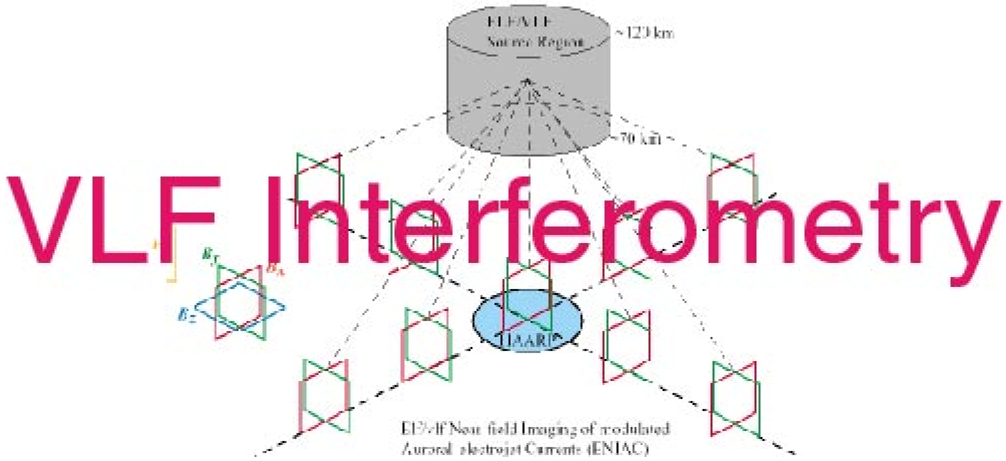



*Umran S. Inan*

## Outline

# A. ABSTRACT

The nine-element ELF/VLF interferometer system is used as a source current

imaging array in support of the High-frequency Active Auroral Research Program (HAARP) in

Alaska. HAARP is a congressionally initiated program jointly managed by the U.S. Air Force

and U.S. Navy. The goal of the program is to provide a state-of-the-art U.S. owned ionospheric

research facility readily accessible to U.S. scientists from universities, the private sector and

government.

One of the research topics of present interest is the generation of ELF/VLF waves through

HF heating of the auroral electrojet, the intense current system that flows in the auroral regions

between 70 and 120 km altitude. Potential DoD applications of this research are to provide

communications to submerged submarines at ELF frequencies and to use the generated waves

to locate and probe underground structures.

The purpose of the ELF/VLF current imaging array is to provide an experimental

tool that can be used to determine the HF heater-induced time varying electrojet currents that

actually radiate the ELF/VLF waves. Without this knowledge there is presently little hope of

understanding and optimizing the process by which the waves are produced.

To resolve the important unknowns concerning the spatial distribution of the modulated

currents,

we propose to construct and deploy an ELF/VLF current imaging system near the HAARP

facility in Alaska. The ELF/VLF interferometer system would consist of nine ELF/VLF receivers,

each with triaxial crossed loop antennas and one vertical electric antenna, arranged in

the form of a cross with the central receiver located within ~10 km of the HAARP facility. Each

leg of the cross consists of five receivers, each spaced by a distance of 70 km, with the central

receiver being common to both legs of the cross.

The array would be used to map out the modulated currents using the near field of these

currents. The known relationship between the near fields and the modulated currents provides

the link which makes this possible.

## B. INTRODUCTION

A low-power (battery operated) nine-element interferometric array is to be constructed and

assembled for ELF/VLF measurements in remote regions. An important application of this new array

include ( imaging the three dimensional structure of the HF heater modulated auroral electrojet currents

that radiate ELF/VLF waves, with specific application to the High-frequency Active Auroral Research

Program (HAARP) in Alaska. The new method is based on measurements of wideband ELF/VLF

waveforms at nine suitably distributed (Figure 1) remote sites, with a GPS-based absolute timing accuracy between distant sites of <1 us. The GPS timing allows the waveform data from the different sites to be phase

comparable in the same sense as a traditional *interferometer*, except for the fact that the object being

'imaged' is in the near-field (rather than far-field as in most other interferometric applications) of the

sensors.

The ELF/VLF interferometer system consists of nine low power radio receivers as

shown in Figure 1, allowing the specification of the three dimensional distribution of the source

current region with ~5 km resolution in both the vertical and lateral dimensions. One of the

important applications of the new interferometer will involve its use in connection with the

powerful HAARP HF heater, for which the array design will be specifically tailored. HAARP is

a congressionally initiated program jointly managed by the U.S. Air Force and U.S. Navy with

the overall goal of providing a state-of-the-art ionospheric research facility readily accessible

to U.S. scientists from universities, the private sector and government. This facility is currently

operational at a total radiated power level of 960 kW, and has been successfully used controlled

heating of the ionosphere, for production of artificial ionospheric irregularities, and for generation

of ELF/VLF signals. When the full array of transmitting antennas are completed within the next

few years, the HAARP facility will be the most advanced and powerful ionospheric heater

in the world, capable of producing the most intense ELF/VLF signals that can be used for

remote sensing of underground structures, for probing the earth's outer radiation belts, and for

communication with submerged vehicles.

The interferometer is a unique experimental tool that can be used to determine the HF

heater-induced time varying electrojet currents that actually radiate the ELF/VLF waves. This

knowledge will not only enhance our understanding of the fundamental processes of ELF/VLF

generation but will also allow the optimization of the process by which the waves are produced.

The data to be obtained from the proposed program will be used to analyze basic properties of

ionospheric ELF/VLF radiating systems and to assess the potential for developing ionospheric

enhancement technology for communications and surveillance purposes.

# C. SCIENTIFIC BACKGROUND

ELF/VLF waves are important not only as communication tools, but also as remote diagnostic

probes to determine the characteristics of the Earth, the ionosphere, and the magnetosphere.

Since the controlled production of these waves on the ground generally requires large, elaborate

and expensive antennas and associated facilities [*C. H. Richard, Sub vs. Sub*, Orion Books, New

York, 1988], it is important to explore alternate means of generating these waves.

One promising alternate method for producing ELF/VLF waves is to use a powerful ground based HF radar to modulate the intense auroral electrojet currents that flow in the auroral D

and E regions, causing these natural currents to radiate ELF/VLF waves from an altitude range

of 70-110 km, depending upon the HF frequency. This technique works in the following way.

The HF waves heat the ambient electrons in the D and E-regions where the electrojet current

flows, causing the electrons to collide more frequently with the ambient neutral particles. The

increased electron collision rate changes the local conductivity of the medium, and this in turn

changes the electrojet current flow. If the HF heater is modulated at a frequency in the ELF/VLF

range, the electrojet current will vary at this same frequency and will then radiate waves at this

frequency.

Controlled experiments using this technique have been successfully conducted in Norway

[*Stubbe et al.*, 1982; *Barr and Stubbe*, 1984; *Reitveld et al.*, 1986; *Barr and Stubbe*, 1991], Russia

[*Kapustin et al.*,1972], and Alaska [*Ferraro et al.*,1982; *McCarrick et al.*, 1990; *Villasenor et*

*al.*, 1996]. Furthermore, VLF waves generated in the D-region by ground based HF heaters

have been detected by a number of spacecraft, including ISIS 1 [*James et al.*, 1984], Aureol 3

[*Lefeuvre et al.*, 1985], DE 1 [*Inan and Helliwell*, 1985], and Akebono [*Kimura et al.*, 1991,

1994].

Although it has been amply demonstrated that HF heaters can modulate the auroral electrojet

currents to produce ELF/VLF waves in the D-region, there is very little known about the actual

details of the mechanism through which the waves are generated. For example, the horizontal

spatial distribution of the currents that radiate the waves is not known. Thus the waves could be

produced through quadrupole radiation rather than through dipole radiation. Furthermore the

altitude of the modulated currents is not known, other than the fact that they must be located above

70 km where the conductivity is high enough to support intense electrojet currents [*Rowland et*

*al.*, 1996].

Since very little is known about the spatial distribution of the modulated currents that produce

the ELF/VLF waves, there is no experimentally verified model which could be used to optimize

the wave generation process. Instead, trial and error methods have been employed which are

very difficult to interpret because of the well known variability of the auroral ionosphere.

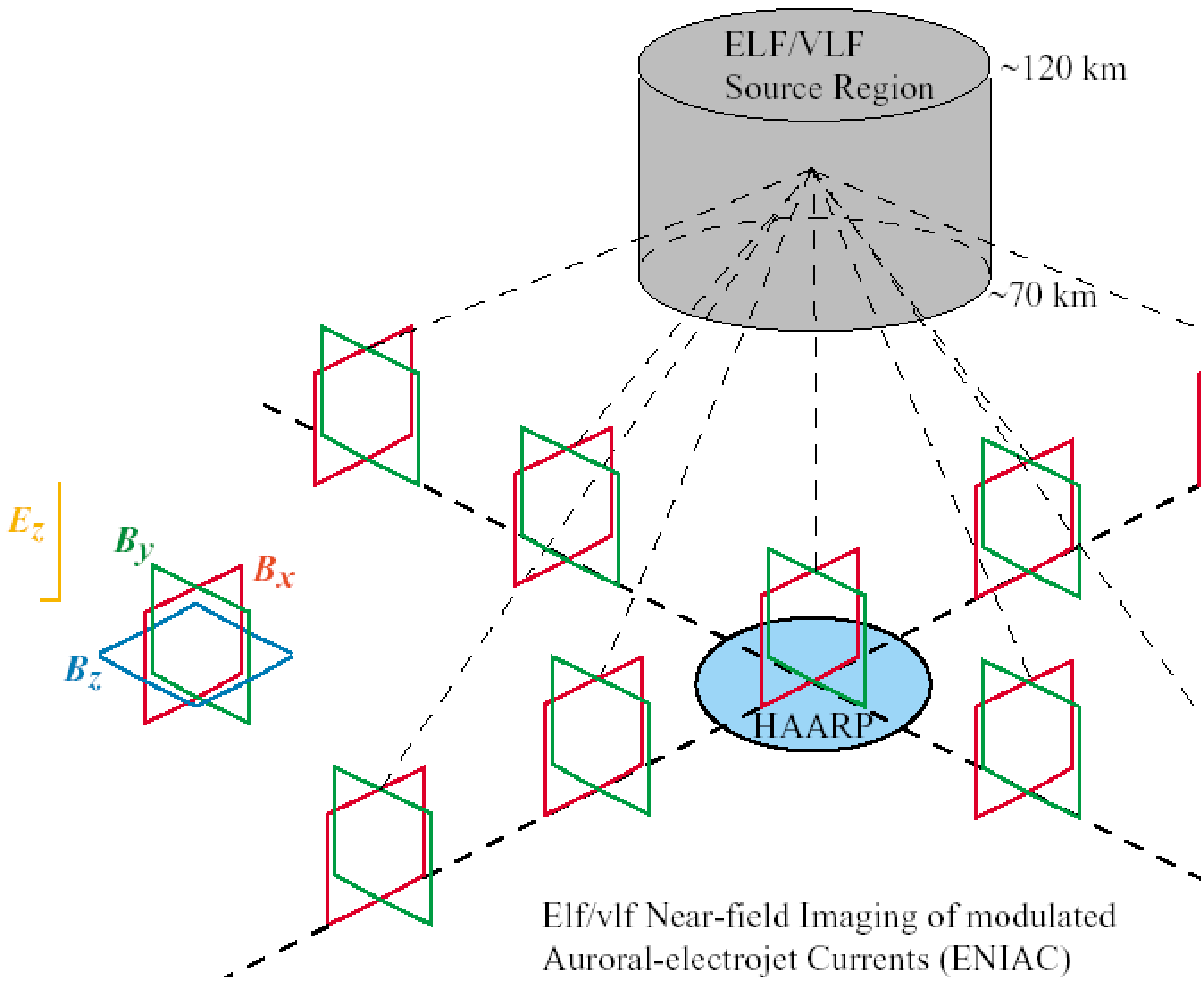
To resolve the important unknowns concerning the spatial distribution of the modulated currents,

we propose to construct and deploy the ELF/VLF inteferometer array near the HAARP

facility in Alaska. As shown in Figure 1, the system would consist of nine ELF/VLF receivers,

each with triaxial crossed loop antennas and a vertical electric antenna, arranged in the form of

a cross with the central receiver located within ~10 km of the HAARP facility. Each leg of the cross consists of five receivers, each spaced by a distance of ~70 km.




The interferometer array would be used to map out the modulated currents using the near field of these currents. The known relationship between the near fields and the modulated currents

provides the link which makes this possible. The spatial resolution of the imaging will depend

upon the signal-to-noise ratio of the near field measurements. However since this ratio can

generally be improved by averaging, we believe a 20 dB ratio is achievable. In this case the

imaging should be able to achieve a spatial resolution of ~5 km or better in both the horizontal

and vertical directions. Achieving this goal will require operations in which the HF beam is

directed away from the vertical, but always well within normal operating configurations. A

resolution of ~5 km appears sufficient for most applications, since simulations suggest that

ELF/VLF radiation is enhanced for a fixed HF power level when the heated region is made as

large as possible [*Taranenko et al.*, 1992]. The modulated auroral electrojet currents produce

a magnetic field at ground level which is described by Maxwell's equation

$$\nabla \times \vec{B} = \frac{1}{c^2}\frac{\partial E}{\partial t} + \mu_o \vec{J}$$

where $B$ is the magnetic field, $E$ is the electric field, $c$ is the velocity of light, $t$ is the time, .is the

divergence operator, and $J$ is the sum of the modulated source current density and eddy currents

in the ground induced by the time varying magnetic field. The $E$ field in (1) is predominently

produced by space charge . in the source region which is associated with the current flow. The quantities *J* and . are related through the equation of continuity.

$$\nabla \cdot J + \frac{\partial \rho}{\partial t} = 0$$

Within the source region the local charge density . is significant only in regions where there are

significant gradients in the local conductivity, such as near the boundaries of the heated volume.

Since it is the time derivative of . which enters into (2), it is clear that the effects of . on *J*

decrease as the driving frequency is decreased. In the limit of decreasing driving frequency, (1)

and (2) can be approximated by the relations:

$$\nabla \times \vec{B} = \mu_o \vec{J}$$

$$\nabla \cdot \vec{J} = 0$$

In cases when ground eddy currents are negligible the relationship between the *B* field at the

ground and the source currents can be described through the generalized Biot-Savart Law [*Inan*

*& Inan*, 1999]:

$$\vec{B}(\vec{r}) = \frac{\mu_o}{4\pi} \int \frac{\vec{J} \times \widehat{R}}{R^2} dV'$$

where *B* is the field produced by the currents, *J* is the current density in the source region, *R* is a

unit vector along the line connecting the source and observation points, *R* is the distance between

the source and observation points, and the integral includes the volume of space containing the modulated currents, and *dV* is a volume element in the source region.

To solve (1) for *J*, given *B* at the ground, we divide the source regions into identical small

volume elements .*V* and approximate the integral by the finite sum:

$$\vec{B}(r) = \frac{\mu_o}{4\pi} \sum_i \frac{\vec{J}_i \times \hat{R}_i}{R_i{}^2} \Delta V$$

Assuming that the summation has *i* elements and that we have measured *B*(*r*) at *i* separate

locations, we can then write (5) as the matrix relationship

$$\overline{B} = \overline{\overline{M}}\,\overline{J}$$

where *B* is a column vector containing the *B* measurements and *J* is a column vector containing

the 3*i* unknown values of □*J* in the discretized source region. Given that *M* is not singular, we

can invert (3) to obtain the current density from the measured values of *B*:

$$\overline{J} = \left[\overline{\overline{M}}\right]^{-1} \overline{B}$$

In cases where ground eddy currents are significant, (4) must be modified through the inclusion

of the image currents. However, the solution proceeds in a similar manner.

In general the horizontal scale of the modulated currents is just the full width of the HF beam

at ~80 km altitude, which is generally less than 50 km. The vertical scale is unknown, but

probably of the order of 25 km. For a spatial resolution of 5 km we would then have *i* 500 in

the summation of (5). To obtain 500 separate measurements of *B* at our 9 sites, it is necessary to use the HF beam pointing capability to move the heated region with respect to the fixed sites.

This can be done quite simply for example, by tilting the HF beam a fewdegrees from the vertical

and then sampling $B$ at the 9 sites as the azimuth is changed in steps. Then tilting the beam a

few degrees more from the vertical and repeating the azimuth sean.

Given that the maximum inclination angle from the vertical is 30. for the HAARP HF beam

and that the source currents are located somewhere between 70 to 120 km altitude, the mimimum

effective area that can be sampled with the current imaging array is shown in Figure 2. In this

figure the center circle includes all the points with respect to the center of the heated region that

can be sampled by the central site of the array as the HF beam moves from 0 to 30. with respect to

the vertical, and at each zenith angle moves through 360. of azimuth. The other circular regions

represent the effective area sampled at each of the remaining 8 sites. The dashed circle in the

center of the central circular area represents the projection on the ground of the area illuminated

by the HF beam at 80 km altitude when the HF frequency is 2.8 MHz and the beam is vertical.

It is clear that the central site of the array can effectively sample all points on the ground directly

beneath the heated region and that measurements can be made at any point up to 175 km from

the center of the heated region along each leg of the cross. In the central region the sample

points can be arranged in a rectangular grid with axes parallel to the cross axes and with 5 km

separation between sample points. This scheme produces ~150 measurements of $B$. At the 4

sites closest to the central site the sample points can be more widely separated because of the

increased distance from the source region. With a rectangular sampling grid with a separation of

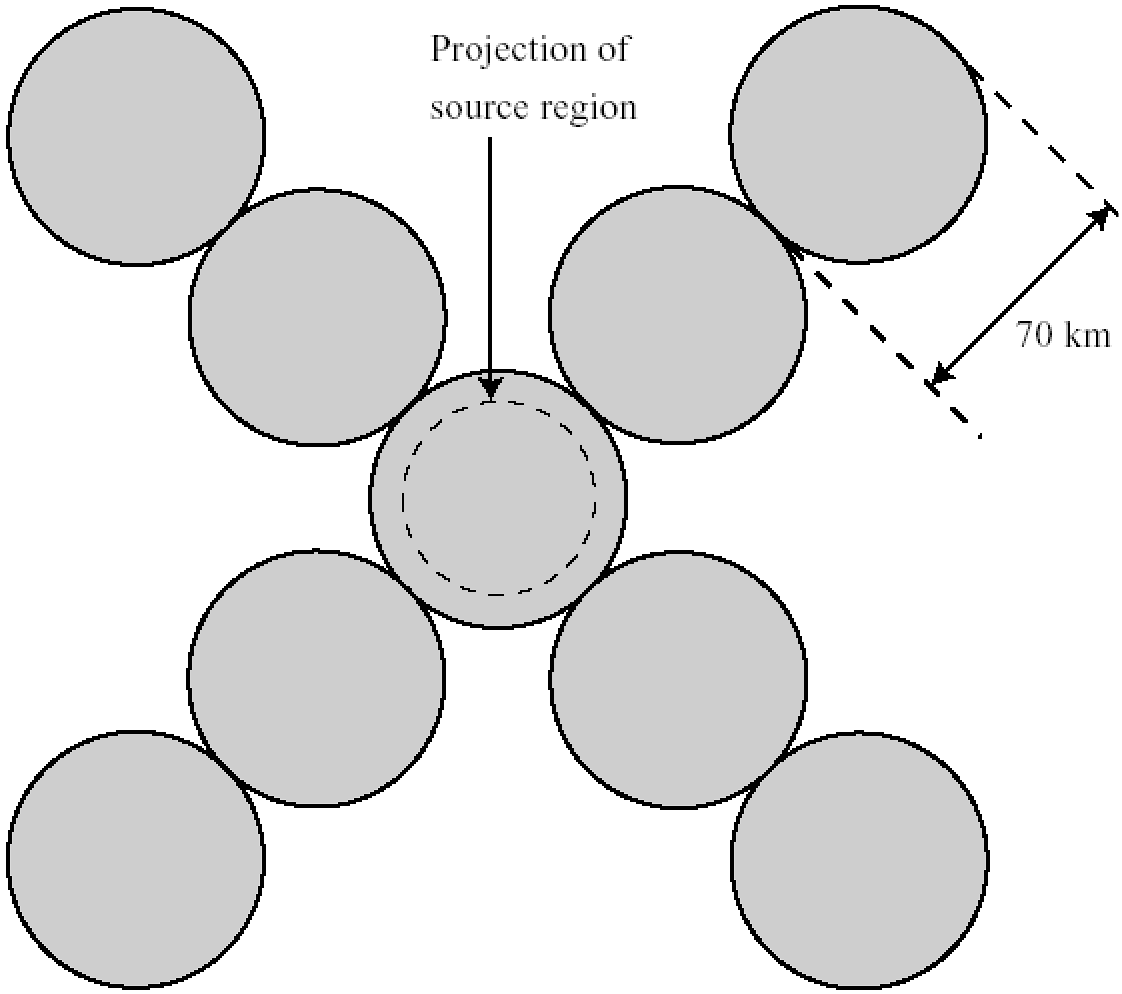
8.5 km between sampling points we get ~220 measurements of $B$ in these 4 sites. Finally in the

outermost sites with a separation of 11 km between sampling points we get ~130 measurement

of $B$ for a grand total of 500 measurements of □$B$, as required.

**Fig. 2. Effective area sampled by the proposed ELF/VLF interferometer array.** The center solid circle includes all points with respect to the center of the heated region that can be sampled by the central site of the array as the HF beam moves from 0 to 30 degrees from the vertical and at each zenith angle moves through 360 degrees of azimuth. The other circular regions represent the effective area sampled at the other 8 sites as the beam swings through

the same angular range. The dashed circle at the center of the central solid circle is the projection of the source region onto the ground when the HF beam is vertical and the frequency is 2.8 MHz.




The dwell time of the HF beam at each location would be ~1 second. Thus the entire

measurement sequence requires less than 10 minutes to complete. When the HF frequency is

higher than 2.8 MHz, the HF beam width will decrease, as will the horizontal scale of the heated

region. In these cases we divide the heated volume into 500 sections as before so that the spatial

resolution is inversely proportional to the frequency and always a fixed percentage of the diameter

of the beam at ~ 80 km.

Since it is possible that space charge effects may be important at all ELF frequencies, we

monitor these effects by measuring the vertical component of $E$ at each site. The relation between the vertical $E$ and . is given by the relation

$$E_z = -\frac{(1+\eta)}{4\pi\varepsilon_o} \int \frac{\rho\, z'}{R^3}\, dV'$$

where $z$ is the vertical axis, $z$□ is the altitude of the charge, and . is a quantity that depends upon

the local ground conductivity. For a highly conducting ground, . ~= 1. Since we know the values

of $E_z$ at the ground, (8) represents an integral equation for .. We solve it by the same procedure

we used to arrive at (7). That is, we approximate the integral by a summation over 500 volume

elements to create a matrix relationship:

$$\overline{E}_z = \overline{\overline{C}}\,\overline{\rho}$$

where $E_z$ is a column vector containing the 500 measured values of $E_z$ and . is a column vector

containing the 500 unknown values of .. Inversion of (9) gives the relationship for .:

$$\overline{\rho} = \left[\overline{\overline{C}}\right]^{-1} \overline{E}_z$$

In general, □$J$ can be expressed as the sum of two parts:

$$\vec{J} = \vec{J}_1 + \vec{J}_2$$

where . $J_1$ = 0, .$J_2$ = 0, and $J_2$ is associated with the space charge .. The quantity $J_1$ can

always be found from (7), while $J_2$ is found from (2):

$$\nabla \cdot \vec{J}_2 = -\frac{\partial \rho}{\partial t}$$

Since by definition $.J_2 = 0$, we can express $J_2$ as the gradient of a scalar $\Phi$, i.e., : $J_2 = .\Phi$.

Now (12) becomes similar to Poisson's equation:

$$\nabla^2 \Phi = -\frac{\partial \rho}{\partial t}$$

Since the right hand side of (13) is known through (10), (13) can be solved numerically to find

$\Phi$, and then to find $J_2$. Thus the complete current $J = J_1 + J_2$ can be found in the source region

for any driving frequency in the ELF range.

# D. THE EQUIPMENT

At each site the ELF/VLF signals from the three orthogonal loop antennas and the vertical whip

antenna are fed into a four channel preamplifier box. The 4 outputs from the preamplifier are sent

to a Stanford-built 4 channel presampling filter and clipper circuit where the signals are broadband

filtered to remove high frequency noise and clipped to prevent saturation from impulsive signals

(due to lightning discharges). The 4 signals are then fed into a programmable i386-Engine-M

processor, which extracts the average variation of each field component over the course of a

single cycle of the HAARP heater. The HAARP transmission and modulation schedules are

known *a priori* and the processor is programmed to process the data only during these times and at the specified frequencies, thus minimizing on-time for the processor (to save power) and data

volume. The processed data is stored in flash memory cards. The stored data is downloaded

(by connecting a portable NoteBook computer) from the memory cards during regular visits

to the site. Any changes in recording schedules and frequencies are also downloaded to the

programmable processor during these regular site visits.

The preamplifier is a wideband instrument (300 Hz to 90 kHz) with high linear dynamic range

(~100 dB) and is similar in design to Stanford-built systems used worldwide for highly sensitive

ELF/VLF measurements. For the interferometric measurement proposed here, the sampling rate

of the i386 processor will typically be set at 10 kHz, providing the ability to measure signals in

the frequency range of 300 Hz to 4 kHz. The processor will carry out 'on-board' analysis of

the data as followsby partitioning data into sections of 1 second duration, and in each section

determining the average variation of the field component over the course of a single cycle of the

HAARP heater through a superposed epoch analysis. The information concerning this average

field variation will then be stored in flash memory. This procedure markedly improves the

signal-to-noise ratio by which the field components can be determined and also greatly reduces

the amount of data that must be subsequently stored.

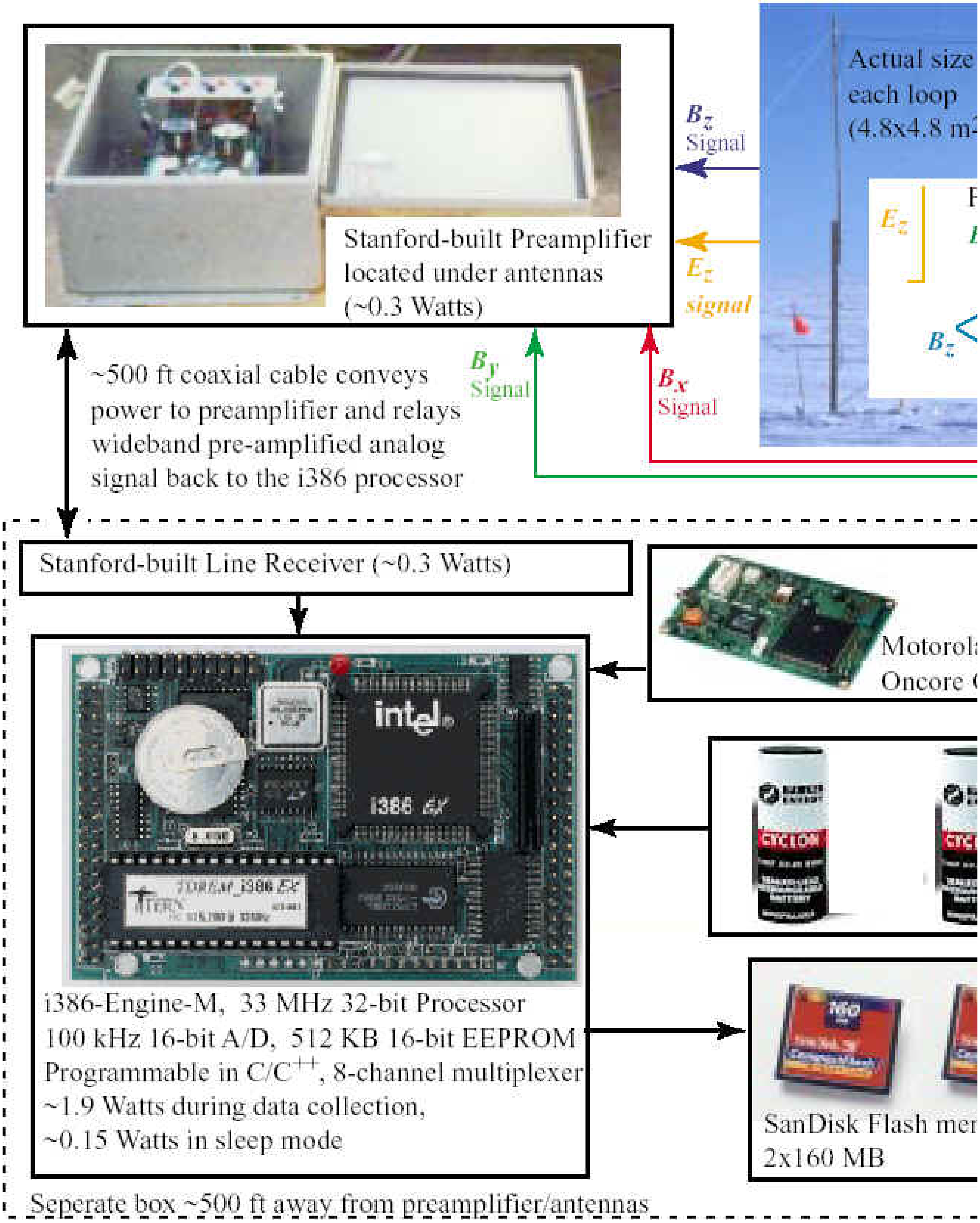



**Fig. 3. System diagram of one of the nine identical ELF/VLF receivers constituting the proposed inteferometer array.** signals from the 3 orthogonal loop antennas and the vertical whip antenna are fed into a Stanford-built 4 channel preamplifier preamplifier are sent to a Stanford-built 4 channel line receiver where the signals are broadband filtered to remove high frequ

prevent saturation from impulsive signals (due to lightning discharges). The 4 signals are then fed into a programmable i386- extracts the average variation of each field component over the course of a single cycle of the HAARP heater. The HAARP t schedules are known a priori and the processor is programmed to process the data only during these times and at the specifiec on-time for the processor (to save power) and data volume. The processed data is stored in flash memory cards. The stored d connecting a portable NoteBook computer) from the memory cards during regular visits to the site. Any changes in recording also downloaded to the programmable processor during these regular site visits.

## Logistics and General Operational Procedure

The logistics of the field deployment and use of the proposed ELF/VLF interferometer is envisioned

to involve the following steps:

1) Identify nine sites that are electromagnetically quiet (away from power lines) and accessible

by road (with car or snowmobile).

2) Visit each site and deploy the ELF/VLF antennas (see Figure 3). This deployment could be

semi-permanent, and can be done in advance to save time.

3) Visit each site (this could also be done durign the previous visit) and deploy the system

shown in Figure 3, except for batteries.

4) At this point, the ELF/VLF interferometer is in place and ready for measurement of HAARP

signals. One day before the start of a HAARP experimental campaign, visit each site and

connect the batteries.

5) During the experimental campaign, visit each site once every two days (40-hours; see subsection

on Data Storage below) to download data from Flash Memory cards, by connecting

them to the poratble NoteBook computer. Downloads of new recording schedules (based

on new planned HAARP transmission schedules) into the i386 processor EEPROMare also

done in these visits.

6) Visit each site once every five days (see subsection on Batteries) to replace batteries.

Items (5) and (6) above will be continued until the end of the experimental campaign.

## Stanford-built Preamplifier and Line Receiver

The Stanford-built preamplifier and line receivers are very similar in design to those previously

constructed by Stanford University and currently in use at many sites worldwide. These systems

have operated successfully in each case and planned goals were uniformly achieved. Thus, the

construction of nine such units for the proposed ELF/VLF interferometer poses no schedule, cost,

or performance risk. In past applications, the analog outputs from these units would be fed into

an A/D board connected to a Pentium computer, with the digitized broadband signals recorded

on hard disk and ultimately on CD-ROMs or digital tapes. The primary difference between the

new systems proposed here and the previous systems is the fact that a low-power procesor (i386)

is used instead of the Pentium computer and data is stored on Flash Memory cards instead of

CD-ROMs, both features being necessary to facilitate battery-powered operation.

In general, it is important to note that line drivers and line receivers are required to drive

(i.e., power is sent to the preamplifier from the line receiver) and receive (preamplified signal

transmitted back to the line receiver) signals off on long lines. These units provide for correct

cable termnation, common mode rejection, power-from-signal isolation, clipping to prevent

saturation (due to impulsive signals produced by lightning discharges) and other important

signal conditioning. When a wire of any length is used for signals of large dynamic range
and

significant bandwidth (in this connection ELF/VLF is extrememly wide bandwidth
compared to

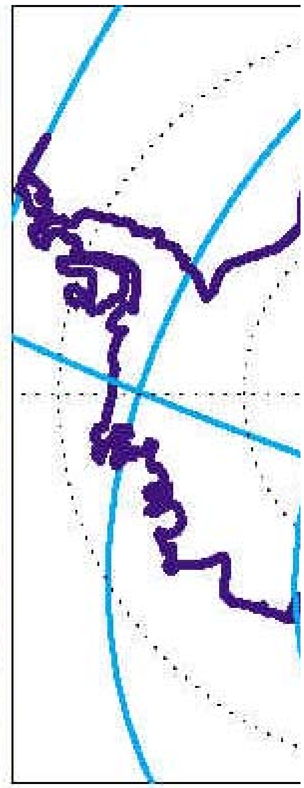


**Fig. 4. Stanford ELF/VLF receivers at unmanned automatic geophysical observatory sites.** This system, currently opera
sites is currently deployed at the AGO sites P1, P2, P3,P4, and P5. It consists of a magnetic loop antenna (either a 1.7x1.7m
connected to a preamplifier (grey box with sealed lid shown in lower left) buried immediately underneath, which is powered
rolled up) to the station (shown in upper left), in which resides the main receiver unit (the box with the blue front panel) cons
channels, and a broadband snapshot system, as depicted in the block diagram. This 'low power' ELF/VLF system specially d
nevertheless consumes ~6 to 7 W, depending on operational modes. The broadband snapshot system in these units (the upper
utilize the programmable i386-Engine-M processor, which also forms the basis for the individual elements of the proposed E

most things, covering, usually, three decades (30 Hz to 30 kHz) of frequency) it is
necessary to

have special terminations at both the send and receive ends.

## i386-Engine-M Processor

The use of the programmable i386 processor also does not pose any risk since Stanford University

instruments currently located at unmanned automatic geophysical observatories in Antarctica

(see Figure 3) have recently been redesigned to use this processor for capturing wideband

snapshots of ELF/VLF activity. As a result, expertise in the use and programming of this

particular card for processing analog outputs from preamplifier systems already resides in our

research group. The graduate student funded under the proposed program will take advantage

of this expertise and will be responsible for programming the software interfaces for flexible use

of the i386 processor for extraction of ELF/VLF waveforms at specific times and frequencies

during which modulated heater transmissions will be carried out with the HAARP facility.

In terms of our application the i386 processor has the following key features:

Low power consumption: 1.9 Watts in normal operation, and 0.15 Watts in sleep mode.

512-KB 16-bit EEPROM, programmable in C/C++, with quick debugging/testing.

512-KB 16-bit SRAM, with memory expansion board available.

100 kHz 16-bit A/D, with 8-channel multiplexer.

These features allow for minimal power consumption, especially in view of the fact that the

processor will need to be ON only during specified (a priori) periods of HAARP transmission/

modulation, and can be in the SLEEP mode at other times. On average, we expect the duty

cycle of HAARP transmissions in any given targeted hour to be no more than 30-seconds every

5-minutes, which means that the processor can operate at an *average* power draw level of ~0.3

Watts. At other times, when no HAARP transmissions are made, the system will SLEEP while

consuming only ~0.15 Watts.

## Stable Time and Frequency Reference

The proposed VLF receiver incorporates a compact GPS receiver card as the source of a stable

time and frequency reference. The power and size of GPS receivers has been shrinking rapidly,

and the Motorola UT Plus Oncore card we propose to use operates at a power level of ~0.9

Watts. At first, this might seem to be a significant power draw, compared to the preamp/line

receiver and the i386 systems. However, it should be noted that the ~1 *u*sec time resolution

needed in an ELF/VLF receiver (note that the maximum bandwidth proposed is 100 kHz so that

1 *u*sec resolution is well enough) can be realized by using the GPS receiver only occasionally,

for example once or twice per day, to synchronize a thermally isolated crystal resonator which

is then the source for a timing generator and frequency reference. A thermally isolated, good

quality crystal resonator has an Allen Deviation of typically better than $10^{-10}$, for 1000 to

10,000 sec, which is about ~1 *u*sec/day. The drift due to aging is larger, about ~10 usec/day.

By synchronizing to GPS once or twice per day, the effects of drift and variation could easily be compensated to the precision needed by the ELF/VLF receiver. GPS satellite lock is achieved

(with the Motorola UT Encore card) generally in at most ~4 minutes, so that the duty cycle of

the GPS receiver would be 4 minutes every 12 hours, so that a ~0.9 W GPS card would only

consume a negligible average power of only ~5 mW.

## Data Storage on Flash Memory

The technology in FLASH memory has been leapfrogging its capacities with no sign of slowing

down. Present commercially available memories have up to 190 Mbyte capacities, so that a few

of these chips would have the capacity to store 1 Gbyte of data. The great advantage of FLASH

memory is retention at zero power. The power used by these memories in writing to them is

dependent on data rates, so that for the small few kHz bandwidths of ELF/VLF applications only

~1 mW is needed. For our application, we propose to use two Sandisk 160 MB flash memory

cards at each site, for a total storage capacity of 320 MB. Within a few months, and certainly

by program start (1 April 2000) we expect at least twice as much capacity to be available at the

same cost.

The data storage requirements are obviously determined by the bandwidth and duty cycle of

operation. As a benchmark, 10 kHz sampling rate at 16-bits allows for ~4 kHz bandwith and produces ~20 kBytes/s. At that rate, 320 MB of storage allows for continuous recordings of a

single waveform for ~5.3 hours.

In practice, however, our expected duty cycle for HAARP transmissions in any given targeted

hour will be no more than 30-seconds every 5-minutes (i.e., ~10%), so that 320 MB storage

allows recordings of a single HAARP-induced waveform for ~53 hours, or more than two

24-hour days. With four channels ($B_x$, $B_y$, $B_z$, and $E_z$), and noting that typically HAARP

operations will be conducted for periods no longer than ~8 hours/day, we can record 4-channels

at 4 kHz bandwidth during HAARP transmissions (30-seconds every 5-minute, for 8-hours/day)

for a period of ~40 hours. In view of the overall logistical approach described above, and with

the distance between sites of ~70 km (see Figure 2), this provides ample time for visiting the

sites, to download flash memories and replace batteries (if needed; see below).

The above data volume estimates are in fact quite conservative, and assume that the raw 16-bit

waveforms of signalswould be retained with full 4 kHz bandwidth. The actual data requirements

are likely be substantially lower due to the facts that:

The processor can carry out 'on-board' analysis of the data by partitioning data into sections

of 1 second duration, and in each section determining the average variation of the field

component over the course of a single cycle of the HAARP heater through a superposed

epoch analysis. Only the information concerning this average field variation (rather than the full waveform) will have to be stored in flash memory. This procedure markedly improves

the signal-to-noise ratio by which the field components can be determined and also greatly

reduces the amount of data that must be subsequently stored. In cases where data volume

is not a limitation, full waveforms can be retained and the superposed epoch procedure can

be carried out after the data is extracted from Flash Memory.

In general, HAARP transmission schedule and modulatioin frequencies will be known in

advance so that the waveform needs to be captured only in a narrow band (e.g., 400 Hz)

centered around the ELF/VLF frequency used (e.g., 3 kHz), rather than the full 4 KHz

bandwidth. This approach would relax data storage requirements by a factor of ~10.

## Batteries

Based on the above discussion, the total average power consumption of each of the nine ELF/VLF

interferometer elements is as follows:

**Component Duty Cycle Average Power Consumption**

Stanford-built Preamplifier 100% 0.3 Watts

Stanford-built Line Receiver 100% 0.3 Watts

i386-Engine-M Processor 30-s per 5-mins 0.3 Watts

Motorola Oncore GPS Card 4-min per 12-hrs 0.005 Watts

**TOTAL 0.95 Watts**

With a total continuous power consumption of only ~1Watt, the proposed ELF/VLF receiver system can be ideally powered by batteries. For this purpose, we propose to use batteries

produced by Hawker, Inc., which are currently used in remote regions such as Antarctica. Our

preliminary investigation indicates that their Cyclon series of the Hawker batteries works down

to -65. C. To supply ~1 Watt for 24-hours at 4 Volts, we need ~6 amp-hours. The Hawker

J-cell specifications, in the Cyclon series, is 8 amp-hours, at 2 V, in an approximately 5 cm

diameter, 14 cm high, rigid plastic container that weighs 840 gm. For our purposes, we can

connect two of these in series and then five such pairs in parallel to provide 30 amp-hours at 4

Volts, or 5-days of continuous power. The batteries would then weigh~8.4 kg, and would still be

relatively easy to handle.

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Last Updated: June 2001.