shielded from the HAARP emitters. This approach is appropriate if the user's mission can be accomplished at the new location and the resultant shielding of the HAARP emitter signal strength is adequate to reduce the interference to an acceptable level.

Mitigation approaches utilized by mobile users of the electromagnetic spectrum might include:

a. Change of user system frequency. A small change in the operating frequency, of for example a VOR radionavigation system, might move the user's receive system from a bothersome harmonic of the HAARP IRI. A change to a different operating band could possibly eliminate a confirmed interference situation.

b. Establishment of a restricted airspace. Avoidance of the restricted airspace would preclude impacts on aviation radionavigation and/or communication systems. Such restrictions could be established to be in effect only during scheduled periods for HAARP emitter operations or could be established as a blanket restriction when HAARP emitters might be expected to operate in response to unpredictable ionospheric and/or auroral conditions.

c. Use of a preselection filter for the receiving system. This approach could be employed for those situations where a nearby mobile user experiences a saturated receiver. This filter selectively suppresses the interfering signal while simultaneously allowing the reception of the desired signal. This approach is appropriate only for signals that are not co-channel.

HAARP could mitigate confirmed IRI interference scenarios to both fixed and mobile users through

a. Judicious selection of frequencies to maintain a clear-channel, noninterference operation within the 2.8- to 10-MHz band.

b. Expansion of the list of forbidden frequencies or bands.

c. Placement of antenna nulls (reducing the power density emitted in a specific direction) in the direction of affected users.

d. Amplitude tapering of the IRI emissions to reduce (in all directions) the power density in the antenna sidelobes.

e. Establishment of additional forbidden frequencies for the operation of the HAARP emitters. This approach would probably be most appropriate for users systems bothered by harmonic frequencies of the HAARP IRI operating frequency. Examples include VHF communication and VOR radionavigation systems.

SECTION 6

CONCLUSIONS

It is recognized that operation of the HAARP emitters would change the electromagnetic environment over the frequency bands of operation (and their harmonic frequencies) within the physical space their energy reaches. An analysis predicts that several worst-case scenarios may cause interference to some user systems that would share the RF spectrum. Despite the theoretical worst-case analyses, examples of similar IRI and radar systems employed elsewhere in the world suggested that compatible operations are practical. While specific interference effects are difficult to predict reliably, the potential for interference from the HAARP emitters is recognized.

Given this recognition, the following approaches to minimize the EMI impact have been suggested for consideration and possible employment:

a. A measurement program during the development testing of the HAARP emitters. This could serve to define and quantify interference scenarios.

b. Interference reporting. This could be used during periods when the HAARP emitters are operating.

c. Mitigation measures. These could be employed in the event of a confirmed interference scenario.

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APPENDIX A

RECEIVING SYSTEM SENSITIVITIES

A.1 INTRODUCTION

The principal receiving systems in the vicinity of the HAARP study areas and their nearest distances to HAARP emitters are enumerated in tables C-1 and C-2 of appendix C. The receiving systems are ground based (dwelling, HAARP facility, air-field facility), mobile (highway, trail), and, in the case of avionics and EEDs, airborne. The RF operating frequencies of the receiving systems may be in-band or out-of-band from those of the HAARP emitters.

The interference from the HAARP emitters to the receiving systems is transmitted via a spacewave (through the troposphere or by reflection from the ionosphere) or via a groundwave along the surface of the Earth. In the case of spacewave propagation, the HAARP emitters are in the far field of the receiving antennas. However, the receiving systems may be in the near field or far field of the HAARP emitters. The distances to the far fields of the receiving systems or emitters are determined by their respective antenna aperture sizes.

The available power densities $s_o\left(\mathrm{W/m^2}\right)$ of the interference signals from the HAARP emitters at the nearest distance of each receiving system are calculated in appendix B. Only the spacewave power densities are calculated in appendix B. Groundwave power densities are calculated for OTH-B in the Environmental Impact Statement [6] for the cancelled OTH-B radar system that was planned for Gulkana. The impact of groundwave interference on receiving systems in the vicinity of Gulkana was found in the Impact Statement to be insignificant for the OTH-B radar emitter. The groundwave power densities from the HAARP emitters are expected to be less than those from the OTH-B radar, as explained in appendix B.

The sensitivities of the receiving systems to the spacewave interference from the HAARP emitters are modeled in section A.2 and numerically evaluated in section A.3. The receiving system sensitivities are expressed in terms of the receiving system noise available power density $n_o\left(\mathrm{W/m^2}\right)$ referenced to the terminals of the equivalent lossless receiving antenna. The impact of the spacewave interference from the HAARP emitters on any particular receiving system may be determined by computing the ratio s_o/n_o. The impact is large, small, or moderate for $s_o/n_o >> 1$, $s_o/n_o << 1$, $s_o/n_o \approx 1$, respectively.

A.2 MODEL

With reference to figure (A-1), the predetection signal-to-noise ratio s_o/n_o of a receiving system is given by reference 1:

$$\frac{s_o}{n_o} = \frac{s_o}{n/a} \qquad \text{(A-1)}$$

where s_o = signal available power density, incident on the equivalent lossless receiving antenna, within the limiting bandwidth of the receiving system $\left(\mathrm{W/m^2}\right)$

n_o = system noise available power density referred to the terminals of the equivalent lossless receiving antenna $\left(\mathrm{W/m^2}\right)$

n = system available noise power referred to the terminals of the equivalent lossless antenna (W)

a = collecting area of the receive antenna $\left(\mathrm{m^2}\right)$

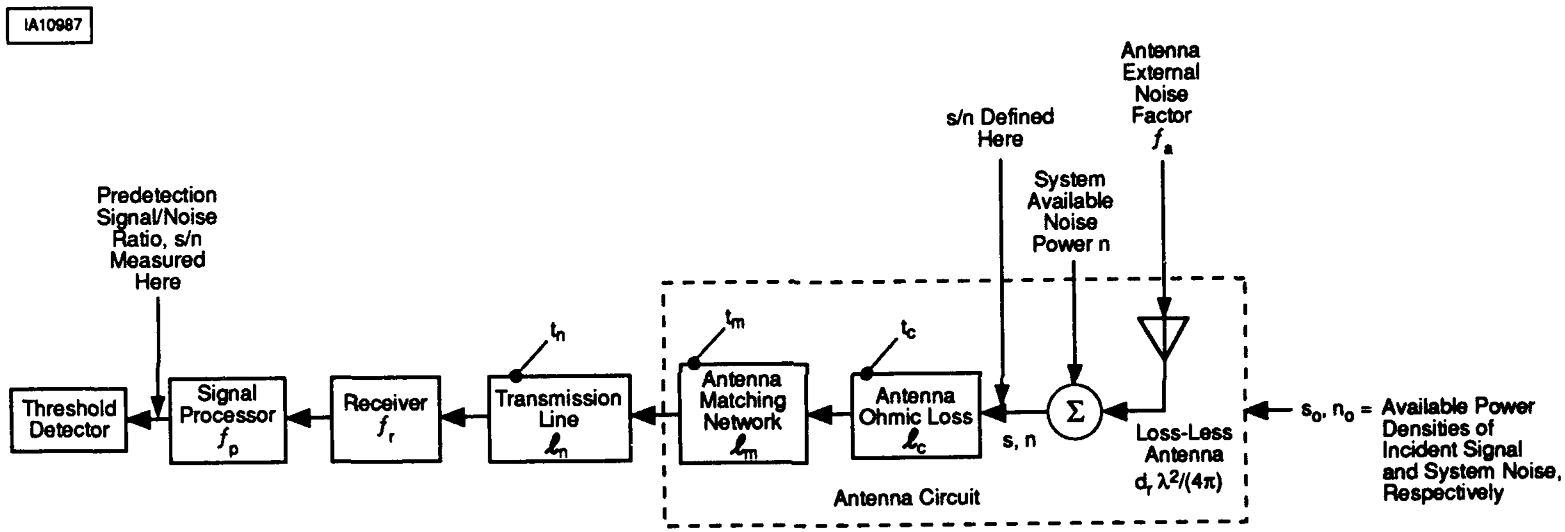

Figure A-1. Signal/Noise Equivalent Circuit of a Receiving System

The system noise available power density n_o is also known as "noise equivalent power density" and, for the purpose of the present study, is designated as the "receiving system sensitivity." The receiving system sensitivities n_o in the vicinity of the HAARP study areas are calculated in this appendix.

The system noise available power n is given by reference 1:

$$n = kt_{ref}bf \qquad \text{(A-2)}$$

where k = Boltzmann's constant = 1.38 x 10^{-23} (J/K)

t_{ref} = reference noise temperature (K)

f = system operating noise factor relative to the reference noise temperature (numeric)

b = baseband limiting bandwidth of the receiving system (Hz)

It is convenient to set $t_{ref} = 288\text{K}$ because measurements of atmospheric noise and man-made environmental noise are usually referenced to thermal noise at that temperature and because at that temperature $10 log_{10} kt_{ref} = -204.0059$ dBj is approximately a whole number. The system operating noise factor f, when expressed in dB, is defined as the system operating noise figure F and is given by

$$F = 10 log_{10} f \quad \text{(dB)} \qquad \text{(A-3)}$$

The system operating noise factor f is given by reference 1:

$$f = (f_a - 1 + \ell_c \ell_m \ell_n f_r) f_p; \quad t_c = t_m = t_n = t_{ref} \qquad \text{(A-4)}$$

where f_a = receive antenna external noise factor integrated over the antenna pattern function (numeric)

ℓ_c, ℓ_m, ℓ_n = available loss factors (numerics $\geq$ 1) of the antenna, matching network, and transmission line, respectively.

f_r = receiver noise factor (numeric $\geq$ 1)

f_p = signal/noise processing factor (numeric $\geq$ 1)

t_c, t_m, t_n = ambient temperatures (K) of the antenna, matching network, and transmission line, respectively.

The processing factor f_p is the signal-to-noise available power ratio at the output of a signal processor with a matched filter to that for the same signal processor, but with a weighted filter. The processing factor includes range, Doppler frequency, and beam forming processing and is restricted to processing before threshold detection. Threshold detection is defined at the point at which RF phase information is lost. The civilian receiving systems in the vicinity of the HAARP study areas generally do not have signal processors. Therefore, in the present study, it will be assumed that $f_p = 1$. For this condition equation (A-4) reduces to

$$f = f_a - 1 + \ell_c \ell_m \ell_n f_r; \quad f_p = 1, \ t_c = t_m = t_n = t_{ref} \qquad \text{(A-5)}$$

If the signal power density s_o is that of an incident spacewave whose source is in the far field of the receive antenna, then the collecting area a of the equivalent lossless receiving antenna is given by

$$a = \left(\lambda^2 / 4\pi\right) d_r \qquad \text{(A-6)}$$

where λ = RF wavelength (m)

d_r = receiver antenna directivity (numeric relative to isotropic)

With the substitution of equations (A-2), (A-5), and (A-6) into equation (A-1), the system noise available power density n_o is given by

$$n_o = \left(kt_{ref}b\right)\left(f_a - 1 + \ell_c\ell_m\ell_n f_r\right) \Big/ \left[\left(\lambda^2/4\pi\right)d_r\right] \qquad \text{(A-7)}$$

In equation (A-7), the terms $(f_a - 1)$ and $\ell_c\ell_m\ell_n f_r$ represent noise that is generated externally and internally, respectively, to the system.

Consider now the special cases of external-noise-limited and internal-noise-limited receiving systems. A receiving system is external-noise-limited if $(f_a - 1) >> \ell_c\ell_m\ell_n f_r$. For an external-noise-limited system, equation (A-7) reduces to

$$n_o = \left(kt_{ref}b\right)\left(f_a - 1\right) \Big/ \left[\left(\lambda^2/4\pi\right)d_r\right]; \ (f_a - 1) >> \ell_c\ell_m\ell_n f_r, \qquad \text{(A-8)}$$

external-noise-limited

A receiving system is internal-noise-limited if $\ell_c\ell_m\ell_n f_r >> (f_a - 1)$. For an internal-noise-limited system, equation (A-7) reduces to

$$n_o = \ell_c\ell_m\ell_n kt_{ref}bf_r \Big/ \left[\left(\lambda^2/4\pi\right)d_r\right]; \ \ell_c\ell_m\ell_n f_r >> (f_a - 1), \qquad \text{(A-9)}$$

internal-noise-limited

Numerical values of atmospheric and man-made external noise figure F_a, referenced to 288K, have been published by the International Radio Consultative Committee [French: Comite Consultatif International des Radiocommunications (CCIR)]. CCIR expected

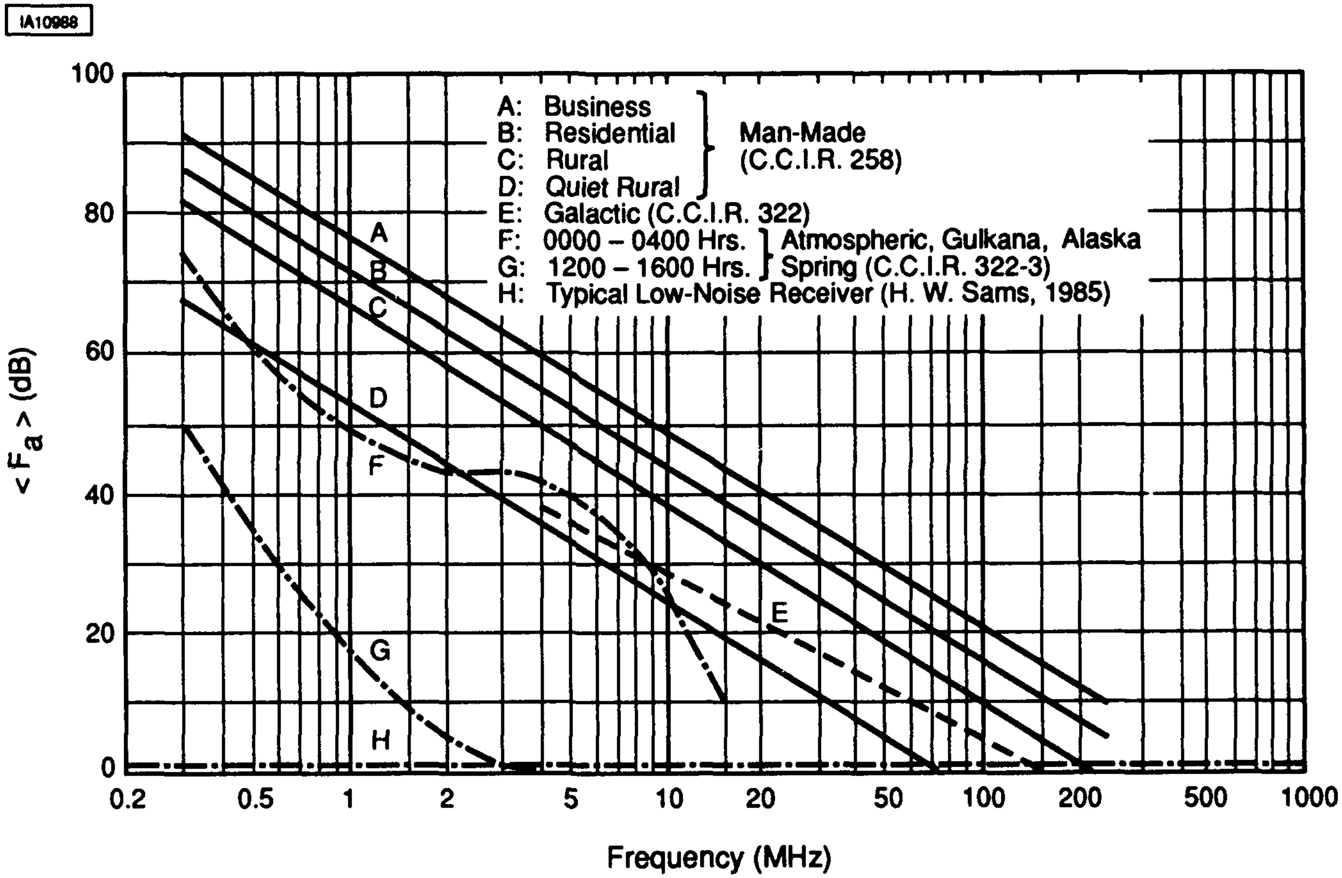

Figure A-2. Expected Values of Man-Made, Galactic, Atmospheric, and Receiver Noise values $\langle F_a \rangle$ for man-made, galactic, and atmospheric external noise over the frequency range 0.2-200 MHz are compared in figure A-2 with the noise figure for a typical low-noise receiver.

External noise generally decreases with increasing frequency whereas receiver noise increases with increasing frequency. In the HF band (3-30 MHz) or at lower frequencies, receiving systems are usually external-noise-limited. In the VHF band (30-300 MHz), receiving systems are external-noise-limited at the lower end of the band but are internal-noise-limited at the upper end of the band. At frequencies above the VHF band, receiving systems are usually internal-noise-limited. Man-made noise is characterized for business, residential, rural, and quiet-rural areas. Rural noise is characteristic of a location where land usage is primarily for agricultural or similar pursuits, and dwellings are no more than one every five acres. Quiet-rural noise is characteristic of a rural location that is located at least several kilometers from power lines and electrical equipment [2]. Quiet-rural noise is approximately 15 dB less than that of rural noise. In the HF band, atmospheric noise can be greater or less than quiet-rural-noise depending upon the time of year and day. In particular, during the spring at mid-day, the measured external noise (curve G) at 5 MHz can be 20 dB less than quiet-rural noise for locations remote from transmission lines.

Man-made noise in the vicinity of the HAARP study areas is probably less than rural noise but more than quiet-rural noise because of the presence of open-wire power transmission lines. Since the impact of HAARP emitters is greater for receiving systems with smaller system noise power densities, the noise level at the HAARP study areas shall be assumed to be that of quiet-rural noise as a worse-case scenario for most of the time. The analytic expression for the expected value $\langle F_a \rangle$ of quiet-rural noise figure (curve D in figure A-2) is given by

$$\langle F_a \rangle = -27.7 log_{10} f_{MHz} + 52 \quad \text{(dB), quiet-rural noise} \qquad \text{(A-10)}$$

where f_{MHz} is the radio frequency in MHz.

The noise figure $\langle F_r \rangle$ of a typical low-noise receiver with a 300K ambient temperature field-effect-transistor (FET) front-end (curve H in figure A-2) is given by reference 3 as

$$\langle F_r \rangle \approx 1 \text{ dB}, \quad f < 10 \text{ GHz}, \text{ typical low-noise receiver} \qquad \text{(A-11)}$$

The corresponding noise factor is $f_r = 1.26$ where the noise factor f_r(numeric) and the noise figure F_r(dB) are related by $F_r = 10 log_{10} f_r$.

The quiet-rural noise figure $\langle F_a \rangle$ (curve D) is equal to the receiver noise figure $\langle F_r \rangle$ (curve H) at the frequency f = 70 MHz. At 40 MHz, $(f_a - 1)/f_r \approx 3$. At 90 MHz, $f_r/(f_a - 1) \approx 3$. The system noise power density n_o of internal-noise-limited receiving systems is minimized when the available loss factors ℓ_c, ℓ_m, ℓ_n of the antenna, matching network, and transmission line, respectively, are minimized [see equation (A-9)]. Accordingly, as a worse case of EMI, it shall be assumed in this study that

$$\ell_c = \ell_m = \ell_n = 1; \text{ worse case, internal-noise-limited system} \qquad \text{(A-12)}$$

Upon the basis of equations (A-10) through (A-12), equation (A-7) reduces to

$$n_o = \begin{cases} kt_{ref} b(f_a - 1) / \left[\left(\lambda^2 / 4\pi \right) d_r \right], & \text{f} < 40 \text{ MHz (external–noise –limited)} \\ kt_{ref} b(f_a - 1 + f_r) / \left[\left(\lambda^2 / 4\pi \right) d_r \right], & 40 \le \text{f} \le 90 \text{ MHz} \\ kt_{ref} b f_r / \left[\left(\lambda^2 / 4\pi \right) d_r \right], & \text{f} > 90 \text{ MHz (internal–noise – limited)} \end{cases} \qquad \text{(A-13)}$$

Equation (A-13) is the model used in this study for evaluating the sensitivities of receiving systems in the vicinity of the HAARP study areas. Equation (A-13) assumes that the incident interference from the HAARP emitters is via a spacewave and that the HAARP emitters are in the far field of the receiving systems. Equation (A-13) is a function of the parameters f_a, f_r, b, λ, and d_r. The external noise factor f_a and the receiver noise factor f_r are determined from equations (A-10) and (A-11), respectively. The receiving system baseband bandwidth b and the RF wavelength λ of the incident interference within the bandwidth of the receiving system, for each receiving system in the vicinity of the HAARP study areas, are enumerated in section A.3. The antenna directivity d_r is discussed in the remainder of this section.

The antennas for the receiving systems in the vicinity of the HAARP study areas are for the most part either dipoles (when ground planes are not convenient) or monopoles (when ground planes are convenient). The length of these antennas can be electrically short (much less than a wavelength) or resonant (half-wave for dipoles and a quarter-wave for monopoles). Furthermore, these antennas may be ground based, mobile, or airborne. Resonant antennas have only 0.2 dB to 0.4 dB more directivity than electrically short antennas [4] (see table A-1). Resonant and electrically short dipole and monopole antennas in free space have peak directivities of 1.8 dBi to 5.2 dBi (see table A-1). If these same antennas are in close proximity to Earth, the peak directivity is approximately 5.2 dBi regardless of the size of the ground plane [5] (see figure A-3). The numeric directivity corresponding to 5.2 dBi is 3.28. Those same antennas with a peak numeric directivity of 3.28 have zero directivity on the radio horizon because of the multipath null introduced by the Earth [5] (see figure A-4). Figure A-4 does not include the groundwave electric field on the radio horizon. As a worse case of EMI from an incident spacewave whose source is in the far field of these antennas, it shall be assumed in this study that the antenna directivity d_r is given by

$$d_r = 3.28; \text{ worse case, monopole and dipole antennas} \qquad \text{(A-14)}$$

The antenna directivities for those receiving systems that do not have simple dipole or monopole antennas, are given in section A.3.

A.3 NUMERICAL VALUES

Nominal values of the receiving system parameters and resulting sensitivities are summarized in table A-2. The tabulated entries are RF wavelength λ (m), baseband bandwidth b (Hz), antenna directivity d_r (numeric), noise factor f (numeric), and the system noise available

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Table A-1. Electrical Properties of Monopole and Dipole Antennas in Free Space

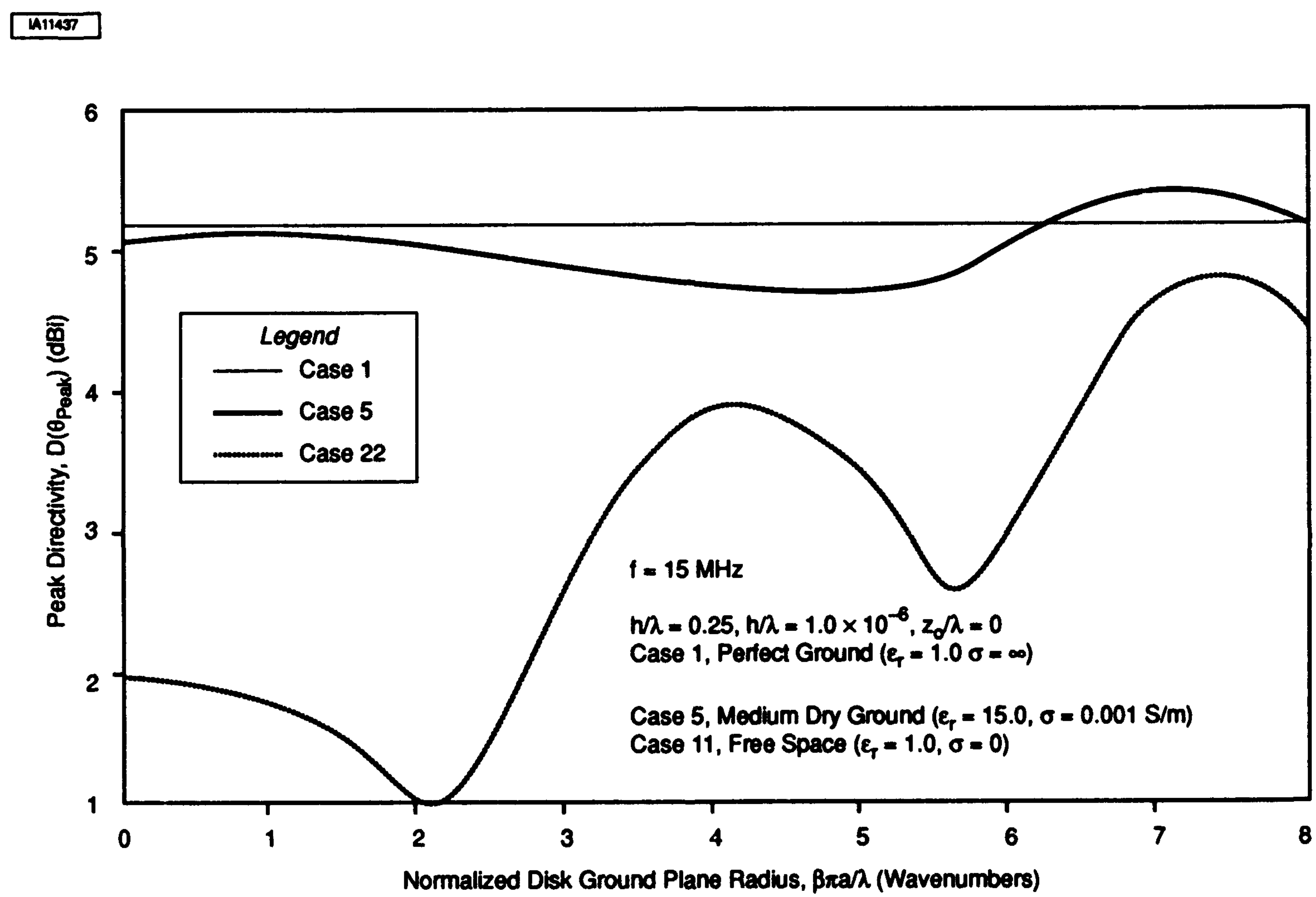
Antenna Structure	Ground-Plane Radius (Wave-numbers), $2\pi a/\lambda$	Element Length (Wave-lengths) h/λ	Peak Directivity*		Directivity on Horizon		Input Impedance	
			$d(\theta_p)$ (numeric)	$D(\theta_p)$ (dBi)	$d(\theta = \pi/2)$ (numeric)	$D(\theta = \pi/2)$ (dBi)	Radiation Resistance (Ω)	Reactance‡ (Ω)
Monopole	0	$\ll 1$	1.500	1.761	1.500	1.761	$20\pi^2(h/\lambda)^2$	$-\infty$
	0	0.25	1.543	1.882	1.543	1.882	19.43	$-\infty$
	$\gg 1$, FINITE	$\ll 1$	3.000	4.771	0.750	−1.249	$40\pi^2(h/\lambda)^2$	$-\infty$
	$\gg 1$, FINITE	0.25	3.282	5.161	0.820	−0.859	36.54	21.26
	∞	$\ll 1$	3.000	4.771	3.000	4.771	$40\pi^2(h/\lambda)^2$	$-\infty$
	∞	0.25	3.282	5.161	3.282	5.161	36.54	21.26
Dipole†	0	$\ll 1$	1.500	1.761	1.500	1.761	$80\pi^2(h/\lambda)^2$	$-\infty$
	0	0.25	1.641	2.151	1.641	2.151	73.08	42.52
Idealized isotropic radiator			1.000	0	1.000	0	—	—

*Direction of peak directivity is $\theta_p = \pi/2$ rad, except for monopole elements on ground planes of finite but nonzero extent, in which case $\theta_p < \pi/2$ rad.

†Very thin dipole of half-length h.

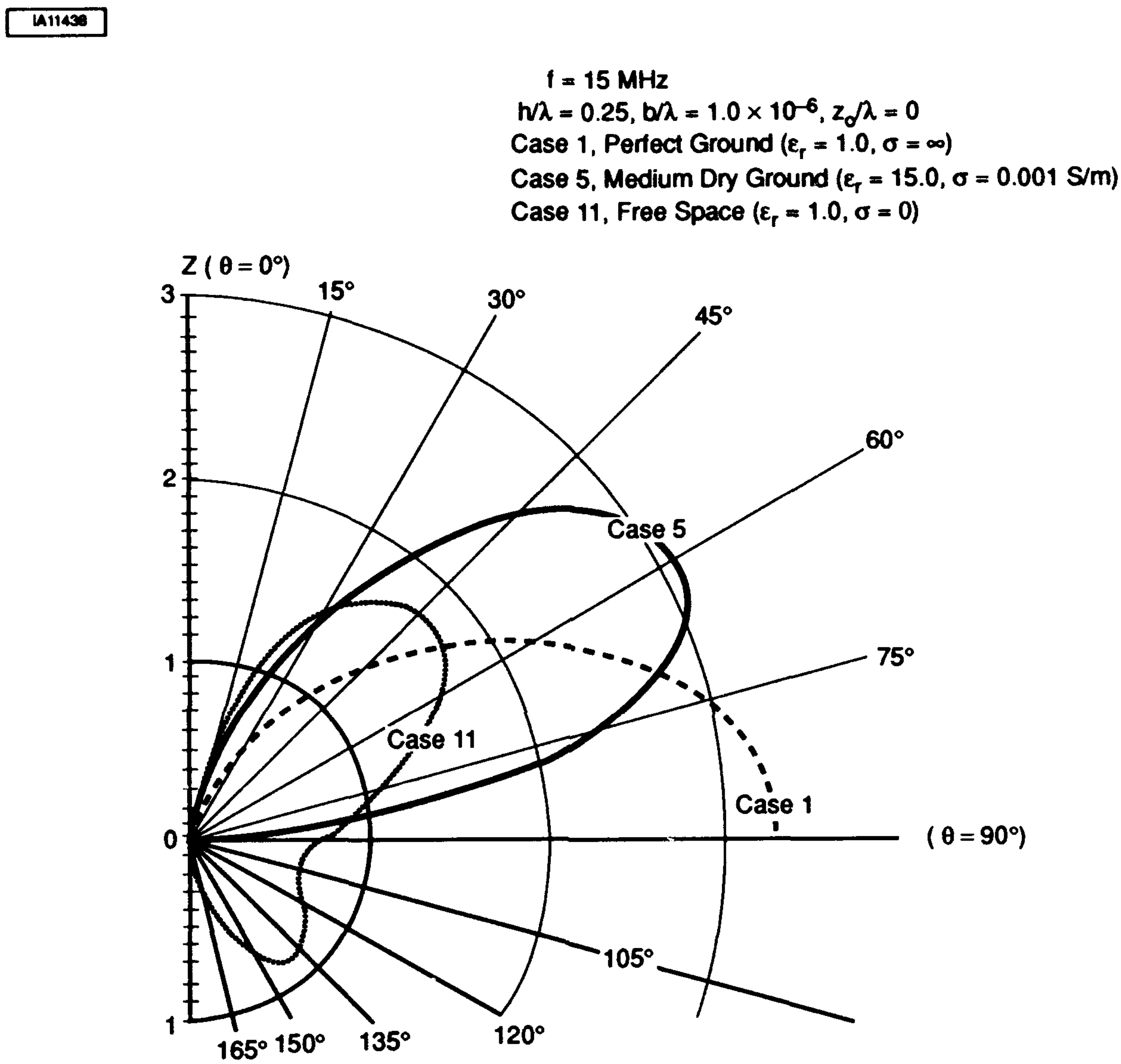
‡Reactance is in the limit of an infinitely thin element.

Source: Weiner, et al., 1987



(from Weiner, 1991)

Figure A-3. Peak Directivities of Quarter-Wave Monopole Elements with Disk Ground Planes Resting on Flat Earth



(from Weiner, 1991)

Figure A-4. Numeric Directivity Polar Plot for a Quarter-Wave Monopole Element with Disk Ground Plane (Normalized Radius = 3.0 Radians) Resting on Flat Earth

Table A-2 Nominal Values of Receiving System Parameters and Sensitivities

Notation: $aEb \equiv a \times 10^b$

Receiving System		RF Wavelength, λ (m)	Baseband Bandwidth, b (Hz)	Antenna Directivity, d_r (numeric)	System Noise Factor, f (numeric)	Receiving System Sensitivity, n_o (W/m^2)
No.	Name					
1	Cellular Telephone 870-890 MHz	3.4E-1	6.0E+3	3.3E+0	1.3E+0	9.9E-16
2	HAARP Riometer 38.2 MHz	7.9E+0	5.0E+5	7.1E+2	5.6E+1	3.2E-18
3	Satellite Television					
	a. 5925-6875 MHz	4.7E-2	4.5E+6	9.1E+3	1.3E+0	1.4E-14
	b. 12,500-12,750 MHz	2.4E-2	4.5E+6	5.1E+4	1.3E+0	9.6E-15
4	HF Communications 2.1-30 MHz	1.0E+1	6.0E+3	3.3E+0	1.2E+1	1.1E-17
5	Television Broadcast 54-216 MHz	5.0E+0	4.5E+6	3.3E+0	2.1E+0	5.9E-15
6	AM Radio Broadcast 0.535-1.7 MHz	3.0E+2	6.0E+3	3.3E+0	1.6E+5	1.6E-16
7	FM Radio Broadcast 92.9-106.7 MHz	3.0E+0	2.0E+4	3.3E+0	1.3E+0	4.3E-17
8	Avionics					
	a. GPS 1227, 1575 MHz	2.4E-1	2.1E+6	3.3E+0	1.3E+0	7.0E-13
	b. VHF Radio 118-137 MHz	2.5E+0	3.0E+3	3.3E+0	1.3E+0	8.9E-18
	c. UHF Radio 960-1215 MHz	1.3E+0	3.0E+3	3.3E+0	1.3E+0	6.0E-16
	d. VOR 108-117 MHz	2.6E+0	2.0E+4	3.3E+0	1.3E+0	5.8E-17
	e. ADF 0.21-0.53 MHz	7.5E+2	4.0E+3	3.3E+0	2.0E+6	2.2E-16

Table A-2 Nominal Values of Receiving System Parameters and Sensitivities (Concluded)

Receiving System		RF Wavelength, λ (m)	Baseband Bandwidth, b (Hz)	Antenna Directivity, d_r (numeric)	System Noise Factor, f (numeric)	Receiving System Sensitivity, n_o (W/m^2)
No.	Name					
9	Cardiac Pacemakers a. Incident Pulsed b. Incident CW	-- --	-- --	-- --	-- --	1.0E+02* >>1.0E+02*
10	Electro-Explosive Devices a. Exposed b. In Metal Container	-- --	-- --	-- --	-- --	1.0E-02** 1.0E+02**
11	Mobile VHF Radio 38-166 MHz	7.9E+0	3.0E+3	3.3E+0	5.7E+0	4.2E-18
12	Wildlife Trackers 30-220 MHz	1.0E+1	1.0E+3	4.7E+0	1.2E+1	1.3E-18
13	Citizen Band Radio 26.9-27.4 MHz	1.1E+1	1.0E+4	3.3E+0	1.6E+1	2.0E-17
14	Handheld Transceivers a. VHF 118-174 MHz b. UHF 403-470 MHz	2.5E+0 6.4E-1	3.0E+3 3.0E+3	3.3E+0 3.3E+0	1.3E+0 1.3E+0	3.0E-18 4.7E-17
15	HAARP Scintillation Receiver 240-245 MHz	1.3E+0	1.0E+1	4.0E+0	1.3E+0	1.0E-19
16	Radio Telephone a. VHF 152-158 MHz b. UHF 454-460 MHz	1.9E+0 6.6E-1	3.0E+3 3.0E+3	8.0E+0 1.6E+1	1.3E+0 1.3E+0	6.3E-18 2.7E-17
17	Pipeline Systems a. Control 157, 162 MHz b. VHF Comm. 150-162 MHz c. UHF Comm. 450-460 MHz	1.9E+0 1.9E+0 6.6E-1	4.0E+3 3.0E+3 3.0E+3	6.3E+0 3.3E+0 3.3E+0	1.3E+0 1.3E+0 1.3E+0	1.1E-17 1.6E-17 1.3E-16
18	Terrestrial Microwave a. 2127-2177 MHz b. 5945-6094 MHz	1.4E-1 5.0E-2	3.0E+3 3.0E+3	1.8E+3 1.4E+4	1.3E+0 1.3E+0	5.4E-18 5.4E-18

*Design Susceptibility Threshold
**Safe-Exposure Limit

power density (receiving system sensitivity) n_o $\left(\mathrm{W/m^2}\right)$. The derivations of these entries for each receiving system are given in the following subsections for each receiving system.

A.3.1 Cellular Radio Telephone

Cellular radio telephones are used to transmit voice and data in the 870-890 MHz RF band. The receiving antenna is typically a half-wave dipole or quarterwave monopole that may be mounted on a vehicle. The baseband bandwidth is 6 kHz for voice and 25 kHz for data. The receiving system is internal-noise-limited. Nominal values of the system parameters are $\lambda = 0.34\mathrm{m}$, $b = 6$ kHz, $d_r = 3.28$ and $f = 1.26$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(6\times10^{3}\right)(1.26)\right] / \left[(0.34)^2(3.28)/4\pi\right]$$

$$= \left(3.00\times10^{-17}\right) / \left(3.02\times10^{-2}\right) = 9.94\times10^{-16}\,\mathrm{W/m^2} \qquad \text{(A-15)}$$

A.3.2 HAARP Riometer

The HAARP riometer will be a 59 m × 59 m imaging array of 256 crossed dipole elements with half-wavelength spacing and a groundscreen. The riometer receives right-hand circular polarization at a radio frequency of 38.2 MHz. The baseband [intermediate frequency (IF)] bandwidth is 500 kHz. The peak directivity is in the direction of the sky. The receiving system is external-noise limited. Nominal values of the system parameters are $\lambda = 7.85$ m, $b = 500$ kHz, $d_r = 706.8$, and $f = 5.57$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(5\times10^{5}\right)(5.57)\right] / \left[(7.85)^2(706.8)/4\pi\right]$$

$$= \left(1.107\times10^{-14}\right) / \left(3.47\times10^{3}\right) = 3.19\times10^{-18}\,\mathrm{W/m^2} \qquad \text{(A-16)}$$

A.3.3 Satellite Television

Satellite television is received with a paraboloidal reflector antenna, of 2-m nominal diameter, pointed in the direction of the synchronous orbit of the satellite (near the radio horizon at Gulkana). The RF bands are 5925-6875 MHz (C-band) and 12,500-12,750 MHz (Ku-band). The baseband (IF) bandwidth is 4.5 MHz. The receiving system is internal-noise-limited. Nominal values of the system parameters are $\lambda = 0.047$ m (C-band) and 0.024 m (Ku-band), $b = 4.5$ MHz, $d_r = 9.1 \times 10^3$ (C-band) and 5.1×10^4 (Ku-band), and $f = 1.26$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \begin{cases} \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(4.5\times10^{6}\right)(1.26)\right] \Big/ \left[(0.047)^2\left(9.1\times10^{3}\right)/4\pi\right] \\ = \left(2.25\times10^{-14}\right)/1.60 = 1.41\times10^{-14}\ \text{W/m}^2, \quad \text{C-band} \\ \\ \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(4.5\times10^{6}\right)(1.26)\right] \Big/ \left[(0.024)^2\left(5.1\times10^{4}\right)/4\pi\right] \\ = \left(2.25\times10^{-14}\right)/\left(2.34\times10^{2}\right) = 9.62\times10^{-15}\ \text{W/m}^2, \quad \text{Ku-band} \end{cases} \qquad \text{(A-17)}$$

A.3.4 HF Communications

HF communications are in the RF bands 2.1 to 30 MHz for commercial users and 3.5 to 29.7 MHz for radio ham operators. The receiving antennas are usually electrically short or resonant monopole antennas. The baseband bandwidth is 6 kHz. The receiving system is external-noise limited. Nominal values of the system parameters are $\lambda = 143$ m (low HF) and 10 m (high HF), $b = 6$ KHz, $d_r = 3.28$, and $f = 2.03 \times 10^4$ (low HF) and 11.82 (high HF). With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$
n_o = \begin{cases} \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(6\times10^{3}\right)\left(2.03\times10^{4}\right)\right] / \left[(143)^2(3.28)/4\pi\right] \\ = \left(4.84\times10^{-13}\right)/\left(5.34\times10^{3}\right) = 9.07\times10^{-17} \ \text{W/m}^2, \text{ low HF} \\ \\ \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(6\times10^{3}\right)(11.82)\right] / \left[(10)^2(3.28)/4\pi\right] \\ = \left(2.81\times10^{-16}\right)/2.61\times10^{1} = 1.08\times10^{-17} \ \text{W/m}^2, \text{ high HF} \end{cases} \quad \text{(A-18)}
$$

A.3.5 Television Broadcast

Television broadcast in the HAARP study areas is limited to the VHF channels (2 to 13). The receiving antenna is typically a half-wave dipole or quarterwave monopole. The baseband (IF) bandwidth is 4.5 MHz. The receiving system is limited by both external and internal noise on channels 3, 5, and 7 and by internal noise on channels 7, 9, 11, and 13. Nominal values of the system parameters are $\lambda = 5$ m (channel 3) and 1.4 m (channel 13), $b = 4.5$ MHz, $d_r = 3.28$, and $f = 2.14$ (channel 3) and 1.26 (channel 13). With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$
n_o = \begin{cases} \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(4.5\times10^{6}\right)(2.14)\right] / \left[(5)^2(3.28)/4\pi\right] \\ = \left(3.83\times10^{-14}\right)/(6.53) = 5.87\times10^{-15} \ \text{W/m}^2, \text{ Channel 3} \\ \\ \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(4.5\times10^{6}\right)(1.26)\right] / \left[(1.4)^2(3.28)/4\pi\right] \\ = \left(2.25\times10^{-14}\right)/0.511 = 4.40\times10^{-14} \ \text{W/m}^2, \text{ Channel 13} \end{cases} \quad \text{(A-19)}
$$

A.3.6 AM Radio Broadcast

AM radio broadcast is within the RF band 526-1606 kHz. The receiving antenna is typically an electrically short monopole. The baseband bandwidth is 6 kHz. The receiving system is external-noise-limited. Nominal values of the system parameters are $\lambda = 300$ m, $b = 6$ kHz, $d_r = 3.28$, and $f = 1.58\times10^{5}$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(6\times10^{3}\right)\left(1.58\times10^{5}\right)\right] \Big/ \left[\left(3\times10^{2}\right)^{2}(3.28)/4\pi\right]$$
$$= \left(3.77\times10^{-12}\right)\Big/\left(2.35\times10^{4}\right) = 1.60\times10^{-16}\ \mathrm{W/m^2} \qquad \text{(A-20)}$$

A.3.7 FM Radio Broadcast

FM radio broadcast in Alaska is within the RF band 92.9 MHz (Anchorage) to 106.7 MHz (Ketchikan). The receiving antenna is typically a dipole or monopole antenna. The baseband bandwidth is 20 kHz. The receiving system is internal-noise limited. Nominal values of the system parameters are $\lambda = 3$ m, $b = 20$ kHz, $d_r = 3.28$, and $f = 1.26$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(2\times10^{4}\right)(1.26)\right] \Big/ \left[(3)^{2}(3.28)/4\pi\right]$$
$$= \left(1.00\times10^{-16}\right)\Big/2.35 = 4.26\times10^{-17}\ \mathrm{W/m^2} \qquad \text{(A-21)}$$

A.3.8 Avionics

Avionics are airborne electronic receiving systems. Representative avionics include a Global Positioning System (GPS) for navigation, a VHF radio, a UHF radio, a VOR direction finder, and an automatic direction finder (ADF). These representative avionics have been selected for analysis because they operate at the same frequencies as some of the emissions from the HAARP emitters. The LORAN Navigation System has not been included because its operating frequency at 100 kHz is a non-radiating subharmonic of the HAARP emitters.

The GPS operates at the radio frequencies 1227 MHz and 1575 MHz. The baseband bandwidths are 20.46 MHz and 2.046 MHz for military and civilian applications, respectively. The antenna is a 3.5-inch circular patch mounted on the top centerline of the fuselage with a peak gain comparable to that of a monopole antenna. The receiving system is internal-noise-limited. Nominal values of the system parameters (worse case) are $\lambda = 0.24$ m, $b = 2.05$ MHz, $d_r = 3.28$, and $f = 1.26$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(2.05\times10^{6}\right)(1.26)\right] \Big/ \left[(0.24)^2(3.28)/4\pi\right]$$
$$= \left(1.03\times10^{-14}\right)\Big/\left(1.47\times10^{-2}\right) = 6.98\times10^{-13}\ \mathrm{W/m^2} \quad \text{(A-22)}$$

The VHF radio operates in the RF band 118 MHz to 137 MHz. The baseband bandwidth is 3 kHz for analog voice and 16 kHz for digital data. The antenna is an electrically short monopole. The receiving system is internal-noise-limited. Nominal values of the system parameters (worst case) are $\lambda = 2.54$ m, $b = 3\times10^3$ Hz, $d_r = 3.28$, and $f = 1.26$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(3.0\times10^{3}\right)(1.26)\right] \Big/ \left[(2.54)^2(3.28)/4\pi\right]$$
$$= \left(1.50\times10^{-17}\right)\Big/1.68 = 8.90\times10^{-18}\ \mathrm{W/m^2} \quad \text{(A-23)}$$

The UHF radio operates in the RF band 225-400 MHz for military applications and 960-1215 MHz for civilian applications. The civilian baseband bandwidth is 3 kHz for analog voice and 16 kHz for digital data. The antenna is typically a quarterwave monopole. The receiving system is internal-noise-limited. Nominal values of the system parameters are $\lambda = 0.31$ m, $b = 3\times10^3$ Hz, $d_r = 3.28$, and $f = 1.26$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(3.0\times10^{3}\right)(1.26)\right] \Big/ \left[(0.31)^2(3.28)/4\pi\right]$$
$$= \left(1.50\times10^{-17}\right)\Big/\left(2.5\times10^{-2}\right) = 5.98\times10^{-16}\ \mathrm{W/m^2} \quad \text{(A-24)}$$

The VOR direction finders in the vicinity of HAARP study areas are shown in figures A-5 and A-6. The receiving antenna pattern is a cardioid. The baseband bandwidth is 21 kHz which includes a voice baseband of 20 kHz. The receiving system is internal-noise-limited. Nominal values of the system parameters are $\lambda = 2.57$ m, $b = 2.1 \times 10^4$ Hz, $d_r = 3.28$, and $f = 1.26$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity has a numerical value given by

$$n_o = \left[\left(1.38 \times 10^{-23}\right)\left(2.88 \times 10^2\right)\left(2.1 \times 10^4\right)(1.26)\right] \Big/ \left[(2.57)^2 (3.28)/4\pi\right]$$
$$= \left(1.00 \times 10^{-16}\right) \Big/ 1.72 = 5.80 \times 10^{-17} \text{ W/m}^2 \qquad \text{(A-25)}$$

The ADF locations and frequencies near the HAARP study areas are shown in figures A-5 and A-6. The ground-based transmitters are non-directional beacons (NDB). The baseband bandwidth is 4 kHz. The antenna is electrically short. The receiving system is external-noise limited. Nominal values of the system parameters are $\lambda = 750$ m (at 0.4 MHz), $b = 4 \times 10^3$ Hz, $d_r = 3.28$, and $f = 2 \times 10^6$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \left[\left(1.38 \times 10^{-23}\right)\left(2.88 \times 10^2\right)\left(4 \times 10^3\right)\left(2.0 \times 10^6\right)\right] \Big/ \left[(750)^2 (3.28)/4\pi\right]$$
$$= \left(3.18 \times 10^{-11}\right) \Big/ \left(1.47 \times 10^5\right) = 2.17 \times 10^{-16} \text{ W/m}^2 \qquad \text{(A-26)}$$

A.3.9 Cardiac Pacemakers

Cardiac pacemakers have a design susceptibility threshold to incident radiation of 100 W/m^2 for pulsed waveforms at 450 MHz. The measured susceptibility threshold to incident radiation is 100 W/m^2 for a CW at 26 MHz (see pages 4-48, 4-49, and C-33 through C-37 of reference 6).

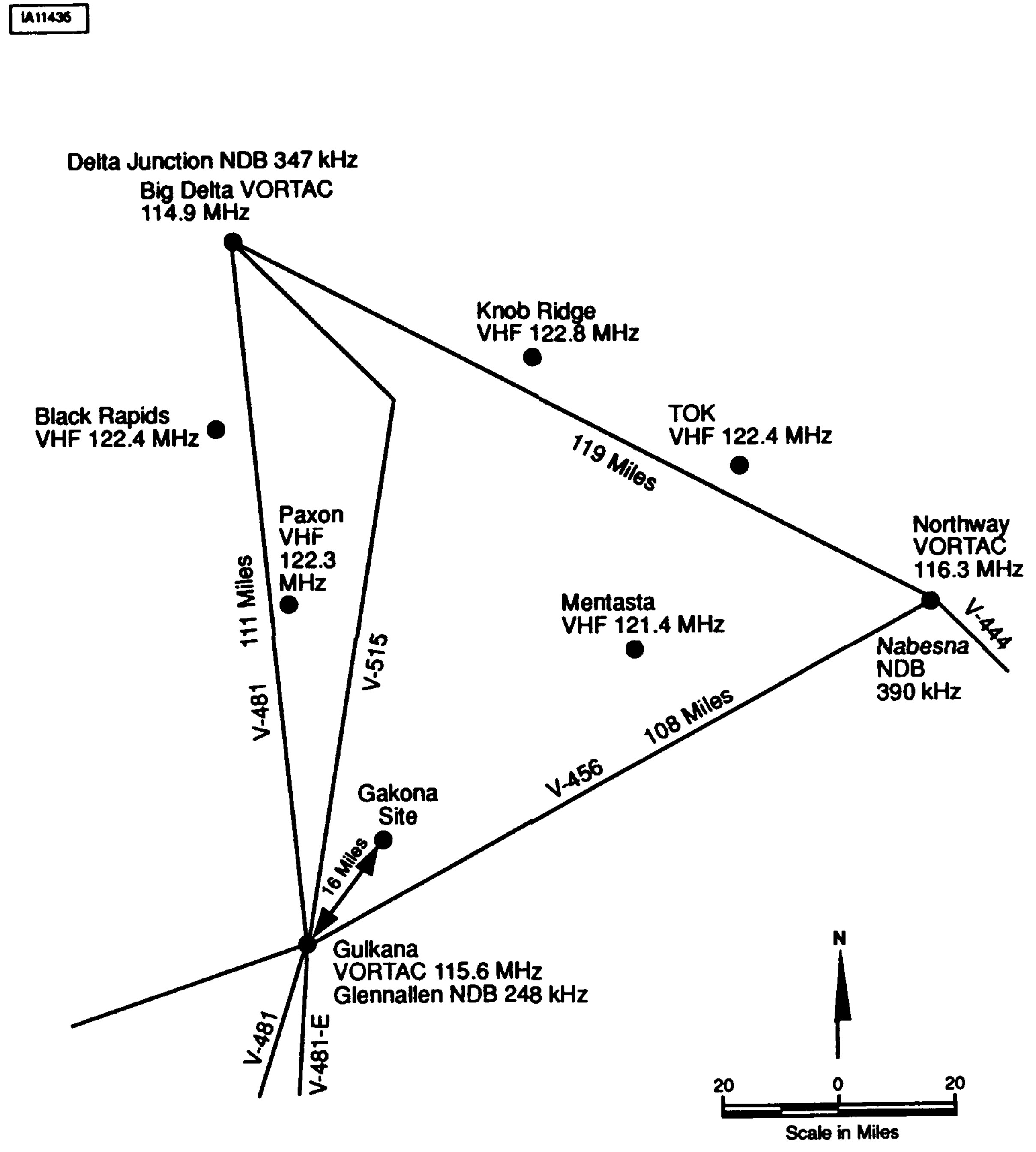


Figure A-5. Low-Altitude Federal Airways and Air-Ground Communication Stations near the Gakona Study Area

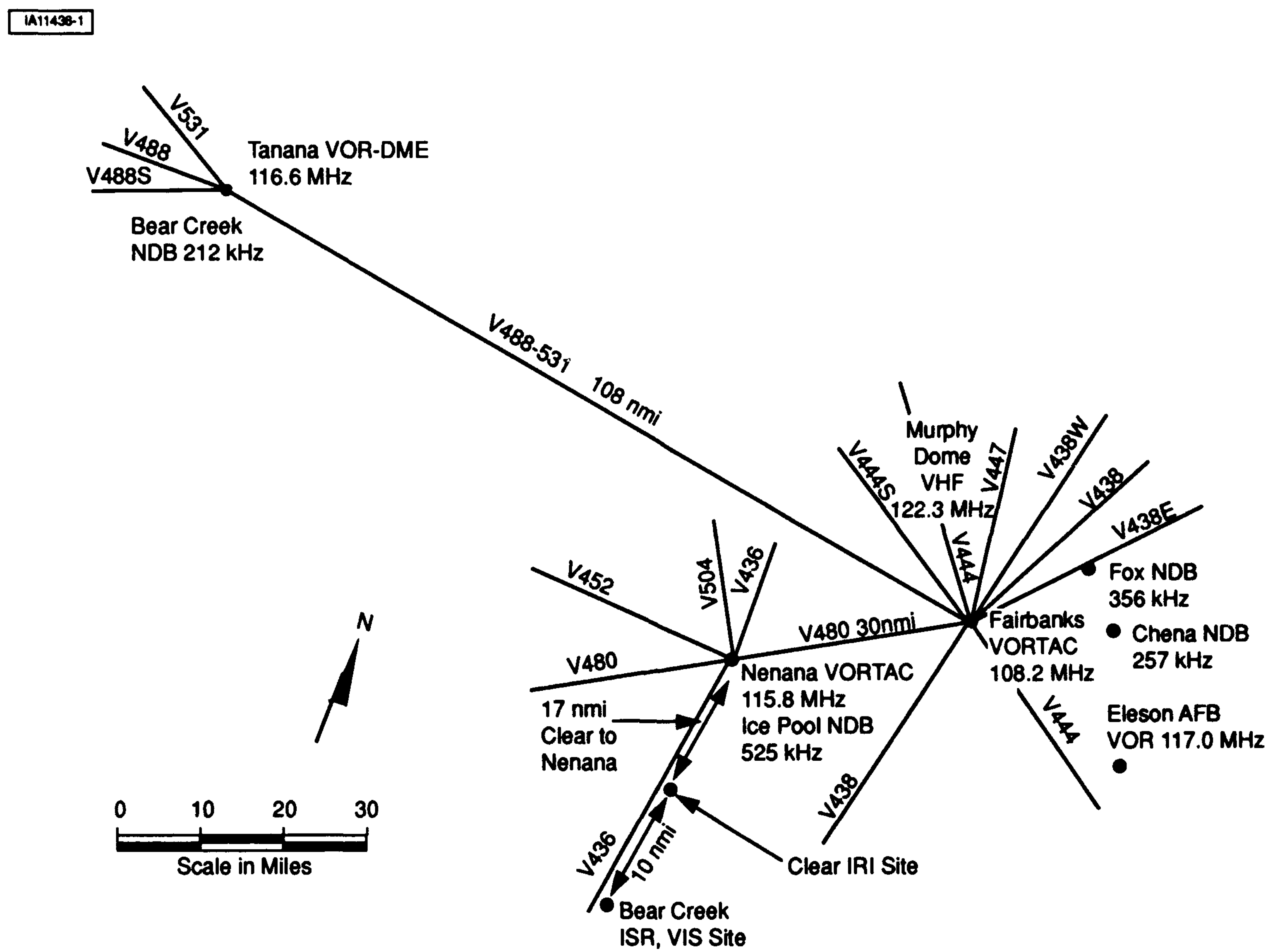


Figure A-6. Low Altitude Federal Airways and Air-Ground Communication Stations Near the Clear Study Area

A.3.10 EEDs

EEDs, when exposed to incident radiation in the RF band 2-48.5 MHz, have a safe exposure limit of (see p. C-40 of reference 6):

$0.01\ \mathrm{W/m^2}$, EED in exposed condition (worse case)

$100.0\ \mathrm{W/m^2}$, EED in metal container (storage or transport)

$0.1\ \mathrm{W/m^2}$, EED in nonmetallic container (storage or transport)

$1.0\ \mathrm{W/m^2}$, EED with externally loaded weapons (aircraft parked or taxiing)

$100.0\ \mathrm{W/m^2}$, EED with externally loaded weapons (aircraft in flight)

A.3.11 Mobile VHF Radio

Mobile VHF radios in the HAARP study areas operate in two bands centered nominally at 45 MHz and 155 MHz. The baseband bandwidth is 3 kHz. The antenna is typically a monopole. The receiving systems may be external-noise-limited, internal-noise-limited, or both. Nominal values of the system parameters are $\lambda = 7.91$ m (37.90 MHz) and 1.86 m (161.01 MHz), $b = 3\times10^3$ Hz, $d_r = 3.28$, and $f = 5.71$ (37.90 MHz) and 1.26 (161.01 MHz). With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \begin{cases} \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(3\times10^{3}\right)(5.71)\right]\Big/\left[(7.91)^2(3.28)/4\pi\right] \\ =\left(6.81\times10^{-17}\right)\Big/\left(1.63\times10^{1}\right)=4.17\times10^{-18}\ \mathrm{W/m^2},\ 37.90\ \mathrm{MHz} \\ \\ \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(3\times10^{3}\right)(1.26)\right]\Big/\left[(1.86)^2(3.28)/4\pi\right] \\ =\left(1.50\times10^{-17}\right)\Big/0.90=1.66\times10^{-17}\ \mathrm{W/m^2},\ 161.01\ \mathrm{MHz} \end{cases} \quad \text{(A-27)}$$

A.3.12 Wildlife Trackers

Wildlife trackers operate in the RF band 30 to 220 MHz. The baseband bandwidth is 1 kHz (channel spacing). A typical receiving antenna at the high end of the VHF band is a directional four-element yagi with a peak gain of 11.2 dBi. At the low end of the UHF band, a typical receiving antenna is a two-element yagi with a peak gain of 6.7 dBi. The receiving system is external-noise limited at the low-end of the band and internal-noise-limited at the high-end of the band. Nominal values of the system parameters are $\lambda = 10$ m (30 MHz) and 1.36 m (220 MHz), $b = 1 \times 10^3$ Hz, $d_r = 4.68$ (30 MHz) and 13.2 (220 MHz), and $f = 11.82$ (30 MHz) and 1.26 (220 MHz). With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \begin{cases} \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(1\times10^{3}\right)(11.82)\right]\Big/\left[(10)^2(4.68)/4\pi\right] \\ = \left(4.70\times10^{-17}\right)\big/37.2 = 1.26\times10^{-18}\ \mathrm{W/m^2},\ 30\ \mathrm{MHz} \\ \\ \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(1\times10^{3}\right)(1.26)\right]\Big/\left[(1.36)^2(13.2)/4\pi\right] \\ = \left(5.01\times10^{-18}\right)\big/1.94 = 2.58\times10^{-18}\ \mathrm{W/m^2},\ 220\ \mathrm{MHz} \end{cases} \qquad \text{(A-28)}$$

A.3.13 Citizen Band Radio

Citizen band radio operates in 40 channels at radio frequencies 26.9 to 27.4 MHz. The baseband bandwidth is 10 kHz. The antenna is an electrically short monopole. The receiving system is external-noise-limited. Nominal values of the system parameters are $\lambda = 11.1$ m, $b = 1\times10^4$ Hz, $d_r = 3.28$, and $f = 16.2$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(1\times10^{4}\right)(16.2)\right]\Big/\left[(11.1)^2(3.28)/4\pi\right]$$

$$= \left(6.44\times10^{-16}\right)\big/32.2 = 2.00\times10^{-17}\ \mathrm{W/m^2} \qquad \text{(A-29)}$$

A.3.14 Handheld Transceivers

Handheld transceivers for land mobile service operate at 118-174 MHz in the VHF band and 403-470 MHz in the UHF band. The baseband bandwidth is 3 kHz. The typical antenna is a monopole. The receiving systems are internal-noise-limited. Nominal values of the system parameters are $\lambda = 2.54$ m (118 MHz) and 0.64 m (470 MHz), $b = 1\times10^3$ Hz, $d_r = 3.28$ and $f = 1.26$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \begin{cases} \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(1\times10^{3}\right)(1.26)\right] \Big/ \left[(2.54)^2(3.28)/4\pi\right] \\ = \left(5.00\times10^{-18}\right)\Big/1.68 = 2.97\times10^{-18}\ \text{W/m}^2,\ 118\ \text{MHz} \\ \\ \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(1\times10^{3}\right)(1.26)\right] \Big/ \left[(0.64)^2(3.28)/4\pi\right] \\ = \left(5.00\times10^{-18}\right)\Big/0.107 = 4.68\times10^{-17}\ \text{W/m}^2,\ 470\ \text{MHz} \end{cases} \quad \text{(A-30)}$$

A.3.15 HAARP Scintillation Receiver

The HAARP scintillation receiver operates in the RF band 240-245 MHz. The baseband bandwidth is 10 Hz to 100 Hz. The peak antenna gain in the direction of the sky is greater than 6 dBi and receives right-hand circular polarization. The receiving system is internal-noise-limited. Nominal values of the system parameters are $\lambda = 1.25$ m, $b = 10$ Hz, $d_r = 4$, and $f = 1.26$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$n_o = \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)(10)(1.26)\right] \Big/ \left[(1.25)^2(4)/4\pi\right]$$
$$= \left(5.00\times10^{-20}\right)\Big/0.497 = 1.0\times10^{-19}\ \text{W/m}^2 \quad \text{(A-31)}$$

A.3.16 Radio Telephone

Radio telephones transmit voice in the VHF (152-158 MHz) and UHF (454-460 MHz) bands. The receiving antenna is typically a yagi with numeric peak directivities of 8 and 16 in the VHF and UHF bands, respectively. The baseband bandwidth is 3 kHz. The receiving system is internal-noise-limited. Nominal values of the system parameters are $\lambda = 1.94$ m (VHF) and 0.656 m (UHF), $b = 3$ kHz, $d_r = 8$ (VHF) and 16 (UHF), and $f = 1.26$ With the substitution of these parameters into equation (A-13), the receiving sensitivity n_o has a numerical value given by

$$n_o = \begin{cases} \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(3\times10^{3}\right)(1.26)\right]\Big/\left[(1.94)^2(8)/4\pi\right] \\ =\left(1.50\times10^{-17}\right)\big/(2.40)=6.26\times10^{-18}\ \text{W/m}^2,\ \text{VHF} \\ \\ \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(3\times10^{3}\right)(1.26)\right]\Big/\left[(0.656)^2(16)/4\pi\right] \\ =\left(1.50\times10^{-17}\right)\big/(0.548)=2.74\times10^{-17}\ \text{W/m}^2,\ \text{UHF} \end{cases} \quad \text{(A-32)}$$

A.3.17 Pipeline Systems

Oil pipeline systems use radio receivers for remote control and monitoring of pipeline equipment and also for maintenance-crew communications. The radio frequencies are 157.3875 MHz and 161.9625 MHz for remote control and 150-162 MHz (VHF) and 450-460 MHz (UHF) for crew communications. The antennas are a dipole-fed corner reflector with a peak directivity of 8 dBi for remote control and a monopole for crew communications. The baseband bandwidth is 4 kHz (includes a coded signal) for remote control and 3 kHz for crew communications. The receiving systems are internal-noise-limited. Nominal values of the system parameters are $\lambda = 1.88$ m (control) and 1.92 m (VHF communications), and 0.659 m (UHF communications); $b = 4$ kHz (control) and 3 kHz (communications); $d_r = 6.3$ (control) and 3.28 (communications); and $f = 1.26$. With the substitution of these parameters into equation (A-13), the receiving sensitivity n_o has a numerical value given by

$$
n_o = \begin{cases} \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(4\times10^{3}\right)(1.26)\right]\Big/\left[(1.88)^2(6.3)/4\pi\right] \\ =\left(2.00\times10^{-17}\right)\big/(1.77)=1.13\times10^{-17}\ \text{W/m}^2,\ \text{remote control} \\ \\ \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(3\times10^{3}\right)(1.26)\right]\Big/\left[(1.92)^2(3.28)/4\pi\right] \\ =\left(1.50\times10^{-17}\right)\big/(0.962)=1.56\times10^{-17}\ \text{W/m}^2,\ \text{VHF communications} \\ \\ \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(3\times10^{3}\right)(1.26)\right]\Big/\left[(0.659)^2(3.28)/4\pi\right] \\ =\left(1.50\times10^{-17}\right)\big/(0.113)=1.32\times10^{-16}\ \text{W/m}^2,\ \text{UHF communications} \end{cases} \qquad \text{(A-33)}
$$

A.3.18 Terrestrial Microwave

Terrestrial microwave RF frequencies are in S band (2127-2177 MHz) and X band (5945-6094 MHz). The receiving antenna is a paraboloidal reflector of 8 ft. nominal diameter. The baseband bandwidth is 3 kHz. The receiving system is internal-noise-limited. Nominal values of the system parameters are $\lambda = 0.140$ m (S band) and 0.050 m (X band); $b = 3$ KHz; $d_r = 1.82\times10^3$ (S band) and 1.41×10^4 (X band); and $f = 1.26$. With the substitution of these parameters into equation (A-13), the receiving system sensitivity n_o has a numerical value given by

$$
n_o = \begin{cases} \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(3\times10^{3}\right)(1.26)\right]\Big/\left[(0.140)^2\left(1.82\times10^{3}\right)/4\pi\right] \\ =\left(1.50\times10^{-17}\right)\big/(2.805)=5.35\times10^{-18}\ \text{W/m}^2,\ \text{S band} \\ \\ \left[\left(1.38\times10^{-23}\right)\left(2.88\times10^{2}\right)\left(3\times10^{3}\right)(1.26)\right]\Big/\left[(0.05)^2\left(1.41\times10^{4}\right)/4\pi\right] \\ =\left(1.50\times10^{-17}\right)\big/(2.805)=5.35\times10^{-18}\ \text{W/m}^2,\ \text{X band} \end{cases} \qquad \text{(A-34)}
$$

LIST OF REFERENCES

1. Weiner, M. M., "Noise Factor and Antenna Gains in the Signal/Noise Equation for Over-the-Horizon Radar," *IEEE Trans. on Aerospace and Electronic Systems*, Vol. AES-27, No. 6, pp. 886-890, November 1991.

2. C.C.I.R., "World Distribution and Characteristics of Atmospheric Radio Noise," Report 322, 10th Plenary Assembly, Geneva (1963), Int. Radio Consultative Committee, Int. Telecommunication Union, Geneva, Switzerland, 1964.

3. Vincent, W. R., "Radio Noise and Interference," Chapter 34, *Reference Data for Radio Engineers*, Indianapolis: Howard Sams & Co., 1985, p. 34-3.

4. Weiner, M. M., et al., *Monopole Elements on Circular Ground Planes,* Norwood: Artech House, 1987, p. 65.

5. Weiner, M. M., "Far-Zone Field of a Monopole Element with a Disk Ground Plane above Flat Earth," MTR-92B0000090, The MITRE Corporation, Bedford, MA, June 1992. Also available from National Technical Information Service as AD-A253580.

6. *Draft Environmental Impact Statement for the Proposed Alaskan Radar System of the Over-the-Horizon Backscatter Radar Program,* Dept. of the U.S. Air Force, Electronic Systems Division, August 1986.

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APPENDIX B

POWER DENSITIES OF HAARP EMITTERS

B.1 INTRODUCTION

In order to determine the risk of EMI posed by the three HAARP emitters, the RF power density of each emitter must be estimated for each user location. Such estimates can be obtained by use of antenna models or, in the case of more conventional antennas, by reference to established approximations in the literature. In some instances for which analysis is either not reliable or too complicated, comparisons with similar existing emitters are cited to assess the risk of interference.

B.2 IRI

The proposed IRI is a large, ground-based phased array of 360 broadband, crossed dipoles. The elements are organized into 12 rows and 15 columns, yielding 180 positions with two (vertically stacked) elements per location. The lower crossed dipole element covers the HF band (7.5 to 10 MHz), while the upper crossed dipole element covers the low-frequency band (2.8 to 7.5 MHz). The 24.3 m row and column (square lattice) spacing is just sufficient to prevent grating lobe incursion at 15° scan off broadside, i.e., from the zenith, at 10 MHz, the highest frequency.

B.2.1 Near-Field Power Calculation

For the purpose of RF power density (W/m^2) estimation, a relatively simple IRI antenna model is adequate. Each element of the array is represented by an electrically short, horizontal dipole suspended one quarter wavelength over a perfect, infinite groundplane. Consider the x-axis aligned dipoles illustrated in figure B-1. For a single dipole at the origin, the field would vary as $\sin\alpha$ in which α is the direction cosine with respect to the x axis. However, when the image dipole is taken into account, the element pattern acquires a two

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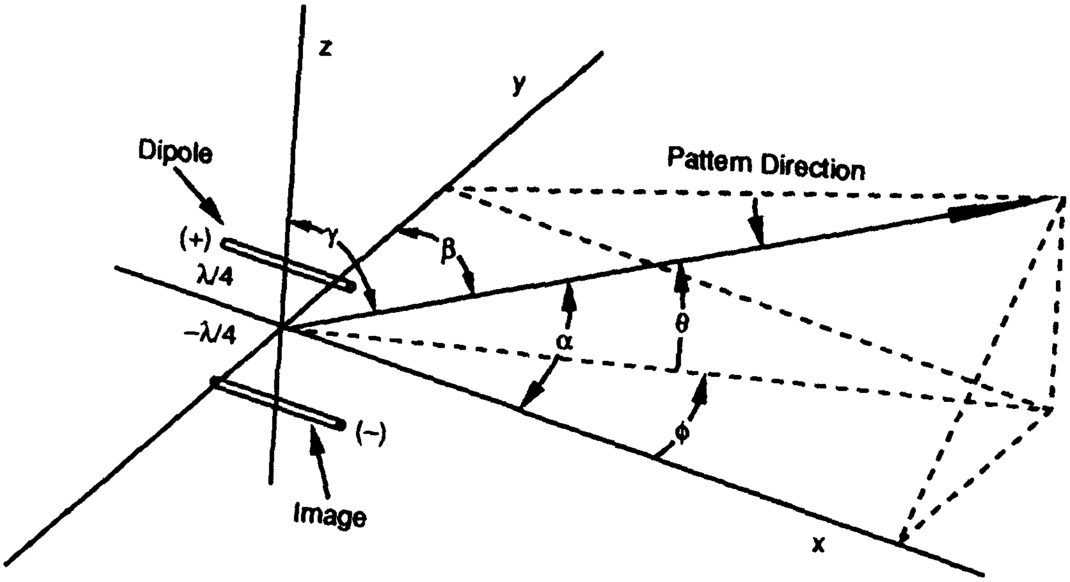

Figure B-1. Element Pattern Geometry

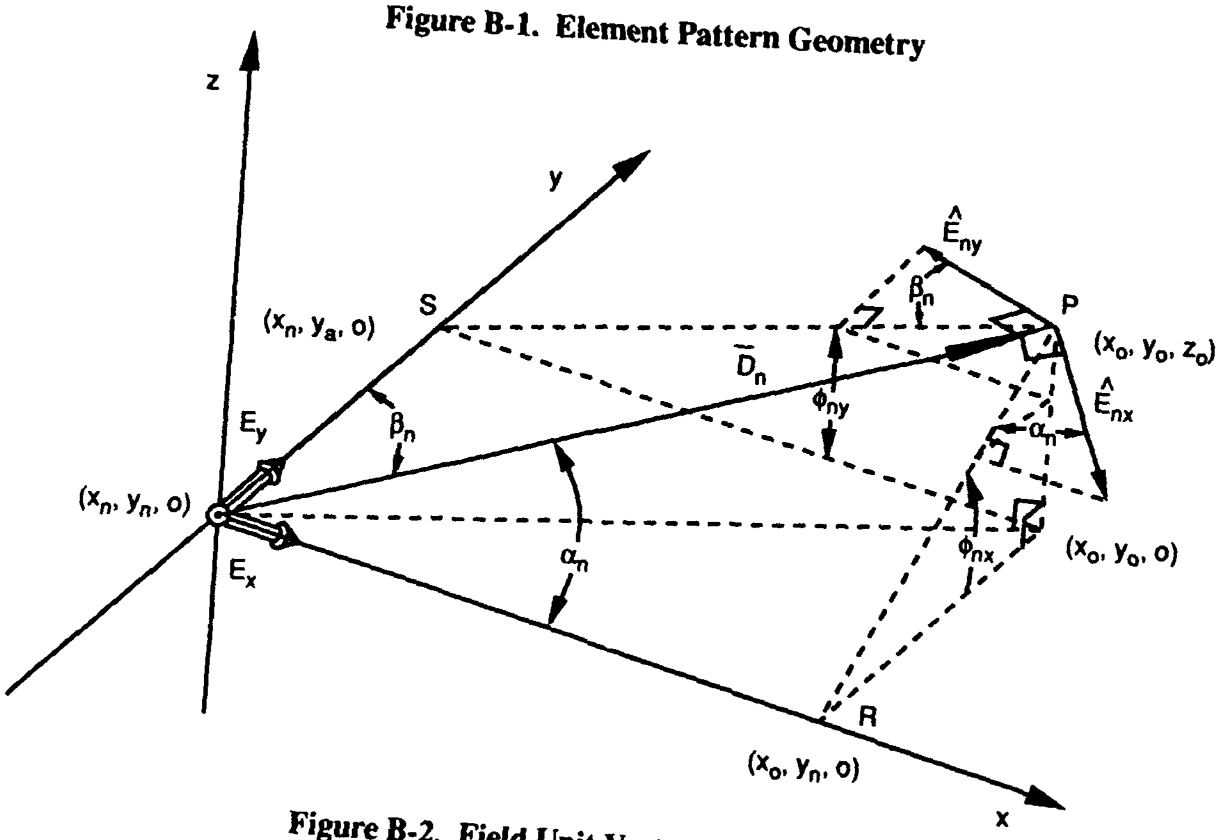

Figure B-2. Field Unit Vectors for nth Element

"element" array factor, with the lower "element" 180° out of phase. The model element power pattern of the x-axis-aligned dipole is therefore

$$P_x = sin^2\alpha \, sin^2\left[\frac{\pi}{2} cos\,\gamma\right], \tag{B-1}$$

in which normalization, which will be considered later, is neglected and γ is the direction cosine angle with respect to the z axis. Note that the element radiation is strongest along the z axis, i.e., towards the zenith ($\alpha = 90°$, $\gamma = 0°$). Similarly, the element power pattern of the y-axis-aligned dipole is

$$P_y = sin^2\beta \, sin^2\left[\frac{\pi}{2} cos\,\gamma\right]. \tag{B-2}$$

The total field at the observation point, *P*, is the vector sum of the elemental fields. In the far field limit all of the elemental fields are aligned, and the total field is simply the product of the element factor and the array factor — a well-known and convenient result. However, in the near field, which encompasses a sizeable volume for an antenna as large as the IRI, the pattern cannot be factorized and each element's contribution is a function of that element's distance from and orientation with respect to the observation point.

If the observation point is in the far field of each of the array elements, the E-field vector lies in the plane that contains the dipole and the element displacement vector, $\overline{D}_n$,

$$\overline{D}_n = (x_n - x_o)\hat{x} + (y_n - y_o)\hat{y} + z_o\hat{z}, \tag{B-3}$$

in which the point "*P*" has coordinates (x_o, y_o, z_o), and the n^th element phase center has coordinates $(x_n, y_n, 0)$, as illustrated in figure B-2. The elemental field unit vector, $\hat{E}_{nx}$ is also perpendicular to $\overline{D}_n$, and, in general, has components along the x, y and z axes. The components of $\hat{E}_{nx}$ can be expressed in terms of the trigonometric functions of the angles α_n and ϕ_{nx}. From careful inspection of figure B-2,

$$\hat{E}_{nx} = \sin\alpha_n \hat{x} - \cos\alpha_n \cos\phi_{nx} \hat{y} - \cos\alpha_n \sin\phi_{nx} \hat{z}. \quad \text{(B-4)}$$

In the above, the nx subscripts pertain to the field associated with the x-axis-aligned dipole of the model, crossed-dipole element. Similarly, the elemental field unit vector associated with the y-axis-aligned dipole may be expressed

$$\hat{E}_{ny} = -\cos\beta_n \cos\phi_{ny} \hat{x} + \sin\beta_n \hat{y} - \cos\beta_n \sin\phi_{ny} \hat{z}, \quad \text{(B-5)}$$

in which β_n is the direction cosine angle of $\overline{D}_n$ with respect to the y axis, and ϕ_{ny}, which is analogous to ϕ_{nx} in equation (B-4), is the dihedral angle between the plane OSQ and the x-y plane, as shown in figure B-2.

All of the trigonometric functions that appear in equations (B-4) and (B-5) can be expressed in terms of the element and observation point coordinates. The distance between the observation point, P, and the n^{th} element is

$$D_n = \left|\overline{D}_n\right| = \left[(x_n - x_o)^2 + (y_n - y_o)^2 + z_o^2\right]^{1/2}, \quad \text{(B-6)}$$

and, with reference to figure B-2,

$$\sin\alpha_n = \left[(y_n - y_o)^2 + z_o^2\right]^{1/2} \Big/ D_n , \quad \text{(B-7a)}$$

$$\cos\alpha_n = (x_o - x_n)/D_n , \quad \text{(B-7b)}$$

$$\cos\phi_{nx} = (y_o - y_n)\Big/\left[(y_o - y_n)^2 + z_o^2\right]^{1/2} , \qquad \text{(B-7c)}$$

$$\sin\phi_{nx} = z_o\Big/\left[(y_o - y_n)^2 + z_o^2\right]^{1/2} , \qquad \text{(B-7d)}$$

$$\sin\beta_n = \left[(x_n - x_o)^2 + z_o^2\right]^{1/2}\Big/D_n , \qquad \text{(B-7e)}$$

$$\cos\beta_n = (y_o - y_n)/D_n , \qquad \text{(B-7f)}$$

$$\sin\phi_{ny} = z_o\Big/\left[(x_o - x_n)^2 + z_o^2\right]^{1/2} , \qquad \text{(B-7g)}$$

$$\cos\phi_{ny} = (x_o - x_n)\Big/\left[(x_o - x_n)^2 + z_o^2\right]^{1/2} . \qquad \text{(B-7h)}$$

The total $\hat{x}$ component of the field is obtained by complex addition of the $\hat{x}$ components of the contributing elements, which are assumed to be weighted uniformly. The element patterns (equations (B-1) and (B-2)), spreading loss $(1/D_n)$, and the relative phase of each elemental contribution must be taken into account:

$$E_{tot,x} = \sum_n \sin\left[\frac{\pi\cos\gamma_n}{2}\right]\frac{e^{-j2\pi D_n/\lambda}}{D_n}\left(\sin^2\alpha_n - \sin\beta_n\cos\beta_n\cos\phi_{ny}\right) . \qquad \text{(B-8a)}$$

Similarly, the y and z components are given by

$$E_{tot,y} = \sum_n \sin\left[\frac{\pi\cos\gamma_n}{2}\right]\frac{e^{-j2\pi D_n/\lambda}}{D_n}\left(\sin^2\beta_n - \sin\alpha_n\cos\alpha_n\cos\phi_{nx}\right) , \qquad \text{(B-8b)}$$

$$E_{tot,z} = \sum_n sin\left[\frac{\pi cos \gamma_n}{2}\right]\frac{e^{-j2\pi D_n/\lambda}}{D_n}\left(-sin\,\alpha_n\,cos\,\alpha_n\,sin\,\phi_{nx} - sin\,\beta_n\,cos\,\beta_n\,sin\,\phi_{ny}\right). \quad \text{(B-8c)}$$

Since beam scanning phases have not been included in equations (B-8), the antenna beam is at broadside, i.e., directed towards the zenith. The total electric field is the vector quantity

$$\overline{E}_{tot} = \left[E_{tot,x}\hat{x} + E_{tot,y}\hat{y} + E_{tot,z}\hat{z}\right]e^{j\omega t}, \quad \text{(B-9)}$$

in which the previously suppressed temporal dependence, $exp(j\omega t)$, appears explicitly.

The mean power density is obtained by adding the component power

$$P_{ave} = a\left[\left|E_{tot,x}\right|^2 + \left|E_{tot,y}\right|^2 + \left|E_{tot,z}\right|^2\right]. \quad \text{(B-10)}$$

The constant "a" is a proportionality factor that is a function of of the array's effective radiated power (ERP). In the far-field limit along the peak of the main beam, the summations of equations (B-8) are easily evaluated, since all $\gamma_n = 0^\circ$, all $\alpha_n = \beta_n = 90^\circ$, and the distance, D_n, is the same for all elements. If N is the total number of elements, then the total power, from equation (B-10) is simply

$$P_{ave} = a\left[\left(\frac{N}{D}\right)^2 + \left(\frac{N}{D}\right)^2\right] = \frac{2aN^2}{D^2}. \quad \text{(B-11)}$$

Note that in the far field there is no contribution from the z component, as expected. For a specified *ERP*, the average power at a distance, *D*, in the center of the beam is given by

$$P_{ave} = \frac{ERP}{4\pi D^2}, \tag{B-12}$$

in which the *ERP* is numeric (not dB). The normalization factor is, therefore,

$$a = \frac{ERP}{8\pi N^2}, \tag{B-13}$$

and the mean power finally becomes

$$P_{ave} = \frac{ERP}{8\pi N^2}\left[\left|E_{tot,x}\right|^2 + \left|E_{tot,y}\right|^2 + \left|E_{tot,z}\right|^2\right]. \tag{B-14}$$

While the above model and derivation are by no means rigorously accurate, they are adequate for near-field IRI RF power density estimates. Power density plots are provided further below for specific "probe" trajectories.

B.2.2 Far-Field Power Model and Theory

While the model and theory of section B.2.1 may also be used at far-field distances, the mathematics is unnecessarily cumbersome and provides no insight. If the largest dimension of the antenna is L, the far field, for most purposes, obtains at distances, D_t, such that

$$D_t \geq 2L^2/\lambda. \tag{B-15}$$

For the IRI, which will be 364.5 m long, the far-field threshold varies from 8.8 to 2.5 km for frequencies of 10 to 2.8 MHz, respectively.

The far-field power pattern for the x-axis-aligned dipoles of an uniformly illuminated array with N columns and M rows may be expressed

$$S^2(\alpha,\beta)=\left[\frac{\sin\alpha \sin\left[\frac{\pi\cos\gamma}{2}\right]}{NM}\ \frac{\sin\left[\frac{\pi N\Delta x(\cos\alpha-\cos\alpha_o)}{\lambda}\right]}{\sin\left[\frac{\pi\Delta x(\cos\alpha-\cos\alpha_o)}{\lambda}\right]}\ \frac{\sin\left[\frac{\pi M\Delta y(\cos\beta-\cos\beta_o)}{\lambda}\right]}{\sin\left[\frac{\pi\Delta y(\cos\beta-\cos\beta_o)}{\lambda}\right]}\right]^2,$$

(B-16)

in which α, β, and γ are the direction cosines of the pattern, and α_o and β_o are the direction cosines of the main beam (at broadside, $\cos\alpha_o = \cos\beta_o = 0$ and $S^2(0,0) = 1$).

For a specified ERP, the power density at a distance, R, is given by

$$P(R,\alpha,\beta) = \frac{ERP}{4\pi R^2} S^2(\alpha,\beta)\,. \qquad \text{(B-17)}$$

The direction cosine angles, α and β, are related to the conventional azimuth and elevation angles, ϕ and θ (see figure 1), by

$$\cos\alpha = \cos\theta\cos\phi \qquad \text{(B-18a)}$$

$$\cos\beta = \cos\theta\sin\phi \qquad \text{(B-18b)}$$

$$\tan\phi = \cos\beta / \cos\alpha \qquad \text{(B-19a)}$$

$$\sin\theta = \cos\gamma = \left[1 - \cos^2\alpha - \cos^2\beta\right]^{1/2} \qquad \text{(B-19b)}$$

Note that γ, which appears in equation (B-16), is not an independent variable if α and β are specified (see equation (B-19b)).

For a uniformly illuminated array, the first sidelobe is 13.2 dB below the peak. Aperture tapering may be used to lower the near-in sidelobes at the expense of peak gain. Tapering has little, if any, effect on the far-out sidelobes, which, for electrically large $(L >> \lambda)$ arrays, have a mean level that is determined by aperture illumination errors.

Note that the pattern of equation (B-16) can be interpreted as the product of an element pattern and two linear array factors — one for an x-axis-aligned array and one for a y-axis-aligned array. This interpretation is valid for any aperture illumination function that is "separable," i.e., that can be expressed as the product of two functions — one dependent on only the element's x coordinate, and the other dependent on only the element's y coordinate. An example of a non-separable illumination function is any function with circular symmetry (apart from the trivial case of uniform illumination). Arrays with separable illuminations have patterns that contain relatively high sidelobe ridges in vertical planes that contain the x and y axes, respectively (at broadside scan), and relatively low sidelobes elsewhere. The ridges correspond to directions for which either of the linear array "factors" has peak value, and, therefore, does not offer any sidelobe reduction. For example, the first sidelobes in the x-z and y-z planes are about 13 dB below peak, while those in the bisecting planes (at 45° and 135° azimuth) are about 26 dB below peak. Clearly, the array orientation may be an important factor when gauging the impact of the emissions on certain area electronics users.

The far-field pattern has additional properties that deserve elaboration. While not always as convenient as the familiar azimuth and elevation angles, direction cosines are the most suitable coordinates for plotting planar array patterns. As can be gleaned from equation (B-16), scanning the array beam to the (α_o, β_o) direction is accomplished by application of the interelement phase shifts

$$\beta_x = \frac{2\pi\Delta x}{\lambda} \cos\alpha_o , \qquad \text{(B-20a)}$$

$$\beta_y = \frac{2\pi\Delta y}{\lambda} \cos\beta_o , \qquad \text{(B-20b)}$$

along the x and y directions, respectively. When plotted in direction cosine space, the pattern is simply translated by the steering phases, as illustrated in figure B-3. Non-linear phase shifts, such as those used for quadratic focusing or beamspoiling, do modify the array pattern. While the pattern function is invariant in direction cosine space, the shapes of pattern features do change in real space as the beam is scanned. For example, the main beam area varies approximately as the reciprocal of $\cos\gamma$ (γ is the scan angle off broadside, i.e., off the zenith). This "inverse cosine" beam broadening does result in "geometrical" scan loss that is generally valid for scan angles up to about 60° off broadside. At wider scan angles, scan loss is typically severe, and is difficult to predict by analysis. The complete scan loss function can be obtained experimentally by measurement of the "embedded element pattern," i.e., the pattern of a single active element embedded in a small array of terminated elements that simulate the array environment.

As is evident from examination of figure B-3, no portion of the main beam lies near endfire (the unit circle at 8 MHz).

B.2.3 IRI Power Density Predictions

A variety of IRI power density profiles based on the near-field power model of section B.2.1 have been computed and are presented below.

For axial profiles, the power density $\left(W/m^2\right)$ is computed as a function of height above the center of the array, which is steered to broadside. Three such axial power density profiles appear in figure B-4 for frequencies of 10, 6.4, and 2.8 MHz, respectively. Since the array has a total radiated power of 3.6 MW (10 kW per polarization per element), the ERP varies as the square of the frequency, i.e., varies as the array peak directivity.

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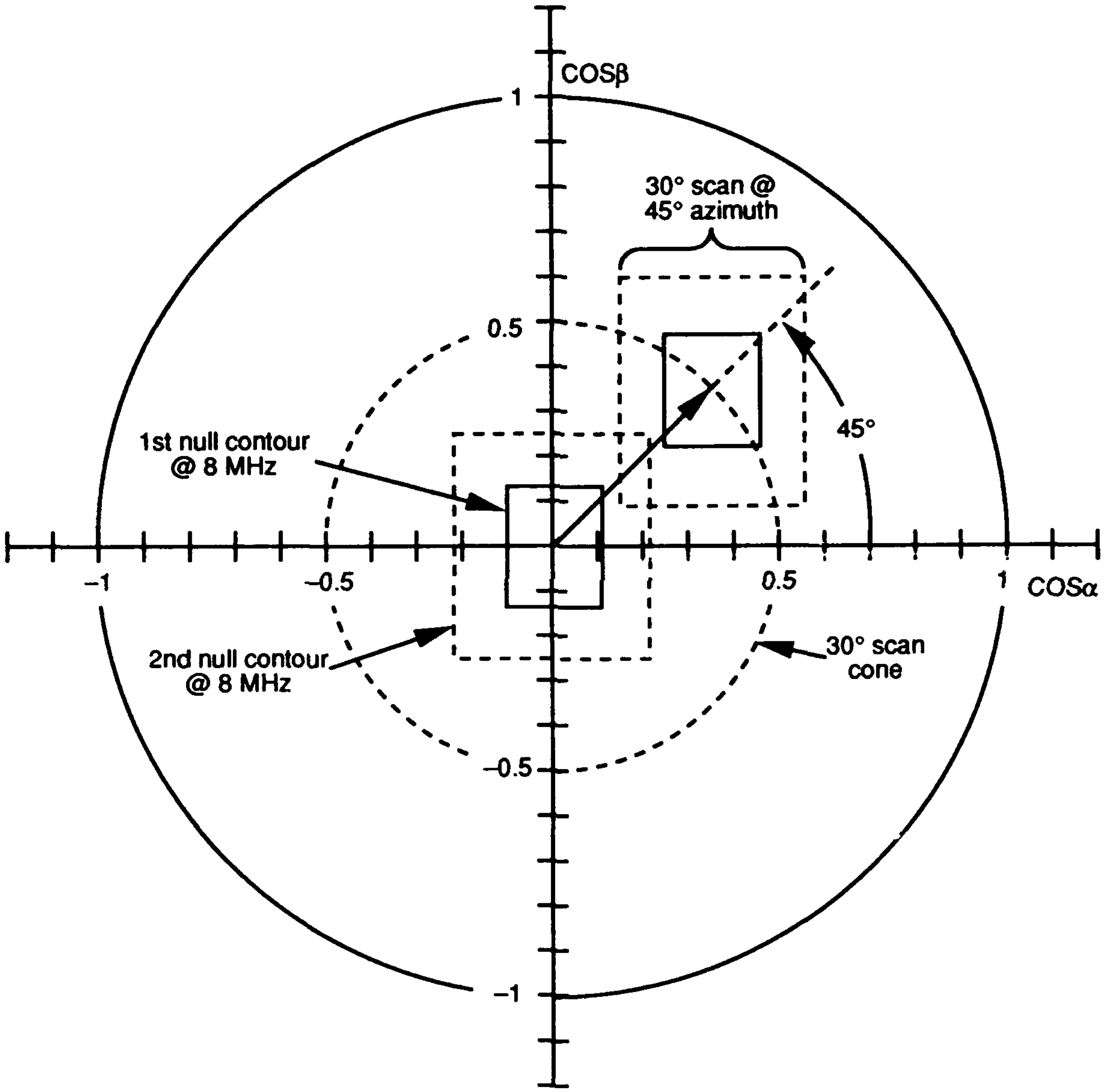

Figure B-3. Scan Invariance of Array Pattern in Direction Cosine Space

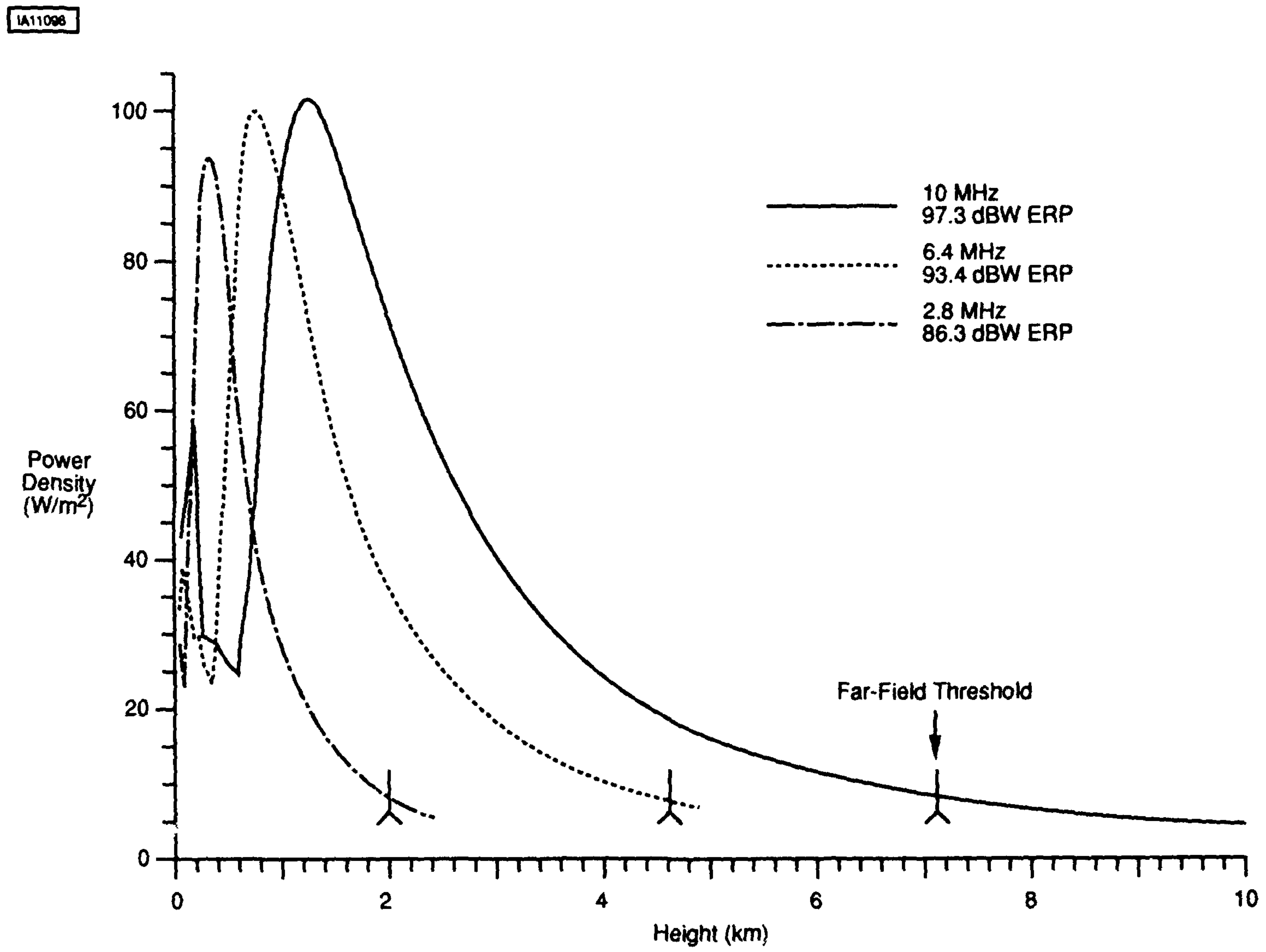

Figure B-4. IRI Power Density vs Height Above Array Center at Three Frequencies

In each example the profile has a distinctive peak that occurs at a height that is proportional to the frequency. Theoretically*, the axial power density profile of a square aperture peaks at a distance,

$$D_p = 0.18 D_t = 0.18\left(\frac{2A}{\lambda}\right), \qquad \text{(B-21)}$$

in which D_t is the conventional far-field threshold distance and A is the aperture area (compare with equation (B-15)). While this result is not strictly applicable to the IRI array, which has a rectangular rather than a square aperture, use of the IRI array area of 1.06×10^5 m^2 in equation (B-21) produces peak distance estimates close to those obtained from the model. For example, at 10 MHz the IRI far-field threshold, D_t, is 7.1 km (equation (B-21)), and D_p is therefore 1.28 km, which is very close to the 1,300 m peak exhibited in the computed profile.

Note that the peak power densities do not vary strongly with frequency, lying between 94 and 100 W/m^2. While the array has more gain at the higher frequencies, the separation of the peak power point decreases with frequency, roughly offsetting this advantage. The peak power densities produced in the near fields of the aperture antennas are, as a general rule of thumb, two to three times as great as the nominal power densities obtained by dividing the total radiated power by the physical aperture area. Since the IRI has a nominal power density of 34 W/m^2, the model results of figure B-4 are reasonable.

While axial power density is an important antenna characteristic, the transverse variation of the power density is of more practical importance for systems (or birds) that overfly the array. The power density plots of figure B-5 are transverse cuts in the x-z plane at heights that correspond to the peak axial power density for each frequency. For example, the

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* Hansen, R. C. Ed Microwave Scanning Antennas, Vol. I, Apertures, pp. 35-37, Academic Press, New York, 1964.

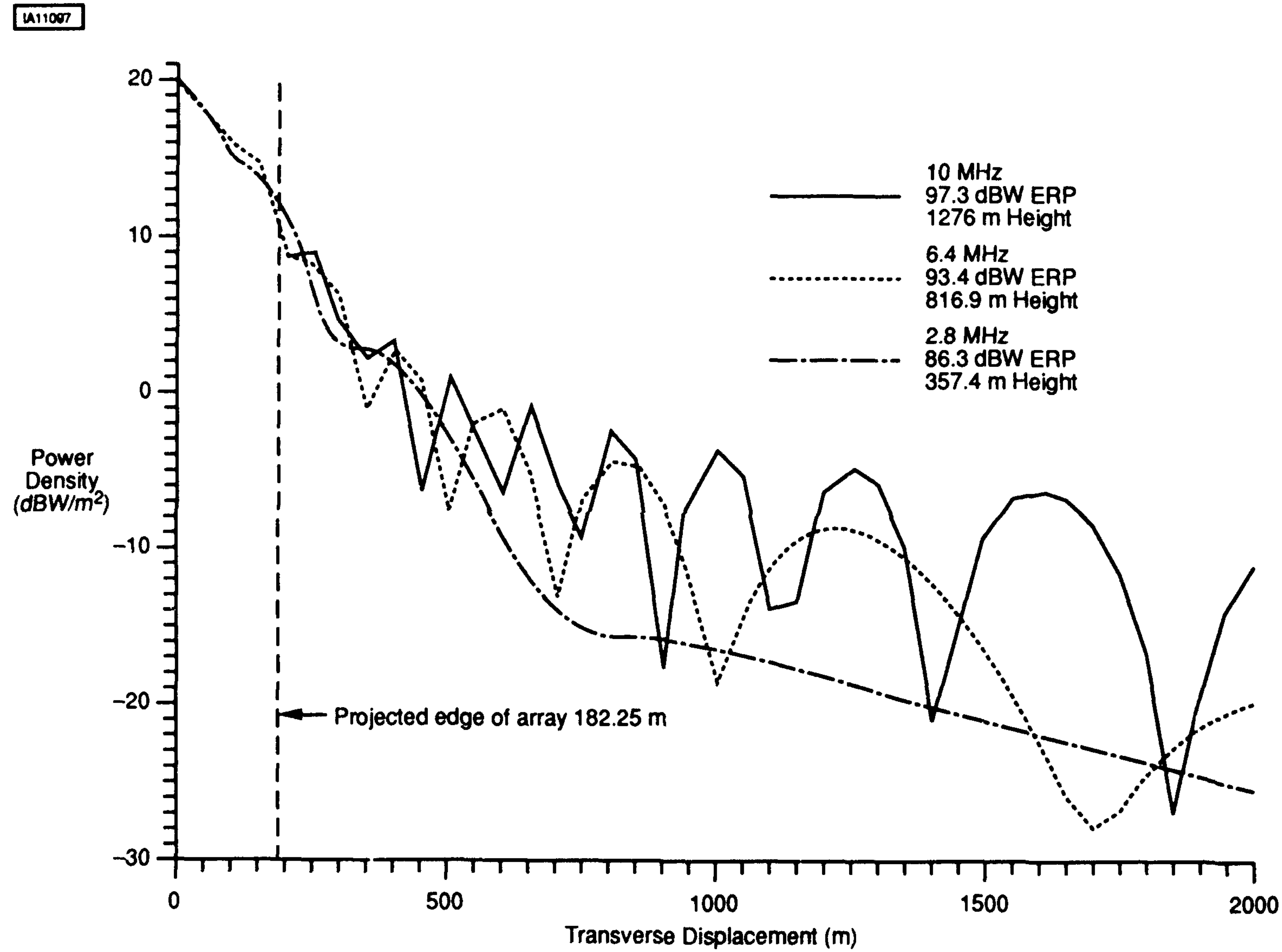

Figure B-5. IRI Power Density vs Horizontal Displacement at Three Frequencies

10-MHz plot represents the field power density along a trajectory parallel to the array's long axis (x axis) at a height of 1,276 m. The vertical dashed line at a transverse displacement of 182.25 m represents the vertical projection of the physical edge of the array. Note that the power density is already down by nearly a factor of ten at the projected aperture boundary. This result bolsters the often-heard claim that most of the near-field radiated power is confined to the tube formed by extension of the outer boundary of the aperture. The power density profiles of figure B-6 follow the format of those of figure B-5; however, in the former case the cuts lie in the vertical plane that passes through the array diagonal at an azimuth of 38.66° (see figure B-1). As in the previous examples, most of the radiated power lies within the aperture tube, which, in the case of the diagonal cut, achieves its maximum half-width of 233.4 m. On the other hand, the power density roll off with transverse displacement is significantly sharper for the diagonal cut. This is not surprising, since the diagonal cut corresponds to the intercardinal plane in the far field. With reference to equation (B-16), intercardinal patterns lie in the sidelobes of both the x-axis and y-axis pattern factors and, therefore, have generally lower sidelobes than either of the principal plane (x-z or y-z plane) cuts. From a diagonal plane perspective, even a uniformly illuminated rectangular array has an effective space density taper that lowers sidelobes in that plane, i.e., the illumination rolls off towards the edges of the aperture due to the "triangular corners" of the diagonally-aligned aperture.

A last example of near-field "patterns" is provided in figure B-7, which contains power density profiles for shallow conical trajectories about the aperture. The upper curve corresponds to a range of only 250 m from the center of the aperture at a constant height of 1 m above the x-y plane (ground plane) of the array. The elevation angle of this trajectory cone is thus only 0.23°. Only the first 180° of the trajectory azimuth need be computed because, owing to the antenna's symmetry, the 180° to 360° sector is a replica of the 0° to 180° sector.

The lower plot of figure B-7 represents the power density along a conical trajectory at a range of 1,600 m (about one mile) from the array center, at a height of 6 m. Clearly, the azimuthal variation of the power density is more pronounced further from the array. In close to the array, the elemental contributions appear to add in a more nearly random fashion, washing

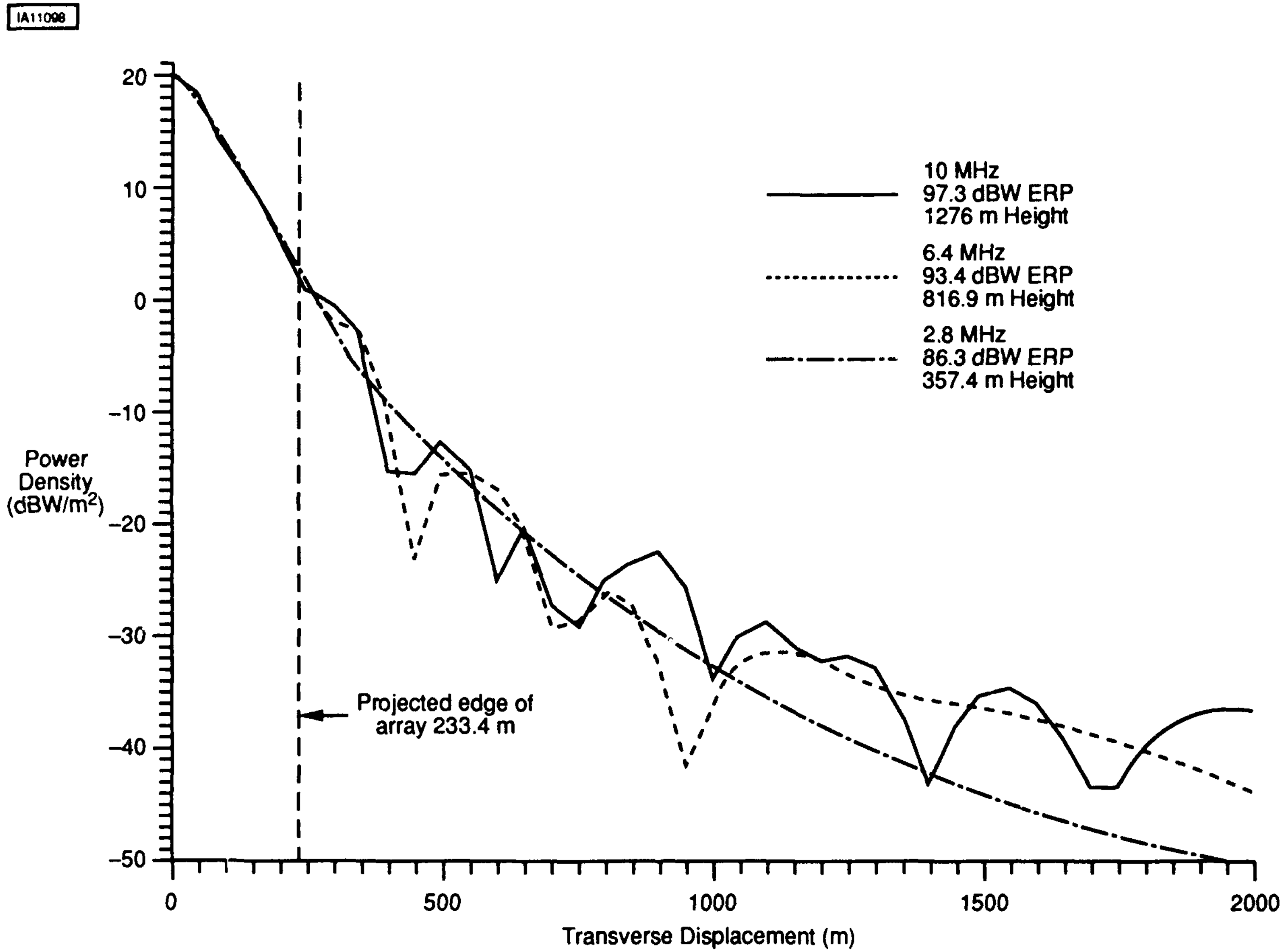

Figure B-6. IRI Power Density vs Diagonal Horizontal Displacement at Three Frequencies

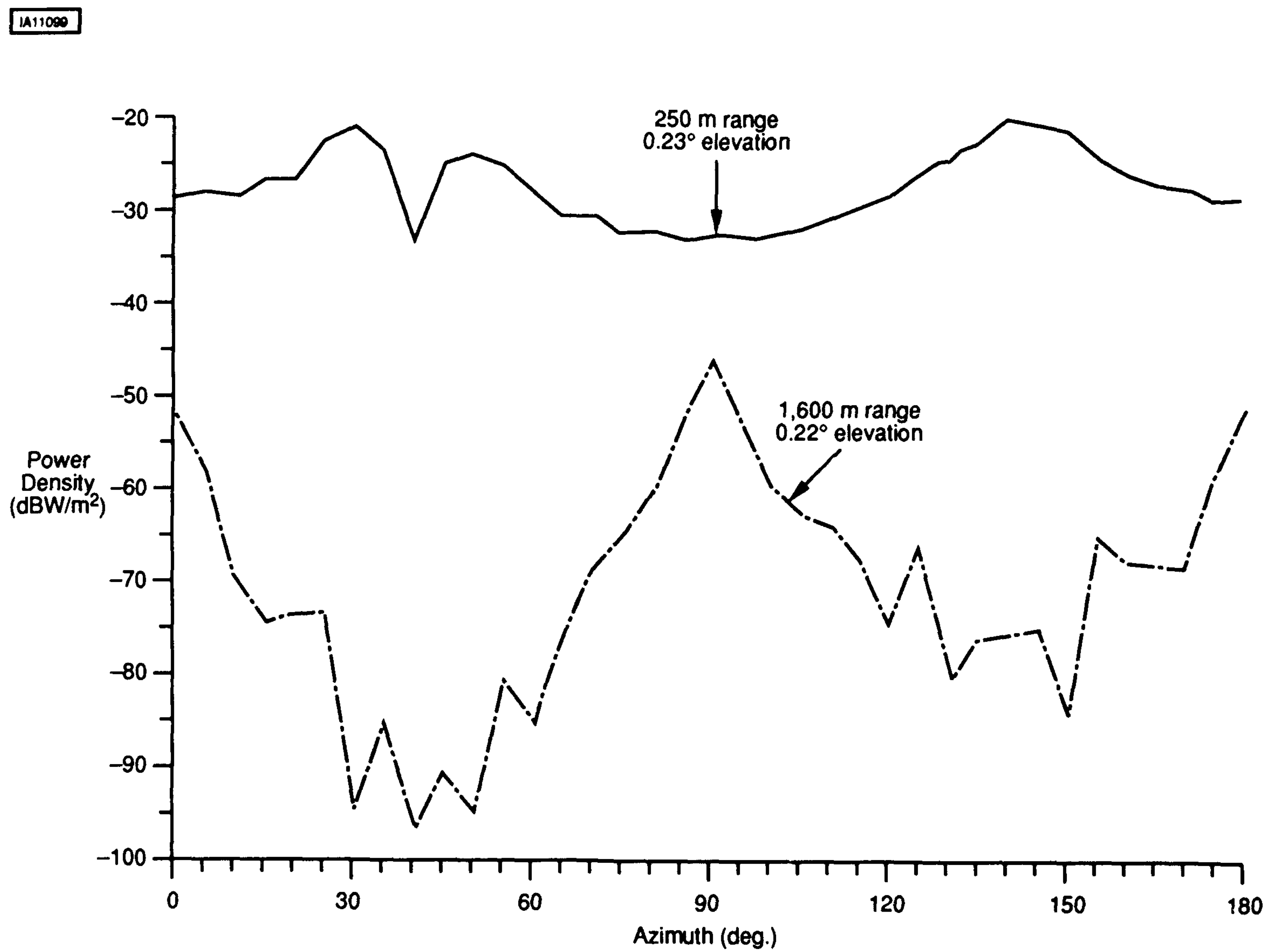

Figure B-7. IRI Power Density vs Azimuth at 10 MHz for Two Ranges out azimuthal variations. The power density is lowest in the vicinity of 30° to 50°, where the field of the y-axis-oriented dipole tends to cancel that of the x-axis-oriented dipole. If the dipoles of the array were phased 90° apart, so as to produce circular polarization along the axis, the azimuthal pattern would be dramatically altered, with less pronounced azimuthal variations.

B.3 ISR

The HAARP ISR is a scientific radar that will be used to study incoherent backscatter from the ionosphere and diagnose any changes induced by the IRI. As presently envisioned, the ISR will employ a parabolic dish antenna with an effective area of about 1,000 m^2 and will radiate about 0.4 MW (average power). At 445 MHz the dish has a gain of 44.4 dBi, which yields an ERP of 100 dBW. The ISR will transmit at frequencies between 444 and 446 MHz, and have a tunable receive bandwidth of 50 MHz, between 400 and 450 MHz. The instantaneous bandwidth will be as large as 2 MHz. Mechanical steering of the dish up to 30° from the zenith is required.

A semi-empirical antenna pattern model developed by P. L. Rice (et al.)* is adopted here. The pattern, which is assumed to have perfect cylindrical symmetry about the paraboloid axis, is divided into four regions: the main beam, the first sidelobe, the remaining sidelobes up to 90° off axis, and the backlobes between 90° and 180°. First, the array directivity is computed via

$$g_o = e_a\left[\frac{4\pi A}{\lambda^2}\right] = e_a\left[\frac{\pi D}{\lambda}\right]^2 = \left[\frac{\pi D_e}{\lambda}\right]^2, \qquad \text{(B-22)}$$

* Rice, P. L., Thompson W.I.III, and Noble, J. L., "Idealized Pencil-Beam Antenna Patterns for Use in Interference Studies," IEEE Trans., Vol. COM-18, No. 1, February 1970.

in which e_a is the aperture efficiency, A is the physical aperture area, D is the physical dish diameter, and D_e is the effective dish diameter. The angular positions of the first and second nulls, which separate regions 1, 2, and 3 of the model pattern are given by

$$\theta_1 = sin^{-1}[\lambda/D_e] = sin^{-1}[\pi/g_o^{1/2}], \qquad \text{(B-23a)}$$

$$\theta_2 = sin^{-1}[2\lambda/D_e] = sin^{-1}[2\pi/g_o^{1/2}]. \qquad \text{(B-23b)}$$

While these null positions are not those customarily calculated for circular apertures by use of the Bessel function, the model pattern provides a more realistic description of measured parabolic reflector patterns. For convenience, the argument, u, is defined (in radians):

$$u = (\pi D_e/\lambda) sin\,\theta = g_o^{1/2}\, sin\theta. \qquad \text{(B-24)}$$

The complete power pattern model can now be expressed, in angular regions 1, 2, 3, and 4:

$$g_1(\theta) = g_o[0.9976(sin\,u/u)^{2.25} + 0.0024], \qquad (0 \le \theta < \theta_1) \qquad \text{(B-25a)}$$

$$g_2(\theta) = g_o[0.1(sin\,u/u)^2 + 0.0024], \qquad (\theta_1 \le \theta < \theta_2) \qquad \text{B-25b)}$$

$$g_3(\theta) = 0.376 g_o u^{-2.75}, \qquad (\theta_2 \le \theta < 90^\circ) \qquad \text{(B-25c)}$$

$$g_4(\theta) = 0.376 g_o^{-0.375}. \qquad (90^\circ \le \theta \le 180^\circ) \qquad \text{(B-25d)}$$

Note that,

$$g_1(0) = g_o\,, \qquad \text{(peak)} \qquad \text{(B-26a)}$$

$$g_2(\theta_1) = 0.0024 g_o \quad (-26.2 \text{ dB})\,, \qquad \text{(first null)} \qquad \text{(B-26b)}$$

$$g_2\left[\sin^{-1}\left(\frac{3\pi}{2 g_o^{1/2}}\right)\right] = 0.0069 g_o \quad (-21.6 \text{ dB}), \qquad \text{(first sidelobe)} \qquad \text{(B-26c)}$$

and that the gain in region 4 (backlobes) is constant and equal to the value in region 3 at $\theta = 90^\circ$.

An ISR antenna pattern based on the semi-empirical model of equations (B-25) is displayed in figure B-8. Based on an effective aperture $(e_a A)$ of $1{,}000 \text{ m}^2$, the 445-MHz pattern has a peak directivity of 44.42 dBi and a backlobe level of -20.91 dBi. The 3-dB beamwidth is 0.90°, and the first sidelobe peak attains a value of 22.89 dBi at 1.5° off axis. Note that if the dish is tilted 30° from the zenith, the gain in the horizontal direction in the plane of tilt is $g_3(60^\circ) = -19.19$ dBi, which differs little from the backlobe gain. It should be emphasized that the semi-empirical pattern of figure B-8 is a far-field, median pattern, and that the standard deviation of actual values relative to the median estimate ranges between 6 and 8 dB for θ values outside the main beam.

A near-field pattern model has not been developed for the ISR; rather, insight into the near-field structure of the ISR is provided via analogy with the IRI, which has been modeled in some detail. The calculation of ISR fields near the dish will be complicated by the probable use of electromagnetic fences or other shielding strategies needed to mitigate orographic clutter returns or BMEWS radar signals at the ISR sites.

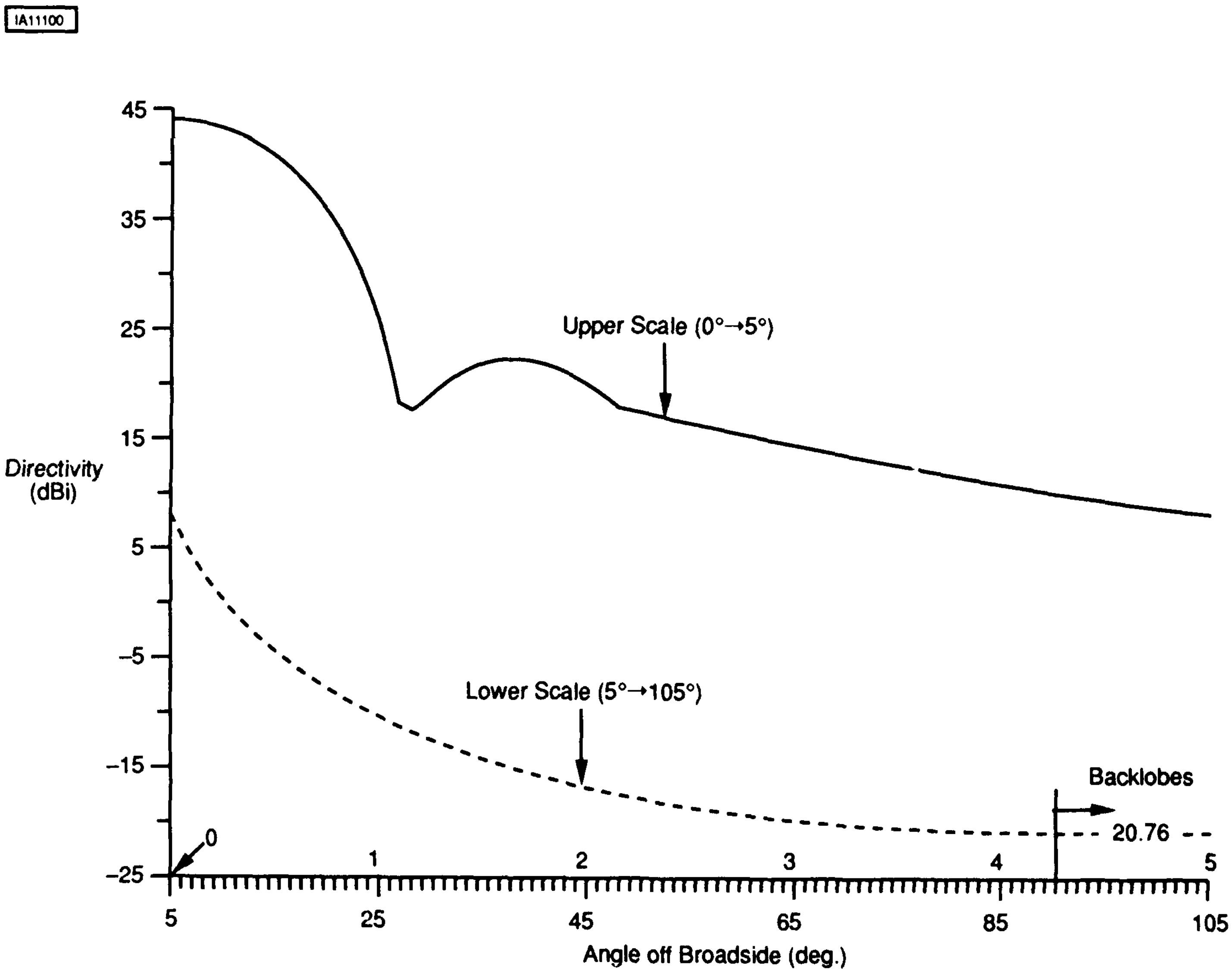

Figure B-8. Generic Power Pattern for ISR Dish Antenna

B.4 VIS

The VIS is used in conjunction with the IRI to probe the ionosphere and help select those frequencies of operation that are most appropriate for a given experiment. Since the VIS must operate over a 1- to 15-MHz band, which comprises almost four octaves, an ultra-wide-band antenna is desirable for efficient operation. While vertical rhombics or variants thereof have been used successfully, pattern data for such antennas over earth are not readily available. Free space patterns, while available, are inappropriate for this analysis because most receivers of interest are located very close to the earth. With these considerations in mind, a vertical log-periodic dipole array of the Technology for Communications International (TCI) model no. 518 design was selected for this analysis. TCI supplied several elevation patterns for this antenna over earth. These patterns were used to calibrate a relatively simple horizontal dipole (over earth) model that was used to estimate the antenna directivity at the various user (receiver) locations.

Since most Gakona and Clear electronics users operate at frequencies that are far from the VIS operational band, the level of spurious emissions produced by the Digisonde Portable Sounder (DPS) transmitter is especially important. Spurious/Harmonic content data have been obtained from Dr. Mark Haines of the University of Lowell's Center for Atmospheric Research. The data available extend out to the fifth harmonic (up to 70 MHz), with higher harmonics presumed to lie below the noise floor, which is between 66 and 57 dB below the carrier. In addition, the DPS transmitter's impedance matching transformer provides approximately 6 dB per octave attenuation with increasing separation from the VIS band. Combining the noise floor data and filter characteristic, we estimate that the far out-of-band emissions of the VIS at frequency, f(MHz), should be suppressed by at least

$$L(f) = -6\left[log(f/15)/log\,2\right] - 57. \quad \text{(dB)} \qquad \text{(B-27)}$$

For example, for cellular telephones that operate at 870 MHz, filter attenuation provides $-6\left[log(870/15)/log\,2\right] = -35.2$ dB of suppression. The 58th to 870th harmonics, that may, in principle, reach to 870 MHz from the 1- to 15-MHz VIS band, have not been measured, but must lie below the -57 dB noise floor. In all likelihood, the estimate of equation (B-27) is very generous, but will be used, nevertheless, in the absence of more accurate data.

The power output of the DPS is 600 W, peak, with a 10% duty cycle. Thus, the average radiated power of the VIS is 60 W (17.8 dBW), which is several orders of magnitude less than that of either the IRI or ISR. Furthermore, in normal operation the VIS sweeps across the 1- to 15-MHz band, so that interference that may occur will be transitory rather than sustained.

The VIS pattern at low elevation angles is modeled as that of a horizontal dipole over earth. If the effective dipole height is h_d, the power pattern in the vertical plane perpendicular to the dipole is given by

$$D_g(\theta) = const. \left| 1 + a_h(\theta) exp\, j \left[\left(\frac{-4\pi\, h_d \sin\theta}{\lambda} - \phi_h(\theta) \right) \right] \right|^2 , \qquad \text{(B-28)}$$

in which θ is the elevation angle, and a_h and ϕ_h are the horizontal-polarization Fresnel reflection coefficient amplitude and phase, respectively. The constant and effective dipole height are selected to provide a good fit to the TCI Vertical Log Periodic patterns at elevation angles up to 30°. A constant of 1.88 and effective heights of 75, 15, and 8.5 m were used at 1, 7.5, and 15 MHz, respectively. Typical earth electrical constants of 0.03 Siemens/m and 15 for the relative dielectric constant were used throughout. The horizontal polarization Fresnel reflection coefficient is not a sensitive function of earth electrical constants at low elevation angles. As expected, the patterns described by equation (B-28) display severe undercut, with the field strength rapidly decreasing with decreasing elevation angle near the earth.

The out-of-band VIS patterns cannot be readily estimated without detailed simulations. At high out-of-band frequencies, the dipoles that comprise the log-periodic array are many wavelengths long, producing narrow fan beams and many high sidelobes. Since all elements of the log-periodic array may contribute, the resulting pattern can be very complex, with no clearly defined main beam, but, rather, a collection of large lobes and high sidelobes. No attempt is made to account for the details of the out-of-band pattern; rather, equation (B-28) is used with Fresnel reflection coefficients evaluated at the out-of-band frequency. In certain directions, the out-of-band VIS directivity will exceed that of equation (B-28); however, over much of the sidelobe region, the estimate should be adequate.

For avionics users, the distance at which the VIS power density is equal to the equivalent power density at the receiver sensitivity threshold (see table A-2) is estimated. If the aircraft-to-VIS separation is denoted R, the VIS directivity is denoted $D_g(\theta)$, the VIS radiated power is P_t, and total losses (including harmonic suppression) are L, then the power density at the aircraft (avionics receiver) is

$$P_d(\theta) = \frac{P_t D_g(\theta) L}{4\pi R^2}. \qquad \text{(B-29)}$$

If the aircraft height is denoted h_a, the range, assuming that the earth is flat, may be expressed

$$R = h_a / \sin\theta, \qquad \text{(B-30)}$$

in which θ is the elevation angle of the aircraft as viewed from the VIS. If the power density is replaced by the sensitivity threshold power density, $S\left(W/m^2\right)$, and equation (B-30) is substituted into (B-29), the following transcendental equation is obtained:

$$D_g(\theta) \sin^2\theta = \frac{4\pi h_a^2 S}{P_t L}. \qquad \text{(B-31)}$$

Using equation (B-28) for $D_g(\theta)$, this equation can be solved for θ, and hence R, by simple numerical evaluation. The range obtained by this method is a function of both S and h_a, the aircraft altitude. The VIS interference ranges of table B-2 are based on a typical aircraft altitude of 1,000 ft. Because of the VIS pattern's strong undercut, sensitivity ranges, as computed above, are somewhat longer for higher aircraft altitudes. Given the uncertainty in the VIS out-of-band pattern, however, all range estimates are crude at best.

B.5 SPECIFIC POWER DENSITY ESTIMATES AT USER RECEIVING SYSTEMS IN GAKONA AND CLEAR STUDY AREAS

In order to evaluate the potential impact of the HAARP emitters on electronics users in the Gakona/Clear region, the RF power densities produced by the emitters at the various known and potential "receiver" locations must be estimated. The antenna models described in the preceding sections have been used for this purpose. Only the spacewave is included in those models. No attempt has been made to account for propagation of RF power via ground wave in the estimates below. Neither the ISR dish antenna nor the IRI, with its elevated ground plane and horizontal polarization, couple strongly enough to the earth to launch ground waves whose strength exceeds the spacewave power density at distances greater than 1,000 ft. Groundwave power densities are calculated for OTH-B in the Environmental Impact Statement (reference 6 of appendix A) for the canceled OTH-B radar system that was planned for Gulkana. The calculated groundwave power densities, at distances more than 1,000 ft from the center of the OTH-B array, were at most one-half that of the calculated peak far-field space-wave power densities (see figures B-5 through B-10 of reference 6 of appendix A). The groundwave power densities of the HAARP emitters are expected to be at least 17.2 dB less than those for the OTH-B emitters. Consequently, groundwave interference from the HAARP emitters is not expected to be as significant as the spacewave interference from the HAARP emitters. The 17.2-dB difference is explained below.

The IRI radiates 4.8 dB more average radiated power than the OTH-B (3.6 MW for the IRI versus 1.2 MW for the OTH-B). However, the 15 ft (.045λ at 3 MHz) elevation of the IRI groundscreen reduces the groundwave power density by 5 dB from that with a groundscreen on the ground (such as that of the OTH-B) (see R. W. P. King. et al., Lateral Electromagnetic Waves, New York: Springer-Verlay, 1991, p. 112). Furthermore, the IRI array elements are horizontally polarized, with a vertical (cross-polarization) component roughly 20 dB below the horizontal component. At least half of the OTH-B radiated power is vertically polarized. The IRI polarization, therefore, reduces the groundwave power density by at least 17 dB from that of the OTH-B because no appreciable groundwave is generated by a horizontally polarized element above the ground. The groundwave power density for the IRI is, therefore, expected to be at least -4.8 + 5 dB + 17 dB = 17.2 dB less than that for the OTH-B. The groundwave power density from the ISR is less than that of the IRI because the ISR average radiated power is only 0.4 MW, the operational frequency is much higher, and the ISR is also horizontally polarized and designed to radiate upwards towards the zenith. The groundwave launched by the VIS is also relatively weak because the elements of the log periodic array are horizontal to the Earth.

The majority of the "receivers" at and near the HAARP sites lie well outside the operational bands of the HAARP emitters. In these instances, the harmonics or other spurious out-of-band signals generated by the emitters must be considered. For purposes of power density estimation, harmonic, subharmonic, and spurious signal levels, referenced to the fundamental or carrier, are taken to be the maximum allowed values as per the IRI system specification, paragraphs 3.7.1.6.1 and 3.7.1.6.3. While realized levels may, in fact, be significantly lower, this conservative approach serves to identify interference problems that may occur despite specification compliance. In the case of the ISR, the harmonic levels cited are based on good engineering judgment. For the VIS, harmonic levels are assumed to be below measurement threshold.

All power density estimates from the HAARP emitters at the Gakona and Clear site receiving systems are summarized along with relevant parameters in table B-1. Interference threshold distances for avionics users are summarized in table B-2.

The specific power density estimate for each receiving system is discussed below in sections B.5.1, B.5.2, and B.5.3 for the IRI, ISR, and VIS emitters, respectively. In all of the situations described below, HAARP emitter power densities for radiation that lies in the band of the user is estimated. Interference can also occur if the power produced in the emitter's band is sufficient to overload the front-end amplifier of the user's receiver. Such overloads

Table B-1. HAARP Emitter Power Density Estimates

Receiving System No.	Receiving System Name	Emitter	Radiated Power (dBW)	Transmit Directivity (dBi)	Harmonic, etc., Suppression (dB)	Element, Misc. Losses (dB)	**Receive Directivity Adjustment (dB)	Free Space Loss Gakona/Clear (dBm^{-2})	Power Density Gakona/Clear ($dBWm^{-2}$)
1	Cellular Telephone (870-890 MHz)	IRI	65.6	3.0	-120.0	-10.0	0	-73.2/-73.2	-134.6/-134.6
		ISR	56.0	--	-80.0	0	0	-78.6/-61.1	-124.0*/-106.5*
		VIS	17.8	3.0	-92.1	0	0	-78.6/-61.1	-149.9+/-132.4+
2	HAARP Riometer (38.2 MHz)	IRI	65.6	3.0	-80.0	-10.0	-43.5	-95.1/-95.1	-160.0/-160.0
		ISR	56.0	--	$-\infty$	0	-43.5	-95.1/-95.1	negligible
		VIS	17.8	-40.0	-25.0	0	-43.5	-95.1/-95.1	-185.8+/-185.8+
3a	Satellite Television (5.9-6.9 GHz)	IRI	65.6	3.0	-120.0	-10.0	-49.6	-90.7/-69.1	-201.7/-180.1
		ISR	56.0	-27.9	-100.0	0	-49.6	-90.7/-75.1	-212.2*/-196.6*
		VIS	17.8	3.0	-109.0	0	-49.6	-90.7/-75.1	-228.5+/-212.9+
3b	Satellite Television (12.50-12.75 GHz)	IRI	65.6	3.0	-120.0	-10.0	-57.1	-90.7/-69.1	-209.2/-187.6
		ISR	56.0	--	$-\infty$	0	-57.1	-90.7/-75.1	negligible
		VIS	17.8	3.0	-115.0	0	-57.1	-90.7/-75.1	-242.0+/-226.4+

*To convert to $dBW/(m^2Hz)$, subtract 57 dBHz (0.5 MHz bandwidth assumed).

**Receive Directivity Adjustment: ratio of receive directivity in direction of emitter to the peak receive directivity.

+To convert to $dBW/(m^2Hz)$, subtract 33 dBHz (2.0 KHz bandwidth).

Table B-1. HAARP Emitter Power Density Estimates (Continued)

Receiving System No.	Receiving System Name	Emitter	Radiated Power (dBW)	Transmit Directivity (dBi)	Harmonic, etc., Suppression (dB)	Element, Misc. Losses (dB)	Receive Directivity Adjustment (dB)	Free Space Loss Gakona/Clear (dBm^{-2})	Power Density Gakona/Clear ($dBWm^{-2}$)
4	HF Comm. 2.8-10 MHz	IRI	65.6	29.8 (8 MHz)	0	-5 (Abs. Loss)	0	-118.2/-118.2	-27.8/-27.8
	10-30 MHz	IRI	65.6	3.0	-80.0	-10.0	0	-81.1/-69.1	-102.5/-90.5
	2.1-30 MHz	ISR	56.0	--	$-\infty$	0	0	-81.1/-75.1	negligible
	2.1-15 MHz	VIS	17.8	9.0	0	-5 (Abs. Loss)	0	-118.2/-118.2	$-96.4^{+}/-96.4^{+}$
	15-30 MHz	VIS	17.8	9.0	-3.0	-5 (Abs. Loss)	0	-123.0/-123.0	$-104.2^{+}/-104.2^{+}$
5	Television Broadcast 54-88 MHz, 200-216 MHz	IRI	65.6	3.0	-120.0	-10.0	0	-81.1/-69.1	-142.5/-130.5
	88-200 MHz	IRI	65.6	3.0	-150.0	-10.0	0	-81.1/-69.1	-172.5/-170.5
	54-216 MHz	ISR	56.0	--	$-\infty$	0	0	-81.1/-75.1	negligible
	54-216 MHz	VIS	17.8	-20.0	-39.0	0	0	-81.1/-75.1	$-122.3^{+}/-116.3^{+}$
6	AM Radio Broadcast (0.535-1.7 MHz)	IRI	65.6	--	$-\infty$	--	0	-81.1/-69.1	negligible
		ISR	56.0	--	$-\infty$	--	0	-81.1/-61.1	negligible
	0.535-1.0 MHz	VIS	17.8	--	$-\infty$	--	0	-81.1/-61.1	negligible
	1.0-1.7 MHz	VIS	17.8	-50.0/-30.0	0	0	0	-81.1/-61.1	$-113.3^{+}/-73.3^{+}$
7	FM Radio Broadcast (92.9-106.7 MHz)	IRI	65.6	3.0	-150.0	-10.0	0	-81.1/-69.1	-172.5/-160.5
		ISR	56.0	--	$-\infty$	0	0	-81.1/-61.1	negligible
		VIS	17.8	-30.0/-10.0	-73.0	0	0	-81.1/-61.1	$-166.3^{+}/-126.3^{+}$

+To convert to $dBW/(m^2Hz)$, subtract 33 dBHz (2.0 KHz bandwidth).

Table B-1. HAARP Emitter Power Density Estimates (Continued)

Receiving System No.	Receiving System Name	Emitter	Radiated Power (dBW)	Transmit Directivity (dBi)	Harmonic, etc., Suppression (dB)	Element, Misc. Losses (dB)	Receive Directivity Adjustment (dB)	Free Space Loss Gakona/Clear (dBm^{-2})	Power Density Gakona/Clear ($dBWm^{-2}$)
8	Avionics				SEE TABLE B-2				
9	Cardiac Pacemakers	IRI	65.6	-37.1	--	--	--	-73.2/-69.1	-44.7/-38.5
		ISR	56.0	-35.0	--	--	--	-78.6/-61.1	-41.6/-24.1
		VIS	17.8	-46.0	--	--	--	-78.6/-61.1	-106.8+/-89.3+
10	Electro-Explosive Devices	IRI	65.6	-37.1	--	--	--	-73.2/-73.2	-44.7/-44.7
		ISR	56.0	-19.0	--	--	--	-78.6/-61.1	-41.6/-24.1
		VIS	17.8	-46.0	--	--	--	-78.6/-61.1	-106.8+/-89.3+
11	Mobile VHF Radio (38-166 MHz)	IRI (38-45 MHz)	65.6	3.0	-80.0	-10.0	0	-73.2/-73.2	-94.6/-94.6
		IRI (45-88 MHz)	65.6	3.0	-120.0	-10.0	0	-73.2/-73.2	-134.6/-134.6
		IRI (88-166 MHz)	65.6	3.0	-150.0	-10.0	0	-73.2/-73.2	-164.6/-164.6
		ISR	56.0	--	$-\infty$	0	0	-78.6/-61.1	negligible
		VIS	17.8	-23.0/-5.0	-28.0	0	0	-78.6/-61.1	-111.8+/-76.3+
12	Wildlife Trackers (30-220 MHz)	IRI (30-45 MHz)	65.6	3.0	-80.0	-10.0	0	-73.2/-73.2	-94.6/-94.6
		IRI (45-88 MHz)	65.6	3.0	-120.0	-10.0	0	-73.2/-73.2	-134.6/-134.6
		IRI (88-200 MHz)	65.6	3.0	-150.0	-10.0	0	-73.2/-73.2	-164.6/-164.6
		IRI (200-220 MHz)	65.6	3.0	-120.0	-10.0	0	-73.2/-73.2	-134.6/-134.6
		ISR	56.0	--	$-\infty$	--	0	-78.6/-61.1	negligible
		VIS	17.8	-36.0/-18.0	-28.0	0	0	-78.6/-61.1	-124.8+/-89.3+

+To convert to $dBW/(m^2Hz)$, subtract 33 dBHz (2.0 KHz bandwidth).

Table B-1. HAARP Emitter Power Density Estimates (Continued)

Receiving System No.	Receiving System Name	Emitter	Radiated Power (dBW)	Transmit Directivity (dBi)	Harmonic, etc., Suppression (dB)	Element, Misc. Losses (dB)	Receive Directivity Adjustment (dB)	Free Space Loss Gakona/Clear (dBm^{-2})	Power Density Gakona/Clear ($dBWm^{-2}$)
13	Citizens Band Radio (26.9-27.4 MHz)	IRI	65.6	3.0	-80.0	-10.0	0	-73.2/-73.2	-94.6/-94.6
		ISR	56.0	--	$-\infty$	0	0	-78.6/-61.1	negligible
		VIS	17.8	-38.0/-21.0	-28.0	0	0	-78.6/-61.1	$-126.8^{+}/-92.3^{+}$
14a	Handheld Transceivers (118-174 MHz)	IRI	65.6	3.0	-150.0	-10.0	0	-73.2/-73.2	-164.6/-164.6
		ISR	56.0	--	$-\infty$	0	0	-78.6/-61.1	negligible
		VIS	17.8	-23.0/-5.0	-75.0	0	0	-78.6/-61.1	$-158.8^{+}/-123.3^{+}$
14b	Handheld Transceivers (403-470 MHz)	IRI	65.6	3.0	-120.0	-10.0	0	-73.2/-73.2	-134.6/-134.6
		ISR	56.0	-19.0	0	0	0	-78.6/-61.1	-41.6*/ -24.1*
		VIS	17.8	-14.0/4.0	-85.0	0	0	-78.6/-61.1	$-159.8^{+}/-124.3^{+}$
15	HAARP Scintillation Receiver (240-245 MHz)	IRI	65.6	3.0	-120.0	-30.0 (diff.) -10.0	0	-101.1/-101.1	-192.5/-192.5
		ISR	56.0	--	$-\infty$	0	0	-100.7/-103.1	negligible
		VIS	17.8	-40.0	-81.0	0	0	-100.4/-103.1	$-203.6^{+}/-206.3^{+}$
16a	Radio Telephone (152-158 MHz)	IRI	65.6	3.0	-150.0	-30.0 (diff.) -10.0	0	-94.2/---	-215.6/---
		ISR	56.0	--	$-\infty$	0	0	-94.2/---	negligible
		VIS	17.8	-7.0	-77.0	0	0	-94.2/---	$-160.4^{+}/--$

*To convert to $dBW/(m^2Hz)$, subtract 57 dBHz (0.5 MHz bandwidth assumed).

+To convert to $dBW/(m^2Hz)$, subtract 33 dBHz (2.0 KHz bandwidth assumed).

Table B-1. HAARP Emitter Power Density Estimates (Concluded)

Receiving System No.	Receiving System Name	Emitter	Radiated Power (dBW)	Transmit Directivity (dBi)	Harmonic, etc., Suppression (dB)	Element, Misc. Losses (dB)	Receive Directivity Adjustment (dB)	Free Space Loss Gakona/Clear (dBm^{-2})	Power Density Gakona/Clear ($dBWm^{-2}$)
16b	Radio Telephone (454-460 MHz)	IRI	65.6	3.0	-120.0	-30.0 (diff.) -10.0	0	-94.2/---	-185.6/---
		ISR	56.0	-19.0	-23.0	0	0	-94.2/---	-80.2**/---
		VIS	17.8	-30.0	-87.0	0	0	-94.2/---	-193.4+/--
17a	Pipeline Systems Control (157, 162 MHz)	IRI	65.6	3.0	−150.0	-30.0 (diff.) -10.0	0	-104.1/-110.7	-216.5/-232.1
		ISR	56.0	--	$-\infty$	0	0	-104.1/-111.4	negligible
		VIS	17.8	0/-38.0	-77.0	0	0	-104.1/-111.4	-163.3+/-208.6+
17b	Pipeline Systems VHF Comm. (150-162 MHz)	IRI	65.6	3.0	-150.0	-30.0 (diff.) -10.0	0	-95.1/-110.7	-216.5/-232.1
		ISR	56.0	--	$-\infty$	0	0	-95.1/-111.4	negligible
		VIS	17.8	0/-38.0	-77.0	0	0	-95.1/-111.4	-154.3+/-208.6+
17c	Pipeline Systems UHF Comm. (450-460 MHz)	IRI	65.6	3.0	-120.0	-30.0 (diff.) -10.0	0	-102.7/-110.7	-195.8/-202.1
		ISR	56.0	-19.0	-18.0	0	0	-102.7/-111.4	-85.4**/-92.4**
		VIS	17.8	7.0/-54.0	-86.0	0	0	-102.7/-111.4	-163.9+/-233.6+
18	Terrestrial Microwave (MHz) (5945.2-6093.5) (2126.8, 2176.8) (5975, 6257)	IRI	65.6	3.0	-120.0	-10.0	-60.2/-52.1	-79.7/-81.1	-201.3/-194.6
		ISR	56.0	-28.0	-100.0	0	-60.2/-35.4	-79.7/-89.1	-211.9*/-196.5*
		VIS	17.8	3.0	-109.0/-100.0	0	-60.2/-52.1	-79.7/-89.1	-228.1+/-220.4+

*To convert to $dBW/(m^2Hz)$, subtract 57 dBHz (0.5 MHz bandwidth assumed).

**To convert to $dBW/(m^2Hz)$, subtract 63 dBHz (2.0 MHz bandwidth assumed).

+To convert to $dBW/(m^2Hz)$, subtract 33 dBHz (2.0 KHz bandwidth assumed).

Table B-2. Avionics-Interference Ranges for HAARP Emitters

Receiving System No. 8	Emitter	Radiated Power (dBW)	Transmit Directivity (dBi)	Harmonic, etc., Suppression (dB)	Element Loss (dB)	Relative Receive Gain (dB)	Bandwidth Loss (dB)	System Sensitivity (dBW/m^2)	Space Loss Factor (dBm^{-2})	Separation (km)/(nmi.)
GPS (1227, 1575 MHz)	IRI	65.6	3.0	-120.0	-10.0	-20.0	0	-121.5	-40.1	0.029/0.015
	ISR	56.0	-23.0	-80.0	0	-20.0	0	-121.5	-54.5	0.15 (2)/0.08 (2)
	VIS	17.8	3.0	-95.1	0	-20.0	0	-121.5	-27.2	<<1
VHF Radio (118-137 MHz)	IRI	65.6	3.0	−150.0	-10.0	0	0	-170.5	-79.1	2.5/1.4
	ISR	56.0	--	$-\infty$	0	--	--	-170.5	∞	See (1)
	VIS	17.8	-8.1	-75.0	0	0	0	-170.5	-105.2	51.4/27.8
UHF Radio (960-1215 MHz)	IRI	65.6	3.0	-120.0	-10.0	0	0	-152.2	-90.8	9.8/5.3
	ISR	56.0	-23.0	-80.0	0	0	-22.2	-152.2	-83.0	4.0(2)/2.2(2)
	VIS	17.8	7.7	-93.0	0	0	0	-152.2	-84.7	4.8/2.6
VOR (108-117 MHz)	IRI	65.6	3.0	-150.0	-10.0	0	0	-162.4	-71.0	1.0/0.5
	ISR	56.0	--	$-\infty$	--	--	--	-162.4	∞	See (1)
	VIS	17.8	-5.2	-74.0	0	0	0	-162.4	-101.0	31.8/17.2
ADF (210-530 KHz)	IRI	65.6	--	$-\infty$	--	--	--	-156.6	∞	See (1)
	ISR	56.0	--	$-\infty$	--	--	--	-156.6	∞	See (1)
	VIS	17.8	--	$-\infty$	--	--	--	-156.6	∞	See (1)

(1) Separation is nil; however, interference may occur in the narrow spatial region of the main beam as a result of high out-of-band power densities that saturate the receiver's RF input stage.

(2) In-band interference may be experienced at greater distances if the aircraft passes through the main beam.

lead to distortion or "clipping" of the received signal with the attendant intermodulation products that may affect the receiver's baseband or "output" signal. The severity of this type of interference depends on the user's receiver design. Receivers with preselection filters that remove out-of-band RF energy should not be affected. Such filters can be added to receivers that do not have them in those instances for which out-of-band signals from HAARP emitters are responsible for interference.

B.5.1 IRI Power Density Estimates

Many types of receivers and electronics users have been identified in the Gakona/Clear region. An estimate of the incident IRI RF power density, with supporting rationale, is provided in each case. The incident power density is provided in units of dBW/m^2 rather than dBW/m^2 per Hz, since a CW IRI signal, which can always be fully contained within a receiver's passband, is assumed. This is a worst-case scenario because any modulation of the IRI signal may spread its spectrum beyond the subject receiver's IF passband, thereby diluting the actual received power that competes with the desired signal. Furthermore, certain portions of the HF band will be forbidden to the IRI, as listed in table B-3, to protect priority users, such as Marine Mobile Services, HAMS, etc.

In many instances below, power density estimates depend on characterization of the IRI antenna pattern at frequencies well above the operational band. Unlike a continuous aperture antenna, an array has distinct elements with fixed spacings. As the frequency of array excitation increases, grating lobes occur and eventually proliferate. As the grating lobes multiply, each becomes narrower, so that the total "beam area" of the antenna remains roughly constant. Thus, each grating lobe maintains about the same directivity as the initial single beam that the array is designed to produce (of course, grating lobes near endfire have much less directivity due to scan broadening; in a more precise treatment, the total beam efficiency is the conserved quantity — not beam area.). As the frequency continues to increase, however, random amplitude and phase errors in the illumination, such as are incurred by element positional errors and component tolerances, become more significant, first reducing the grating lobe peaks and eventually diffusing all of the grating lobe energy into a highly chaotic pattern of random sidelobes. Since there is no main beam, the mean

Table B-3. Distress, Calling and Guarded Frequencies Avoided by the IRI

Frequency (MHz)	Allocated Services
2.706 ± 0.002	Emergency Net - Atlantic and Pacific
3.023 ± 0.002	Search and Rescue (SAR) Control - Atlantic and Pacific
4.050 ± 0.002	Emergency Net - Atlantic and Pacific
5.000 ± 0.005	Standard Frequency
5.320 ± 0.005	International Ice Patrol
5.680 ± 0.020	SAR Control - Atlantic and Pacific
5.6814 ± 0.020	SAR Control - Atlantic and Pacific
6.204 ± 0.020	SAR Control - Atlantic and Pacific
6.2054 ± 0.020	SAR Control - Atlantic and Pacific
6.273 ± 0.010	Aircraft Comm. to Maritime Mobile Stations
7.5084 ± 0.020	Hurricane Warning Net
7.530 ± 0.020	Emergency Net - Atlantic and Pacific
8.364 ± 0.020	SAR Control - Atlantic and Pacific
8.502 ± 0.005	International Ice Patrol
8.7564 ± 0.005	International Ice Patrol
10.000 ± 0.005	Standard Frequency

Note: Bandwidths are representative

level of the random sidelobes is, in fact, the isotropic level. Pattern excursions above the mean level are typically limited to several dB.

The breakup of grating lobes and the overall degradation of the out-of-band pattern with increasing frequency can be greatly accelerated by use of known, randomly selected transmitter-to-element feed lines lengths. The elemental phase shifters can be used to compensate for the line lengths at the desired operational frequency, while the signals at the out-of-band frequencies do not arrive in phase at the elements. This technique is commonly used to eliminate systematic quantization errors otherwise incurred by digital phase shifters. From the point of view of interference abatement or avoidance, randomization of the out-of-band patterns to eliminate large lobes of concentrated, unintended emissions is very effective.

Array elements are designed to operate most efficiently within the operational band of the system (2.8 to 10 MHz for the IRI). Element radiation efficiency suffers considerably as the excitation frequency is increased beyond the band limits. Thus, much out-of-band energy produced by the transmitter, such as harmonics, is ultimately dissipated in the antenna feed cables. An efficiency loss of 10 dB will be assumed where appropriate in most of the power density estimates that follow.

All parameters that are used in these computations are summarized along with the results in tables B-1 and B-2.

B.5.1.1 Cellular Telephones

Cellular telephones, which operate in the 870- to 890-MHz frequency range, are located in vehicles that may pass as close as 0.8 miles (1.29 km) to the IRI. Harmonics that would enter the cellular telephone band must be suppressed by at least 120 dB, in accordance with the IRI specification. Azimuthal radiation patterns computed at HF frequencies (e.g., figure B-7) cannot be used at UHF frequencies. At such high frequencies, the IRI patterns will be dominated by the effects of random phase and amplitude errors and will, therefore, be completely chaotic. The IRI will be modeled as a lossy or inefficient isotropic radiator of

UHF energy with a mean directivity of 3.0 dB over the upper hemisphere. The average power density 1,290 m from the array will be no greater than 65.6 dBW (3.6 MW) + 3 dBi - 120 dB - 10 dB (element loss) - 73.2 dBm^2$\left[-10\ \log\left(4\pi r^2\right)\right] = -134.6\ \mathrm{dBW/m^2}$. Note that for random patterns there is no need to distinguish between the near and far fields.

B.5.1.2 HAARP Riometer

The HAARP Riometer is a 38.2-MHz imaging array that will be situated about 10 miles (16.1 km) from the IRI. The principal mode of interference will be via the direct path, since skywave propagation is negligible at 38.2 MHz. The radiation pattern of the IRI would contain about 29 grating lobes at 38.2 MHz if pattern randomization, as described in B.3.5.1, were not used. With randomization, grating lobes are prevented, and the harmonic energy is much more uniformly distributed over the upper hemisphere. The power is received in the far sidelobe of the riometer, which is taken to be -15 dBi. Since the riometer directivity is 28.5 dBi, the relative sidelobe level is -43.5 dB. Since the system sensitivity calculation of appendix A is based on the full riometer gain, the effective power density at the riometer must be reduced by the relative sidelobe level. In addition, 80 dB of harmonic suppression is specified. The effective power density at the riometer is, therefore 65.6 dBW + 3.0 dB (mean directivity) - 80 dB - 43.5 dB - 10 dB (element inefficiency) - 95.1 dBm^2 = -160.0 dBW/m^2.

B.5.1.3 Satellite Communications

Direct broadcast satellite receiving antennas may be as close as 0.5 miles (0.8 km) to the IRI. These systems operate at either C-band (5.9-6.9 GHz) or Ku-band (12.5-12.75 GHz). As discussed under "Cellular Telephones," the IRI can be viewed as a semi-isotropic radiator (3-dB mean directivity) at these very-high, out-of-band frequencies. The 120 dB of harmonic suppression applies in these cases, and, since the receiving dishes are not pointed at the IRI, -10 dBi directivity will be assumed (this corresponds to an off-axis angle of 20-25° for a 1.6 m-diameter dish). Separations of 6 miles and 0.5 miles are used for Gakona and Clear, respectively. The C-band and Ku-band power density estimates are

a. C-band, Gakona: 65.6 dBW + 3.0 dBi (mean directivity) - 120 dB - 90.7 dBm^2 - 49.6 dB (peak-referenced dish gain) - 10 dB (element efficiency) = -201.7 dBW/m^2.

b. C-band, Clear: 65.6 dBW + 3.0 dBi - 120 dB - 69.1 dBm^2 - 49.6 dB - 10 dB = -180.1 dBW/m^2.

c. Ku-band, Gakona: 65.6 dBW + 3.0 dBi - 120 dB - 90.7 dBm^2 - 57.1 dB (peak-referenced dish gain) - 10 dB (element efficiency) = -209.2 dBW/m^2.

d. Ku-band, Clear: 65.6 dBW + 3.0 dBi - 120 dB - 69.1 dBm^2 - 57.1 dB - 10 dB = -187.6 dBW/m^2.

B.5.1.4 HF Communications

Since HF communications share much of the 2.8- to 10-MHz band with the IRI, interference may occur. The principal mode of interference is via skywave propagation. As a simple example, consider IRI operation at 8 MHz and 30° scan from the zenith. With E-layer refraction at 100 km altitude, the center of the main beam footprint is approximately 115 km distant, with the first outboard sidelobe falling about 200 km away. The IRI scan loss at 30° scan is negligible. The ERP at 8 MHz is 95.4 dBW and the skywave path length is 230 km for the main beam and 280 km for the first outboard sidelobe. Assuming a 5-dB absorption loss in the ionosphere. the incident power density levels at 30° scan are estimated to be (in IRI band, skywave):

a. main beam: 95.4 dBW - 5 dB - 118.2 dBm^2 = -27.8 dBW/m^2
b. first outboard sidelobe: 82.2 dBW - 5 dB - 119.9 dBm^2 = -42.7 dBW/m^2

These values are representative of all scan angles within 30°. For HF users operating above the IRI band, i.e., above 10 MHz, the harmonic suppression and spurious signal suppression factor of 80 dB may be applied, and pattern randomization reduces the directivity in the upper hemisphere to about 3 dBi. The direct path power density estimates are (above 10 MHz, direct wave):

a Gakona, 2 miles: 65.6 dBW + 3.0 dBi - 80 dB - 10 dB (element loss) -81.1 dBm^2 = -102.5 dBW/m^2.

b. Clear, 0.5 mile: 65.6 dBW + 3.0 dBi - 80 dB - 10 dB - 69.1 dBm^2 = -90.5 dBW/m^2.

The footprint of the main beam and principal sidelobes move about as the beam is scanned, covering a broad area. Even when the main beam is directed straight overhead, its 3 dB power contour encloses 209 and 2,700 km^2 at 10 and 2.8 MHz, respectively.

B.5.1.5 Television Broadcast

The region of the proposed HAARP site is served by television broadcasts in the 54- to 216-MHz frequency band. Television viewers may lie as close as 0.5 miles (0.8 km) to the IRI. IRI harmonics and spurious signals that could interfere with television reception must receive 150 dB of suppression within the 88 to 200 MHz band and 120 dB of suppression elsewhere (within the television band). The average response of the IRI antenna at far-out-of-band frequencies is modelled as that of a semi-isotropic radiator with 3 dBi directivity. A 10 dB loss is applied for IRI inefficiency at the television frequencies. The estimated power density is:

a. Gakona, 2 miles (3.2 km), 88-200 MHz: 65.6 dBW + 3.0 dBi - 150 dB - 10 dB - 81.1 dBm^2 = -172.5 dBW/m^2.

b. Gakona, 2 miles (3.2 km), 54-88 MHz, 200-216 MHz: 65.6 dBW + 3.0 dBi - 120 dB - 10 dB - 81.1 dBm^2 =-142.5 dBW/m^2.

c. Clear, 0.5 miles (0.8 km), 88-200 MHz: 65.6 dBW + 3.0 dBi - 150 dB - 10 dB - 69.1 dBm^2 = -160.5 dBW/m^2.

d. Clear, 0.5 miles (0.8 km), 54-88 MHz, 200-216 MHz: 65.6 dBW + 3.0 dBi - 120 dB - 10 dB - 69.1 dBm^2 = -130.5 dBW/m^2.

B.5.1.6 AM Radio Broadcast

AM radio broadcast occupies the 0.535- to 1.7-MHz band. The nearest listeners lie in dwellings as close as 0.5 miles (0.8 km) to the IRI antenna. According to the specification, the IRI should not produce appreciable subharmonics in the AM band. However, the IRI's HF signal may be sufficiently strong to overload the "front-end" amplifiers of nearby AM receivers. When this occurs, the intermodulation products generated may interfere with reception. Prefiltering the signal at the AM radio can eliminate such out-of-band interference.

B.5.1.7 FM Radio Broadcast

FM radio broadcast occupies the 88- to 108-MHz frequency band, and, therefore, any IRI harmonics that lie in this band must be suppressed by at least 150 dB. The nearest listeners are 0.5 miles (0.8 km) away. Treating the IRI as a semi-isotropic radiator (3.0 dBi mean directivity) the power density at minimum separation from the array is estimated to be:

a. Gakona: 65.6 dBW + 3.0 dBi - 150 dB - 10 dB (element inefficiency) - 81.1 dBm^2 = -172.5 dBW/m^2.

b. Clear: 65.6 dBW + 3.0 dBi - 150 dB - 10 dB - 69.1 dBm^2 = -160.5 dBW/m^2.

B.5.1.8 Avionics

A total of five types of avionics have been considered, as described below. In each case the distance to the IRI at which the interference has a power density equal to the threshold level of table 2 of appendix A is estimated.

B.5.1.8.1 Global Positioning System (GPS)

The GPS operates at 1,227 and 1,575 MHz — very far outside of the IRI band. The maximum specified harmonic suppression of 120 dB is assumed, as well as a 10-dB loss for IRI element inefficiency at GPS frequencies. The GPS antenna is a small patch mounted atop the aircraft; therefore, its response to ground-based sources is very weak, and will be assumed to be -20 dB (peak referenced). The receiving system sensitivity, from table A-2 of appendix A, is -121.5 dBW/m^2. The space loss required to equal this level is 65.6 dBW - 120 dB + 3.0 dBi - 10 dB - 20 dB + 121.5 dBW/m^2 = 40.1 dBm^2. This space loss factor represents a separation of only 28.5 m. This result is also applicable to ground-vehicle-mounted GPS receivers that employ a roof-top patch antenna. Essentially, the small estimated separation distance indicates that the IRI will not interfere with the GPS.

B.5.1.8.2 VHF Radio

The aircraft radio band extends from 118 to 137 MHz. The IRI harmonics that may enter this band will be suppressed by at least 150 dB relative to the fundamental radiated power of the array. A nominal loss of 10 dB is applied to account for element inefficiency at VHF. The receiving system sensitivity, from table A-2 of appendix A is -170.5 dBW/m^2. The space loss needed to match this level is 65.6 dBW + 3.0 dBi - 150 dB - 10 dB + 170.5 dBW/m^2 = 79.1 dBm^2, which corresponds to a separation of 2.5 km. (1.4 nmi.)

B.5.1.8.3 UHF Radio

UHF radios used aboard aircraft operate in the 960- to 1215-MHz band. The IRI harmonics that enter this band will be reduced by 120 dB with respect to the fundamental power (65.6 dBW). In addition, a nominal loss of 10 dB is assumed to account for the inefficiency of the IRI element at UHF frequencies. The receiving system sensitivity, from table A-2 of appendix A is -152.2 dBW/m^2. The space loss needed to produce this power density level at the aircraft is 65.6 dBW + 3.0 dBi - 120 dB - 10 dB + 152.2 dBW/m^2 = 90.8 dBm^2, which represents a separation from the IRI of 9.8 km (5.3 nmi.).

B.5.1.8.4 VOR Receivers

VOR transmitters in the vicinity of the proposed sites operate between 108 and 117 MHz, which is just above the FM broadcast band. The IRI harmonics at these frequencies must lie 150 dB or more below the fundamental power. Furthermore, an efficiency loss of 10 dB is assumed for the IRI element at VHF. The VOR receiving system sensitivity, from table A-2 of appendix A, is -162.4 dBW/m^2. The space loss factor that would produce this power density level at the aircraft is 65.6 dBW + 3.0 dBi - 150 dB - 10 dB + 162.4 dBW/m^2 = 71.0 dBm^2, which represents a 1.0 km (0.5 nmi.) separation from the IRI.

B.5.1.8.5 ADF

ADFs aboard aircraft operate between frequencies of 210 and 530 kHz. Comments under B.5.1.6, "AM Radio," are also applicable to ADF receivers.

B.5.1.9 Cardiac Pacemakers

An accepted interference threshold for cardiac pacemakers is a field strength of 200 V/m or, plane-wave-equivalent 100 W/m^2 (20 dBW/m^2) power density. Furthermore, the pacemaker electronics are mainly sensitive to pulsed signals. Since the IRI will have pulsed waveform capability, the potential for pacemaker interference is a serious consideration. Power density versus azimuth angle plots based on the IRI near-field model are displayed in figure B-7. Even 250 m from the center of the array, the power density will not exceed -19 dBW/m^2 (0.013 W/m^2). Power density versus azimuth plots computed for 0.8 mile and 0.5 mile radial separation from the IRI yield peak power estimates of 1.4×10^{-4} W/m^2 and 3.4×10^{-5} W/m^2 for the Clear and Gakona sites, respectively. Similar predictions are obtained at other in-band frequencies. To incur risk, a pacemaker user would likely have to walk to the very edge of the array. A hazard fence, with appropriate warnings, will discourage this.

As illustrated in figure B-4, power densities can rise to 100 W/m^2 or so above the center of the IRI; however, this peak power density obtains over a relatively small region of space. To enter this space, the pacemaker user would have to occupy an aircraft, which, in most cases, would provide adequate shielding.

B.5.1.10 EEDs

Two types of EEDs are considered here: "exposed" (ready for use, e.g., blasting caps) and "in metal containers." Exposed EEDs should not be subjected to power densities greater than 10^{-2} W/m^2 (-20 dBW/m^2). Power densities approximately 0.5 mile from the array are predicted to be well below 10^{-3} W/m^2, as discussed in B.5.1.9. An EED user would have to walk to within 250 m of the array center (~30 m from an array corner) to compromise his safety with an exposed device, as implied in the upper plot of figure B-7.

For EEDs in metal containers, the safety threshold is well in excess of 100 W/m^2. As discussed under paragraph B.5.1.9, the near-field peak power density is ~100 W/m^2 above the array, so that flying over the antenna with EEDs in metal containers would pose no risk. In view of the sensitivity of exposed EEDs, those being transported via aircraft should always be stored in metal containers.

B.5.1.11 Mobile VHF Radio

Mobile VHF radios operate in the 38- to 166-MHz frequency range in the region of the proposed sites. At both Gakona and Clear, a road passes 0.8 mile from the proposed IRI. For that portion of the VHF band that lies below 45 MHz, 80 dB of harmonic and spurious signal suppression is assumed, while the more stringent 120 dB specification value is adopted between 45 and 88 MHz. Above 88 MHz, 150 dB of harmonic and spurious signal suppression is assumed. In the VHF band, the IRI pattern is modeled as that of a semi-isotropic radiator with 3.0 dBi directivity. Since the IRI pattern is chaotic and randomized at high, out-of-band frequencies, the distinction between the near field and far field is lost. While chaotic patterns may contain lobes that rise well above the isotropic level, their occurrence is unlikely. The power density estimates are as follows:

a. Below 45 MHz: 65.6 dBW + 3.0 dBi - 80 dB - 10 dB - 73.2 dBm^2
= -94.6 dBW/m^2.

b. Between 45 and 88 MHz: 65.6 dBW + 3.0 dBi - 120 dB - 10 dB - 73.2 dBm^2 = -134.6 dBW/m^2.

c. Above 88 MHz: 65.6 dBW + 3.0 dBi - 150 dB - 10 dB - 73.2 dBm^2 = -164.6 dBW/m^2.

Above, a 10-dB loss is applied in all cases for IRI element inefficiency at VHF, and the 73.2 dB space loss factor is based on a 0.8 mile (1.3 km) IRI-to-mobile-radio separation.

B.5.1.12 Wildlife Trackers

Wildlife tracking receivers operate in the 30- to 220-MHz band, which lies well above the operational band of the IRI. The IRI pattern is modeled as that of a semi-isotropic radiator, i.e., as a source of uniformly radiated power in the upper hemisphere (3.0 dBi directivity). The following power density estimates are distinguished by the amount of harmonic and spurious signal suppression that is specified within the respective frequency ranges:

a. below 45 MHz: 65.6 dBW + 3.0 dBi - 80 dB (harmonic suppression) - 10 dB - 73.2 dBm^2 = -94.6 dBW/m^2.

b. between 45 and 88 MHz: 65.6 dBW + 3.0 dBi - 120 dB (harmonic suppression) - 10 dB - 73.2 dBm^2 = -134.6 dBW/m^2.

c. between 88 and 200 MHz: 65.6 dBW + 3.0 dBi - 150 dB (harmonic suppression) - 10 dB - 73.2 dBm^2 = -164.6 dBW/m^2.

d. above 200 MHz: 65.6 dBW + 3.0 dBi - 120 dB (harmonic suppression) - 10 dB - 73.2 dBm^2 = -134.6 dBW/m^2.

A separation distance of 0.8 miles (1.3 km) was used to compute the space loss and a 10 dB loss is taken for IRI element inefficiency.

B.5.1.13 Citizens Band Radio

Citizens band radio operates between 26.9 and 27.4 MHz, at the upper end of the HF spectrum. The principal interference path in this band is the direct path, since the skywave will contribute only at shallow take-off angles. Citizens band users in Gakona or Clear only 0.8 mile away in line of sight from the IRI (worst case) are considered. Treating the IRI as a semi-isotropic radiator with 3.0-dBi directivity, the power density estimate is 65.6 dBW + 3.0 dBi - 80 dB (harmonic suppression) - 10 dB (element inefficiency) - 73.2 dBm^2 = -94.6 dBW/m^2.

Skywave propagation could be a factor at very low take-off angles, i.e., at very long ranges. The calculation follows that given above; however, a space loss factor for a typical distance of 1,000 km (-131 dB) yields a power density of -152.4 dBW/m^2.

B.5.1.14 Handheld Transceivers

Handheld transceivers, as are commonly used in the HAARP study area, operate in both the VHF (118-174 MHz) and the UHF (403-470 MHz) frequency bands. IRI emissions that are harmonics of the HF fundamental will enter these bands; however, at least 150 dB of suppression is required in the VHF case and at least 120 dB of suppression is required in the UHF case. The IRI is modeled as an isotropic radiator in the upper hemisphere (3.0-dBi directivity), and a 10-dB loss is taken for inefficiency of the HF elements at VHF and UHF frequencies. The direct path power 0.8 mile from the IRI, is therefore: 65.6 dBW + 3.0 dBi - 150 dB - 10 dB - 73.2 dBm^2 = -164.6 dBW/m^2 for the VHF band, and -134.6 dBW/m^2 (30 dB less harmonic and spurious suppression) for the UHF band.

B.5.1.15 HAARP Scintillation Receiver

The HAARP scintillation receiver will operate between 240 and 245 MHz at a distance of approximately 20 miles (32 km) from the IRI. A 120-dB loss is taken for harmonic suppression and a 10-dB loss is applied for poor IRI element efficiency at VHF. At a 20-mile separation, a direct path between the IRI and Scintillation receiver is unlikely, and a 30-dB diffraction loss is, therefore, applied. At VHF the IRI is modeled as an isotropic radiator in the upper hemisphere (3.0-dBi directivity). The power density incident at the scintillation receiver is estimated to be 65.6 dBW + 3.0 dBi - 120 dB - 10 dB - 30 dB (diffraction loss) - 101.1 dBm^2 = -192.5 dBW/m^2.

B.5.1.16 Radio Telephone

Radio telephone transmissions occupy both the VHF (152-158 MHz) and UHF (454-460) frequency bands. A 150-dB loss is applied for harmonic suppression at VHF and a 120 dB loss is applied for harmonic suppression at UHF. A 10-dB loss is taken for IRI element inefficiency at VHF and UHF. Given the large separation between the radio telephone receivers and the IRI, line of sight interference is unlikely, and a 30-dB diffraction loss is therefore assumed.

a. Gakona, 9 miles (14.5 km): 65.6 dBW + 3.0 dBi - 150 dB - 10 dB - 30 dB (diffraction loss) - 94.2 = -215.6 dBW/m^2 (VHF), 185.6 dBW/m^2 (UHF).

b. Clear: no radiotelephone users have been identified in the Clear area.

B.5.1.17 Alaska Pipeline Systems

Alaska pipeline remote control and maintenance systems employ both the VHF (150-162 MHz) and UHF (450-460 MHz) frequency bands. Since these bands lie well above that of the IRI, at least 120 dB (UHF) and 150 dB (VHF) of harmonic and spurious power suppression is assumed, as well as 10 dB of element loss due to inefficiency. Located 10 miles or more from the IRI, these systems are not likely to be subject to line-of-sight interference. A diffraction loss of -30 dB is, therefore, applied in each of the cases below.

a. Remote Control and VHF Maintenance, Gakona, 10 mile (16.1 km) separation: 65.6 dBW + 3.0 dBi - 150 dBi - 10 dB - 30 dB - 95.1 dBm^2 = -216.5 dBW/m^2.

b. UHF Maintenance, Gakona, 29 mile (46.7 km) separation: 65.6 dBW + 3.0 dBi - 120 dBi - 10 dB - 30 dB - 104.4 dBm^2 = -195.8 dBW/m^2.

c. Remote Control, VHF Maintenance, Clear, 60 mile (96.6 km) separation:
65.6 dBW + 3.0 dBi - 150 dB - 10 dB - 30 dB - 110.7 dBm^2 = -232.1 dBW/m^2.

d. Remote Control, UHF Maintenance, Clear, 60 mile (96.6 km) separation:
65.6 dBW + 3.0 dBi - 120 dB - 10 dB - 30 dB - 110.7 dBm^2 = -202.1 dBW/m^2.

B.5.1.18 Terrestrial Microwave

The Alascom Tower, which supports terrestrial microwave communications between 5,945 and 6,094 MHz, lies 1.7 miles from the proposed IRI site at Gakona. At Clear, a microwave tower that operates at 2126.8 and 2176.8 MHz lies 2 miles from the proposed IRI site. Since both microwave bands lie well above the IRI band, 120 dB of harmonic and spurious signal suppression, and 10 dB of element loss may be applied to the IRI emissions. The 8-ft diameter dish antennas used for terrestrial microwave communications are highly directive. With the generic dish pattern model of section B.3, the peak-referenced gain of the microwave antennas in the direction of the IRI can be estimated for each site. At Gakona, the site is about 45° off broadside, while at Clear the site is in the dish's backlobes. Since the peak dish gain is employed in the system sensitivity calculation, the relative gain is taken into account below in the "effective" power density calculation:

a. Gakona, 1.7 miles (Alascom Tower): 65.6 dBW + 3.0 dBi - 120 dB - 10 dB - 60.2 dB (relative gain) - 79.7 dBm^2 = -201.3 dBW/m^2.

b. Clear, 2 miles: 65.6 dBW + 3.0 dBi - 120 dB - 10 dB - 52.1 dB (relative gain) -81.1 dBm^2 = -194.6 dBW/m^2.

B.5.2 ISR Power Density Estimates

Many types of receivers and electronics users have been identified in the Gakona/Clear region. An estimate of the incident ISR power density, with supporting rationale, is provided in each case. The incident power density is given in units of $dBW/(m^2Hz)$, under the assumption that the power is uniformly spread over a nominal 0.5 MHz-wide spectrum. Unlike the IRI, the ISR does not offer a CW mode, but, rather, will mainly employ pulsed waveforms. Maximum instantaneous bandwidth is specified as ±1 MHz, and the turnable transmit band lies between 444 and 446 MHz.

B.5.2.1 Cellular Telephones

Cellular telephones, which operate in the 870- to 890-MHz frequency range, may be located in vehicles that can pass as close as 0.2 miles (0.32 km) to the ISR. Although design specifications have not yet been established for the ISR transmitter, 80-dB suppression of the first harmonic, which may enter the cellular telephone band, is deemed to be practical. The average radiated power of the ISR will be 0.4 MW (56 dBW), and the sidelobe level 60° off axis (30° tilt towards user assumed) is -21.4 dBi, based on the model described in section B.3. The space loss factor $\left[-10 \log\left(4\pi r^2\right)\right]$ 320 m from the dish is -61.1 dBm^{-2}. The estimated power density at the nearest cellular telephone at Clear is, therefore, 56 dBW - 80 dB (harmonic suppression) - 21.4 dBi - 61.1 dBm^2 = -106.5 dBW/m^2 in the 0.5 MHz bandwidth, or -163.5 dBW/(m^{2}Hz). If the dish is directed towards the zenith, the sidelobe level is 1.7 dB lower, yielding -165.2 dBW/(m^{2}Hz). At Gakona, the ISR-user minimum separation is 1.5 miles (2.4 km), which yields a space loss of -78.6 dBm^2 and power density of -124.0 dBW/m^2 or -181.0 dBW/(m^{2}Hz).

B.5.2.2 HAARP Riometer

The HAARP riometer is a 38.2 MHz imaging array located approximately 10 miles (16.1 km) from the ISR. If the ISR transmitter is properly designed, subharmonics that lie in the riometer's band will be negligible. However, there is the possibility that the UHF emissions of the ISR could overload the "front end" of the riometer's receiver, generating intermodulation products that may lie within the receiver's passband and degrade performance. If such interference were to occur, the signal entering the riometer receivers would have to be prefiltered.

B.5.2.3 Satellite Communications

Direct broadcast satellite receiving antennas at Clear are as close as 1 mile (1.6 km) to the ISR, while at Gakona the corresponding figure is 6 miles (10 km). These systems operate at either C-band (5.9-6.9 GHz) or Ku-band (12.5-12.75 GHz). Higher order ISR harmonics may enter the lower band. Although design specifications have not been established for the ISR, 100-dB suppression of the high order harmonics that may enter the lower satellite communication band is deemed to be practical. The average radiated power of the ISR will be 0.4 MW (56 dBW), and the sidelobe level of the ISR antenna dish 60° off axis (30° tilt towards user is assumed) is -27.9 dBi at C-band, as derived from the pattern model of section B.3. The relative receive sidelobe level is -49.6 dB (peak referenced) for a 1.6 m dish 20°-25° off broadside. The estimated effective power densities at the nearest C-band satellite receiver dishes are, therefore

a. Gakona: 56 dBW - 100 dB - 27.9 dBi - 49.6 dB - 90.7 dBm^2 = -212.2 dBW/m^2 or -269.2 $dBW/(m^2\ Hz)$.

b. Clear: 56 dBW - 100 dB - 27.9 dBi - 49.6 dB - 75.1 dBm^2 = -196.6 dBW/m^2 or -253.6 $dBW/(m^2\ Hz)$.

Non-harmonic spurious emissions at Ku-band are assumed to be negligible.

B.5.2.4 HF Communications

The HF communications band (2-30 MHz) lies well below the band in which the ISR will transmit (444-446 MHz). If the ISR transmitter is properly designed, subharmonics that lie in the HF band will be negligible. However, there is the possibility that the UHF emissions of the ISR could overload the "front end" of HF receivers, generating intermodulation products that may lie within the receiver's passband. If such interference does occur, prefiltering at the receiver may be used to remove the UHF signal.

B.5.2.5 Television Broadcast

The region of the HAARP site is served by television broadcasts in the 54- to 216-MHz frequency band. Television viewers may lie as close as 1 mile (1.6 km) to the ISR antenna. A properly designed ISR transmitter should not produce appreciable subharmonics within the television band. However, ISR emissions at UHF may be sufficiently powerful to overload the "front-end" amplifiers of television receivers, in which case the intermodulation products generated could interfere with reception. Under these circumstances, prefiltering of the television signal at the receiver would be necessary.

B.5.2.6 AM Radio Broadcast

AM Radio broadcasts occur in the 0.535- to 1.7-MHz band. The nearest listeners lie in dwellings as close as 0.2 mile (0.32 km) to the ISR antenna. As in the case of TV broadcast, the ISR should not produce appreciable subharmonics in the AM band. However, the ISR's UHF signal may be sufficiently strong to overload the "front-end" amplifiers of nearby AM receivers. When this occurs, the intermodulation products generated may interfere with reception. A simple prefilter, inserted between the antenna leads and antenna input terminals of the AM radio (e.g., automobile radio) can eliminate such out-of-band interference.

B.5.2.7 FM Radio Broadcasts

FM radio broadcast occupies the 88- to 108-MHz frequency band, which lies well below that of the ISR. While FM radio reception is generally for less susceptible to interference than AM radio reception, observations made under B.5.2.6 are applicable here.

B.5.2.8 Avionics

A total of five types of common avionics have been considered, as described below. Where applicable, the distance of aircraft approach to the IRI at which interference may start to become "significant" is provided.

B.5.2.8.1 GPS

The GPS operates at 1,227-MHz and 1,575-MHz frequencies, which lie outside the second (888-892 MHz), third (1332-1338 MHz), and fourth (1776-1784 MHz) ISR harmonic bands. However, spurious components of the ISR transmit spectrum may occur at GPS frequencies. Although design specifications have not been established for the ISR, 80 dB of spurious signal suppression is deemed to be desirable and practical. The average radiated power of the ISR will be 0.4 MW (56.0 dBW), and at 1,227 MHz the far sidelobes of the ISR dish are about 23 dB below isotropic. The GPS antenna is a small patch mounted atop the aircraft; therefore, its response to ground-based sources is very weak. A peak-referenced far sidelobe level of -20 dB is assumed for the GPS patch. The receiving sensitivity, from table 2 of appendix A, is -121.5 dBW/m^2. The ISR signal bandwidth of 0.5 MHz is well within the 2.1 MHz basebandwidth of the GPS receiver. The space loss required to achieve -121.5 dBW/m^2 (sensitivity threshold) at the aircraft is 56.0 dBW - 80 dB - 23 dBi - 20 dB + 121.5 dBW/m^2 = 54.5 dBm^2. This corresponds to an aircraft-to-ISR separation of 150 m. While this result implies that the ISR will not interfere with the GPS, the very narrow spatial region corresponding to the main beam and close-in sidelobes of the dish may cause interference should an aircraft pass through them. For GPS-equipped vehicles on the ground that employ roof-top-mounted patch antennas, however, the beam is inaccessible and the above result is always applicable.

B.5.2.8.2 VHF Radio

The VHF radio band extends from 118 to 137 MHz, which is well below that of the ISR. If competently designed and manufactured, the ISR transmitter will not produce appreciable subharmonics that would directly interfere with VHF radio. However, a sufficiently strong UHF signal can overload the front-end amplifier of a VHF receiver. When this occurs, intermodulation products may interfere with the desired signal. Such interference is most likely when an aircraft passes through the beam and close-in sidelobes of the ISR antenna. Such indirect interference can be eliminated by prefiltering the signal at the output terminals of the VHF radio's antenna (or other suitable location that precedes the radio's RF amplifier).

B.5.2.8.3 UHF Radio

UHF radios used aboard aircraft operate in the 960- to 1,215-MHz band, which lies between the second (888-892 MHz) and the third (1332-1338 MHz) ISR harmonic bands. However, spurious components of the ISR transmit spectrum may enter the UHF band. While design specifications have not been established for the ISR transmitter, 80 dB of spurious signal suppression is considered to be practical. At 1,090 MHz, the ISR antenna's far sidelobes will be about 23 dB below isotropic. With an average radiated power of 56 dBW and UHF receiver sensitivity of -152.2 dBW/m^2, the space loss factor needed to yield a power density at the aircraft equal to the receiver sensitivity is 56 dBW - 80 dB - 23 dBi + 152.2 dBW/m^2 = 105.2 dBm^2. Since the basebandwidth of the UHF receiver is 3 kHz and the ISR spectral bandwidth is a much wider 0.5 MHz, the sensitivity, and hence the space loss, must be reduced by the bandwidth ratio of 22.2 dB to yield 83.0 dBm^2. The corresponding aircraft — ISR separation is 4 km (2.2 nmi.).

B.5.2.8.4 VOR Receivers

VOR transmitters in the vicinity of the proposed sites operate between 108 and 117 MHz. Comments under B.5.2.8.2, "VHF Radios," are also applicable to VOR receivers.

B.5.2.8.5 ADF

ADFs aboard aircraft operate between frequencies of 210 and 530 kHz. Comments under B.5.2.8.2, "VHF Radios," are also applicable to ADF receivers.

B.5.2.9 Cardiac Pacemakers

An accepted interference threshold for cardiac pacemakers is a field strength of 200 V/m or 100 W/m^2 (20 dBW/m^2) power density. Since pacemakers are mainly sensitive to pulsed signals, the potential for interference by the ISR's pulsed waveform is a serious consideration. The average radiated power of the ISR is 0.4 MW. With the dish pointed 30° from the zenith, the median sidelobe level in the horizontal direction is approximately -19 dBi. Minimum separation distances vary from 1.5 miles (2.4 km) at Gakona to 0.2 mile (0.32 km) at Clear. The corresponding power density estimates are 6.9×10^{-5} $\mathrm{W/m^2}$ (Gakona) and 3.9×10^{-3} $\mathrm{W/m^2}$ (Clear) — in both cases well below the threshold.

The nominal power density obtained by dividing the radiated power by the aperture area (1,000 m^2) is 400 W/m^2. In accordance with the discussion in B.2.3, the peak axial power density will occur about 650 m from the dish and be about 1,200 W/m^2. Close to the dish the power density is far less and rolls off rapidly with displacement parallel to the plane of the aperture.

On the earth surrounding the dish, spillover energy from the feed is of concern. Assuming that 10% of the RF energy from the dish feed spills over into a 10° wide conical fan at the edge of the dish, the power density incident on the earth is only about 12 W/m^2, which is far below the threshold of 100 W/m^2 for cardiac pacemakers. This estimate is probably too large, since the dish will be designed to minimize personnel hazard, for which the threshold at 400 MHz is 13 W/m^2 (AFOSH Standard 161-9, 12 February 1987) for a six-minute exposure.

B.5.2.10 EEDs

Two types of EEDs are considered: "exposed" (ready for use, e.g., blasting caps) and "in metal containers." Exposed EEDs should not be subjected to power densities greater than 10^{-2} $\mathrm{W/m^2}$. With reference to B.5.2.9, "Cardiac Pacemakers," power densities 1.5 miles (Gakona) and 0.2 mile (Clear) from the ISR dish are predicted to be 6.9×10^{-5} $\mathrm{W/m^2}$ and 3.9×10^{-3} $\mathrm{W/m^2}$, respectively. In both cases, the power density is well below threshold.

For EEDs in metal containers, the safety threshold is <u>well in excess</u> of 100 $\mathrm{W/m^2}$. As discussed under B.5.2.9, peak power densities along the main axis of the dish may achieve such levels; however, no other location will experience these power densities.

B.5.2.11 Mobile VHF Radio

Mobile VHF radios operate in the 38- to 166-MHz frequency range in the areas of the proposed sites. This band is well below the ISR band and should not contain appreciable RF energy from the ISR if the transmitter is well designed. VHF receiver saturation or overload is possible if the UHF signal has sufficient power. The impact of this type of out-of-band interference depends on the receiver design. Receivers with preselection filters, which filter the RF signal before amplification, would not be affected. If serious interference occurs, filters may have to be added at the antenna input leads of receivers that do not have them.

B.5.2.12 Wildlife Trackers

Wildlife trackers use receivers that operate in the 30- to 220-MHz band, which lies well below the ISR band. Comments under B.5.2.11, "Mobile VHF Radios," are applicable here.

B.5.2.13 Citizens Band Radio

Citizens Band radio receivers operate in the 26.9 to 27.4 MHz band, well below the ISR band. Comments under B.5.2.11, "Mobile VHF Radios," are applicable here.

B.5.2.14 Handheld Transceivers

Handheld transceivers, which are commonly used in the HAARP study area, operate in both the VHF (118-174 MHz) and the UHF (403-470 MHz) frequency bands. Comments under B.5.2.11, "Mobile VHF Radios," are applicable to those handheld transceivers that operate in the VHF band. Those that operate in the UHF band share the frequency range from 444 to 446 MHz with the ISR. The radiated power of the ISR is 0.4 MW (56 dBW), and the dish sidelobe level 60° off axis (30° tilt of the dish towards the ground-based user is assumed) is about -19 dBi. At Clear, the power density 0.2 mile (0.32 km) from the ISR dish is, therefore, approximately 56 dBW - 19 dBi - 61.1 dBm^2 - 57.0 dBHz = -81.1 $dBW/(m^2Hz)$. At Gakona, the minimum separation is 1.5 miles (2.4 km), and the increased space loss lowers the power density estimate to -98.6 $dBW/(m^2Hz)$. Since handheld transceivers have a basebandwidth of 3 kHz, the "effective" power density at the user locations at Clear and Gakona are -46.3 dBW/m^2 and -63.8 dBW/m^2, respectively.

B.5.2.15 HAARP Scintillation Receiver

The HAARP scintillation receiver will operate between 240 and 245 MHz at a distance of 20 miles (32 km) from the ISR. Since the subharmonics of the ISR should be negligible, no inband interference with the scintillation receiver is expected. Owing to the large separation between the ISR and the scintillation receiver, out-of-band interference via receiver saturation is unlikely.

B.5.2.16 Radio Telephone

Radio telephone transmissions occupy both the VHF (152-158 MHz) and UHF (454-460 MHz) frequency bands. Comments under B.5.2.11, "Mobile VHF Radio," apply to VHF radio telephone. The ISR transmit band extends from 444 to 446 MHz, which is relatively close in frequency to the UHF radio telephone band. If the maximum 2-MHz ISR instantaneous bandwidth is in use, spectral components that are only 23 dB down from the peak components may enter the UHF radio telephone band. ISR directivity 60° off broadside (30° tilt towards user system assumed) is about -19 dBi (section B.3 model).

a. Gakona, 9 miles (14.5 km): 56 dBW - 19 dBi - 23 dB (spectral components, 2 MHz instantaneous 3 dB bandwidth assumed) - 94.2 dBm^2 - 63.0 dBHz (2 MHz) = -143.2 $dBW/(m^2Hz)$.

b. Clear: no radiotelephone users have been identified in the Clear area.

B.5.2.17 Alaska Pipeline Systems

Alaska pipeline remote control and maintenance systems employ both the VHF (150-162 MHz) and UHF (450-460 MHz) frequency bands. Comments under B.5.2.11, "Mobile VHF Radio," are applicable to the VHF users, although user receiver saturation by out-of-band signals is not likely, given the large separations (>10 miles) between the ISR and the

Alaska pipeline systems. At UHF, the 450- to 460-MHz maintenance band is relatively close to the 444- to 446-MHz ISR transmit band. If the maximum 2-MHz ISR instantaneous bandwidth is employed, spectral components that are only -18 dB down from the peak components may enter the 450- to 460-MHz maintenance band. ISR directivity 60° off broadside (30° tilt towards user system assumed) is about -19 dBi (section B.3 model). Space loss is site dependent, as indicated in the following power density estimates:

a. Gakona, 29 miles (46.7 km): 56 dBW - 19 dBi - 18 dB (spectral components, 2 MHz instantaneous 3 dB bandwidth assumed) - 104.4 dBm^2 - 63.0 dBMHz = -148.4 $dBW/(m^2Hz)$.

b. Clear, 65 miles (104.6 km): 56 dBW - 19 dBi - 18 dB - 111.4 dBm^2 - 63.0 dBHz = -155.4 $dBW/(m^2Hz)$.

These estimates assume free-space propagation loss because the pipeline control and maintenance systems are assumed to be mounted on tall towers within the line-of-sight of the ISR.

B.5.2.18 Terrestrial Microwave

The Alascom Tower, which supports terrestrial microwave communications between 5,945 and 6,094 MHz, lies 1.7 miles from the ISR site at Gakona. A microwave tower at Birch Creek operates at 5,975 and 6,257 MHz only 5 miles from the proposed ISR site in the Clear region. In both cases, the microwave bands lie well above the ISR transmit frequency, and at least 100 dB of harmonic and spurious ISR signal suppression should be realizable. The 8 ft-diameter parabolic dish antennas used for terrestrial microwave communications are highly directive. The peak-referenced gain of the microwave antennas in the direction of the ISR can be estimated for each site by use of the generic pattern model described in section B.3. At Gakona, the ISR site, as viewed from the microwave dish, is 45° off broadside, while in the Clear region, the ISR site, as viewed from the Birch Creek dish, is only about 5° off broadside. Since the peak microwave dish gain is used in the system sensitivity calculation, the relative gain is applied below in the "effective" power density estimation:

a. Gakona, 1.7 miles (Alascom Tower): 56.0 dBW - 100 dB - 28 dBi (ISR gain 60° off broadside at 6 GHz) - 60.2 dB (relative gain 45° off broadside) - 79.7 dBm^2 = -211.9 dBW/m^2 = -268.9 $dBW/(m^2Hz)$ in 0.5 MHz (57.0 dBHz) bandwidth.

b. Clear, 5 miles (Birch Creek): 56.0 dBW - 100 dB - 28.0 dBi - 35.4 dB (relative gain 5° off broadside) - 89.1 dBm^2 = -196.5 dBW/m^2 = -253.5 $dBW/(m^2Hz)$ in 0.5 MHz (57.0 dBHz) bandwidth.

B.5.3 VIS Power Density Estimates

Power density estimates and interference ranges are provided for the VIS in tables B-1 and B-2, respectively. The actual interference experienced should be, in most cases, far less than that implied by these estimates because the VIS is used intermittently and is swept across the frequency band when active. Furthermore, in the case of far out-of-band receivers, the actual harmonic suppression should be far greater than that derived from equation (B-27). Similar instruments are operated in many parts of the world without objectionable interference.

APPENDIX C

HAARP EMITTER LOCATIONS RELATIVE TO RECEIVING SYSTEMS IN THE VICINITY OF THE GAKONA AND CLEAR AFS (ALASKA) SITES

C.1 GAKONA (ALASKA) PREFERRED SITE

The location of the proposed HAARP facility at the preferred site in Gakona, Alaska is shown in figure C-1. The ISR at the HAARP facility has the map coordinates (145°10'W, 62°24'N). Minor and major airfield facilities are located approximately 8 miles and 20 miles, respectively, southwest of the ISR.

The proposed layout of the HAARP facility is shown in figure C-2. The VIS and the preferred array area of the IRI are located approximately 0.6 miles north and 1 mile south, respectively, from the ISR.

The closest distances of the IRI, ISR, and VIS to a public road (the Tok-Cut on the Glen Highway) are 0.8, 1.5, and 1.8 miles, respectively. The closest distances of the IRI, ISR, and VIS to a public walkway [the Bureau of Land Management (BLM) Trail] are 0.8, 1.5 and 1.5 miles, respectively. The closest distance of the HAARP emitters to a private dwelling is approximately 2 miles.

The closest distances of HAARP emitters to receiving systems in the vicinity of Gakona are summarized in table C-1. For airborne receiving systems, the closest distances are the ranges at which the HAARP aircraft warning radar shuts down the HAARP emitters. Those ranges have not yet been specified. However, appendix B calculates the ranges at which the HAARP emitter power densities are equal to the airborne receiving system noise available power densities.

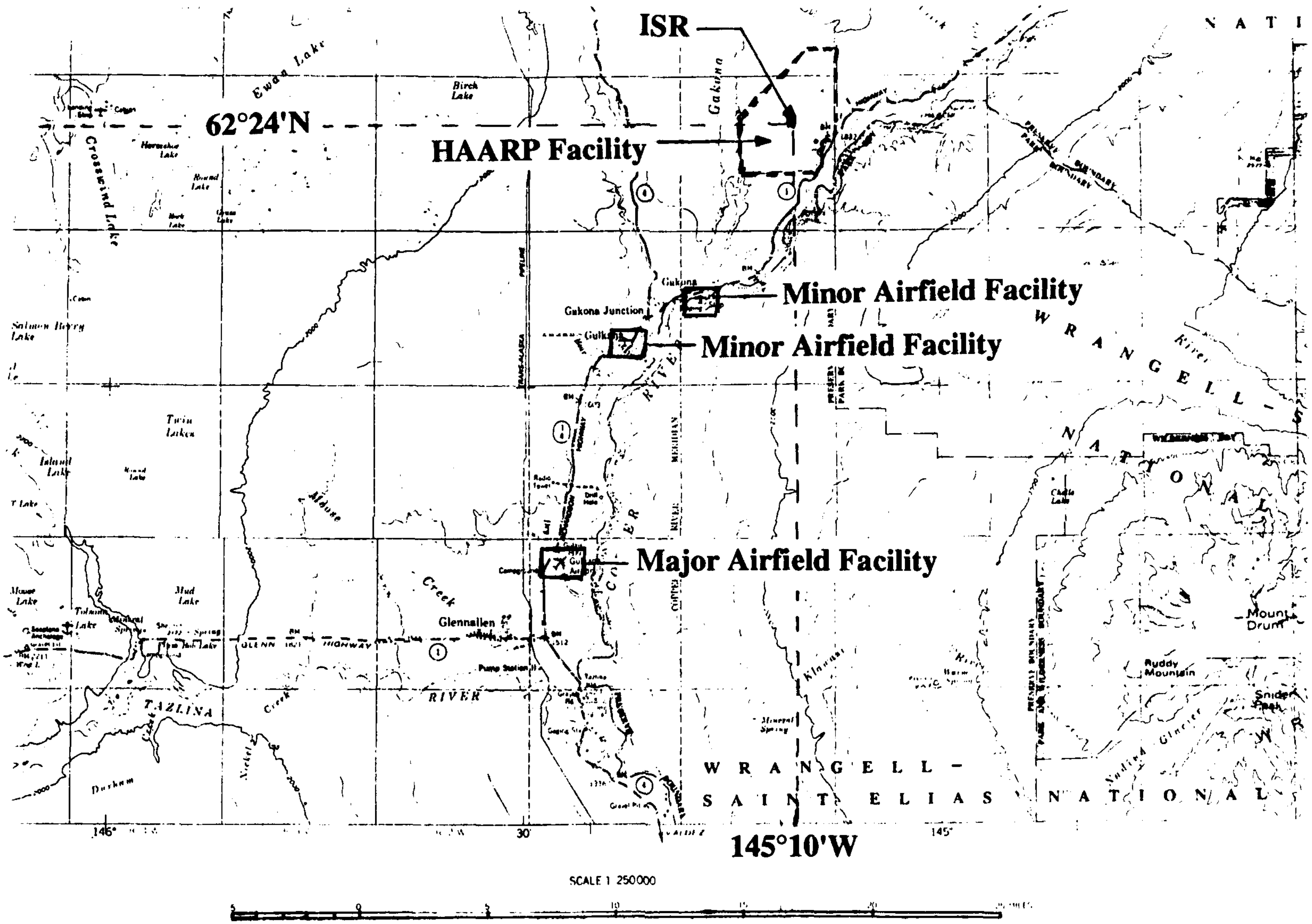

Figure C-1. Location of Proposed HAARP Facility at Gakona (Alaska)

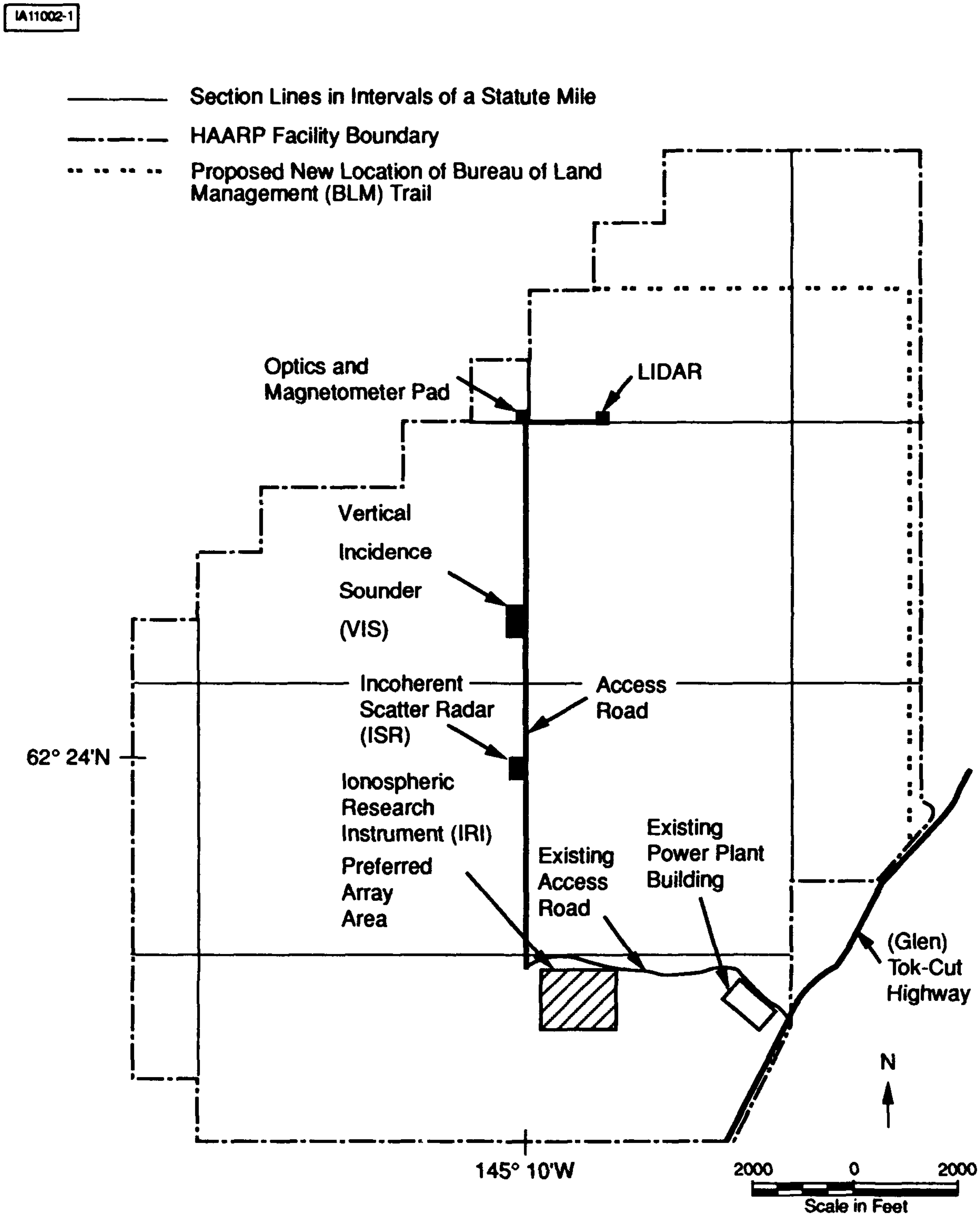

Figure C-2. Proposed HAARP Facility Layout at Gakona

Table C-1. Gakona Study Area, Closest Ranges of HAARP Emitters to User Receiving Systems

Receiving System	Closest Distance of HAARP Emitters (mi)		
	IRI	ISR	VIS
Cellular Telephone	0.8	1.5	1.5
HAARP Riometer	10.0	10.0	10.0
Satellite Television	6.0	6.0	6.0
HF Communications	2.0	2.0	2.0
Television Broadcast	2.0	2.0	2.0
AM Radio Broadcast	2.0	2.0	2.0
FM Radio Broadcast	2.0	2.0	2.0
Avionics	Overflight	Overflight	Overflight
Cardiac Pacemakers	0.8	1.5	1.5
Electro-Explosive Devices	0.8	1.5	1.5
Mobile VHF Radio	0.8	1.5	1.5
Wildlife Tracker	0.8	1.5	1.5
Citizen Band Radio	0.8	1.5	1.5
Handheld Transceivers	0.8	1.5	1.5
HAARP Scintillation Receiver	20.0	19.0	18.4
Radio Telephone	9.0	9.0	9.0
Pipeline Remote Control	10.0	10.0	10.0
Pipeline Maintenance VHF	10.0	10.0	10.0
Pipeline Maintenance UHF	29.0	29.0	29.0
Terrestrial Microwave	1.7	1.7	1.7

C.2 CLEAR AFS (ALASKA) SITE

The location of the proposed HAARP facility at the Clear AFS and Bear Creek alternative site is shown in figure C-3. The layout of the proposed ISR and VIS at the Bear Creek alternative site is shown in figure C-4. The closest distances of HAARP emitters to receiving systems at the Clear AFS alternative site are summarized in table C-2.

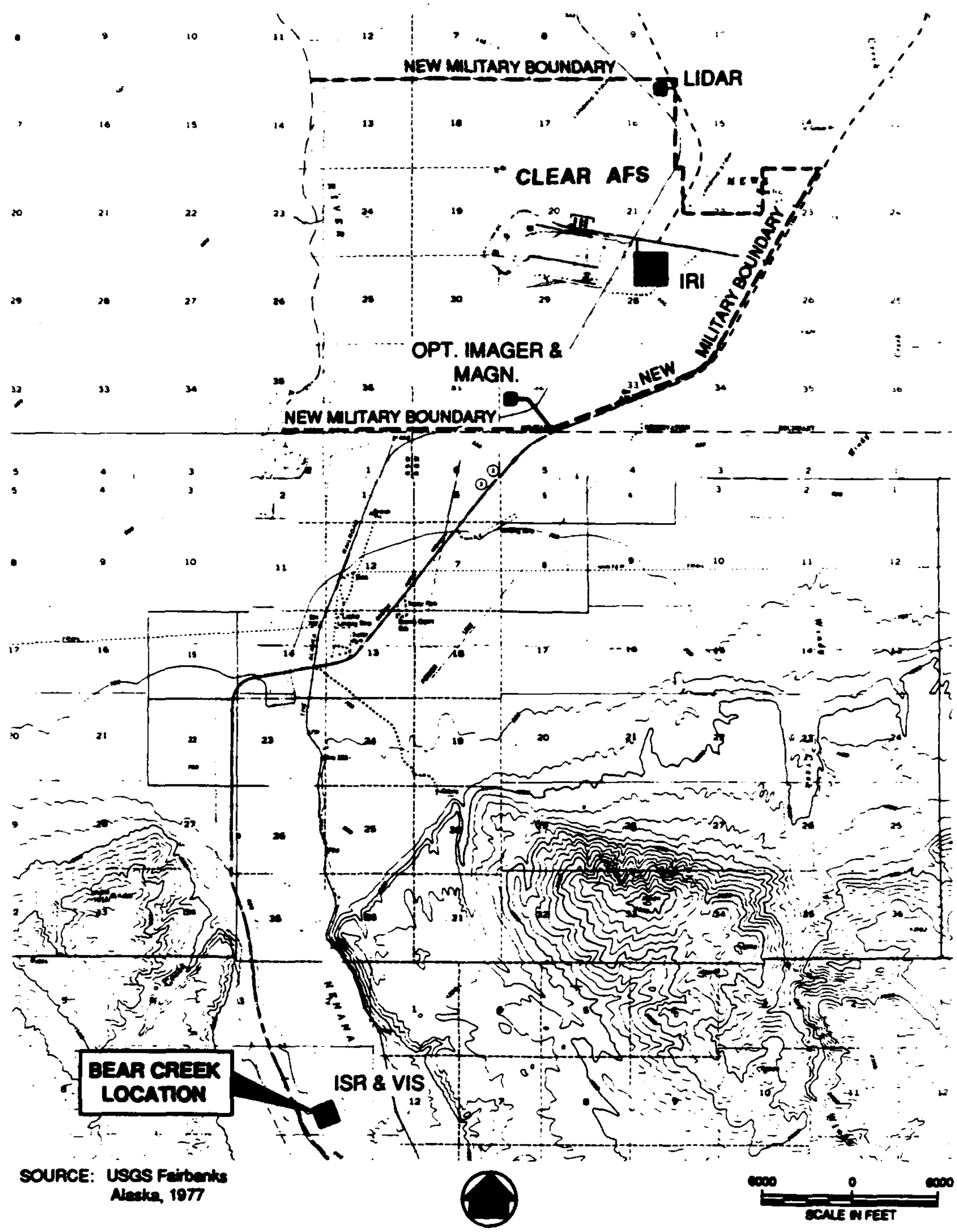

Figure C-3. Proposed Location of the HAARP Facility at the Clear AFS and Bear Creek Alternative Site

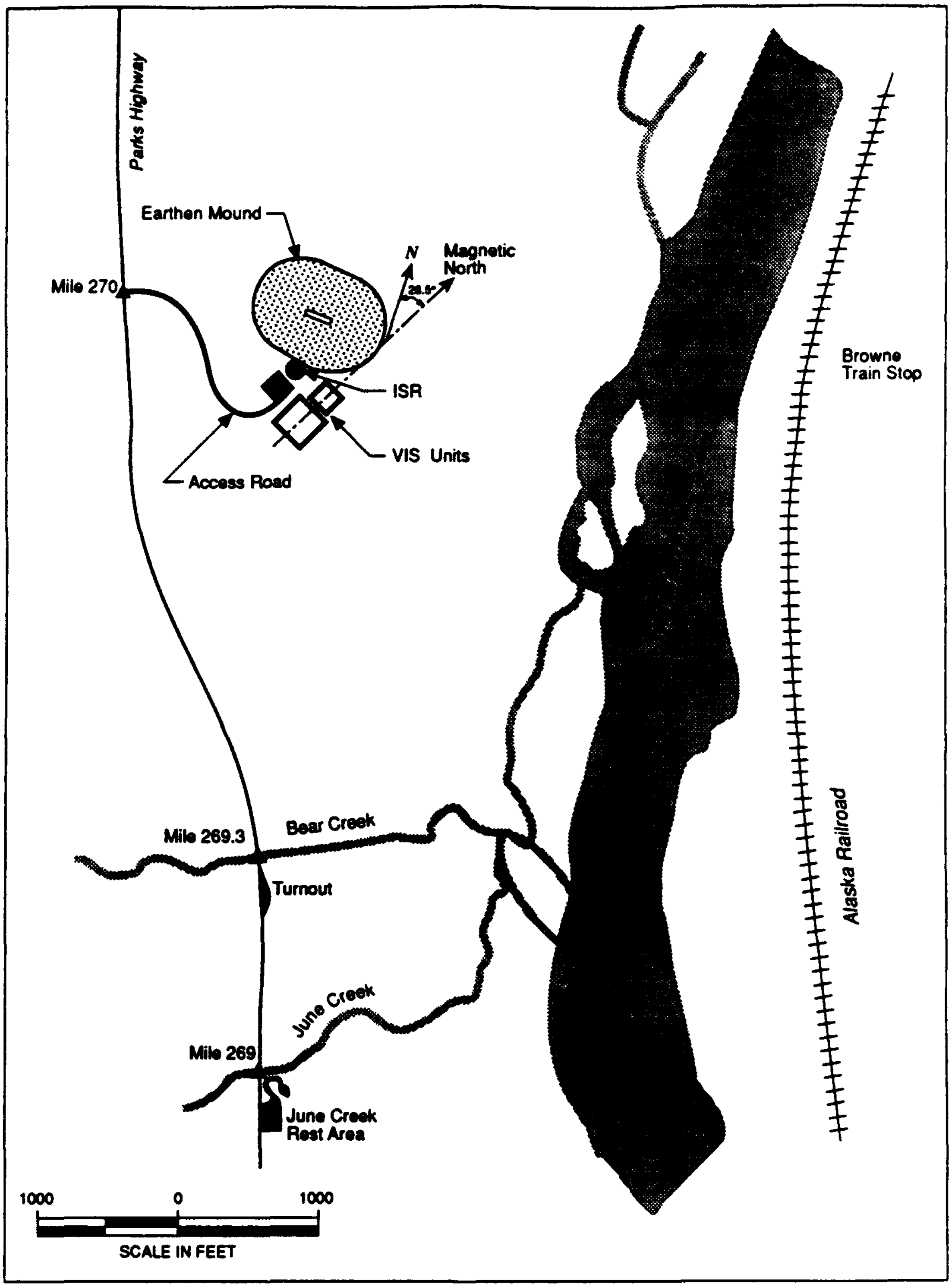

Figure C-4. Proposed Layout of the HAARP ISR and VIS at the Bear Creek Alternative Site

Table C-2. Clear AFS Study Area, Closest Ranges of HAARP Emitters User Receiving Systems

Receiving System	Closest Distance of HAARP Emitters (mi)		
	IRI	ISR	VIS
Cellular Telephone	0.8	0.2	0.2
HAARP Riometer	10.0	10.0	10.0
Satellite Television	0.5	1.0	1.0
HF Communications	0.5	1.0	1.0
Television Broadcast	0.5	1.0	1.0
AM Radio Broadcast	0.5	0.2	0.2
FM Radio Broadcast	0.5	0.2	0.2
Avionics	Overflight	Overflight	Overflight
Cardiac Pacemakers	0.5	0.2	0.2
Electro-Explosive Devices	0.8	0.2	0.2
Mobile VHF Radio	0.8	0.2	0.2
Wildlife Tracker	0.8	0.2	0.2
Citizen Band Radio	0.8	0.2	0.2
Handheld Transceivers	0.8	0.2	0.2
HAARP Scintillation Receiver	20.0	25.0	25.0
Radio Telephone*			
Pipeline Remote Control	60.0	65.0	65.0
Pipeline Maintenance VHF	60.0	65.0	65.0
Pipeline Maintenance UHF	60.0	65.0	65.0
Terrestrial Microwave	2.0	2.0	2.0

*Note: Our survey has not located a radio telephone user within the Clear AFS area

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