NASA/TM-2003-212647

Investigations of Relatively Easy To Construct Antennas With Efficiency in Receiving Schumann Resonances

Preparations for a Miniaturized Reconfigurable ELF Receiver

Brian W. Farmer and Robert C. Hannan
Langley Research Center, Hampton, Virginia

October 2003

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results ... even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at (301) 621-0134

- Phone the NASA STI Help Desk at (301) 621-0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA/TM-2003-212647

Investigations of Relatively Easy To Construct Antennas With Efficiency in Receiving Schumann Resonances

Preparations for a Miniaturized Reconfigurable ELF Receiver

Brian W. Farmer and Robert C. Hannan
Langley Research Center, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

October 2003

Available from:

NASA Center for AeroSpace Information (CASI)
7121 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161-2171
(703) 605-6000

Abstract

Relatively little is known about the cavity between the Earth and the ionosphere, which opens opportunities for technological advances and unique ideas. One effective means to study this cavity is with extremely low frequency (ELF) antennas. Possible applications of these antennas are global weather prediction, earthquake prediction, planetary exploration, communication, wireless transmission of power, or even a "free" energy source. The superconducting quantum interference device (SQUID) and the coil antenna are the two most acceptable receivers discovered for picking up ELF magnetic fields. Both antennas have the potential for size reduction, allowing them to be portable enough for access to space and even for personal ware. With improvements of these antennas and signal processing, insightful analysis of Schumann resonance (SR) can give the science community a band of radio frequency (RF) signals for improving life here on Earth and exploring beyond.

Introduction

Schumann resonances (SR) are the Earth's natural vibrations (fig. 1). They form within the cavity between the Earth and the ionosphere. These resonances are quasi-standing electromagnetic waves that propagate approximately at 7.8 cycles per second (7.8 Hz). These waves have modes that resonate at approximately 14, 21, 26, 33, 39, and 45 Hz, with a daily variation of about ±0.5 Hz. Even though the global Earth-ionosphere system behaves as a spherical-shell-cavity resonator (waveguide), the 7.8-Hz frequency can easily be approximated by using the Earth's circumference. The circumference of the Earth is about 25 000 miles (40 000 km), and the speed of light is about 3×10^8 m/s. It would therefore take light approximately 0.133 second to travel the Earth, which roughly yields 7.5 Hz. This frequency is not 7.8 Hz, even though the circumference of the Earth and the speed of light are constants. This resonance changes because of changes in the Earth's electrical and magnetic activity in the atmosphere and also because of changes in the height of the ionosphere; 7.8 Hz is the average peak frequency over a long period of time.

Finding the Earth's natural frequency was credited in 1954 to the German physicist, W. O. Schumann. Nikola Tesla was the first scientist to harness and explore these waves (in Colorado Springs, 1900). Tesla did pioneering work in this field, especially for his project to find means of transporting power wirelessly by using the Earth's natural frequency. However, Tesla's funding was cut and he later died, leaving little public documentation of his work behind.

Antennas

Our preliminary research is focused on finding relatively easy to construct antennas with efficiency in receiving SR signals. Many types of antennas can be used either for detecting the electric or magnetic field (fig. 2). The ground, rod, and T-shaped antenna electric field receivers were found to be impractical and not as efficient as the magnetic field receivers. Since the signal has such a long wavelength,

$$\lambda = c/f \approx 37\,500 \text{ km @ 8 Hz} \tag{1}$$

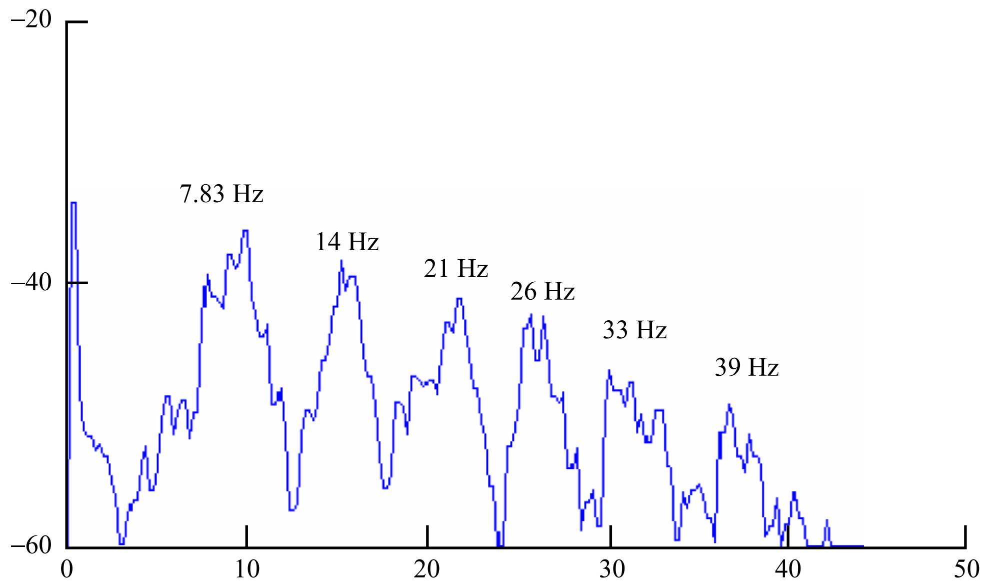

Figure 1. Plot of Schumann resonance magnitude (dBV) versus frequency (ref. 1). (Reprinted with permission)

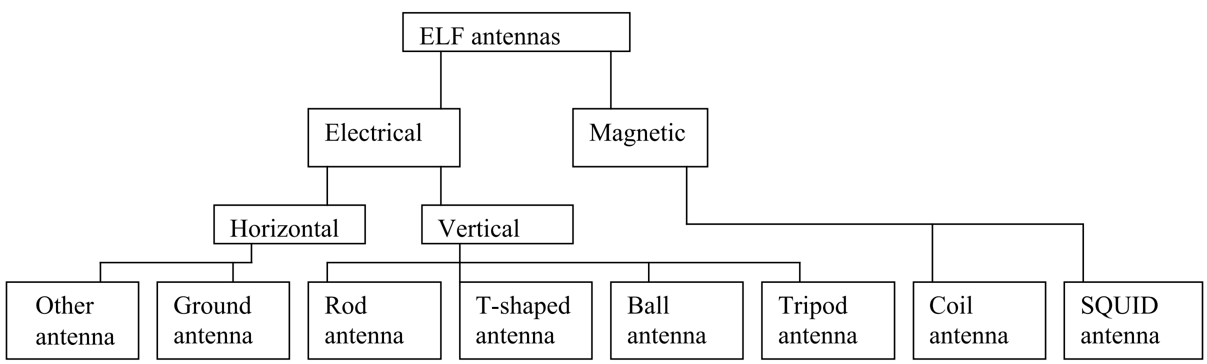

Figure 2. Tree of various antennas used for detecting the Schumann resonance.

an antenna size of half the wavelength would be needed to receive the electric field, which would be over 10 000 miles in wire length. That length would be impractical, and the amount of noise exposure over that distance would deplete the sensitivity of the extremely low frequency (ELF) band. The Navy buried two wires separately in two trenches 28 and 56 mi long to correct the noise problem, yet this design makes the antenna impractical for our purpose. The ball and tripod antennas use a localized capacitance, which allows them to be much shorter. However, a very high leakage resistance of the insulators and stability in time are essential for normal operation of the antennas. Rain, fog, dew, and humidity can decrease the quality of the signal and are usually mounted 5 m off the ground (ref. 2). These antennas are extremely susceptible to noise; in fact, a bird flying over the system has reportedly caused noise. Though the antennas pick up SR, they are not acceptable for our purposes due to their size and the variables affecting their reception. Magnetic sensors, on the other hand, can be small and very sensitive, with a usable signal-to-noise ratio. The sensors that interest us are the coil antennas, which use an active circuit, and the superconductor magnetometer.

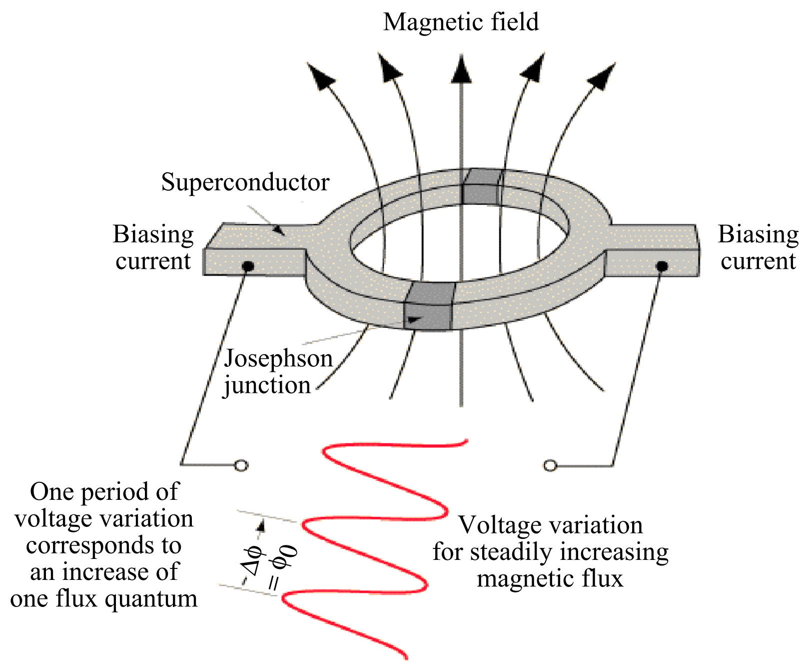

Figure 3. Basic concept of dc SQUID (from ref. 3). (Reprinted with permission)

SQUID

The superconducting quantum interference device (SQUID) is an extremely sensitive sensor of magnetic fields. It has a sensitivity threshold of the magnitude 0.01 pT. As shown in figure 3, the SQUID consists of two superconductors, usually niobium, separated by a thin insulator called the Josephson junction. SQUIDs that measure radio frequency (RF) use only one Josephson junction and dc (perhaps ELF) sensors have two or more. The Josephson junction equations for dc and ac effect are defined by reference 4:

$$I = I_c \sin \phi \qquad \text{dc} \tag{2}$$

$$\frac{\partial \phi}{\partial t} = \frac{2e}{\mathrm{h}} \mathrm{V} \qquad \text{ac} \tag{3}$$

If a dc voltage V is applied to a junction, integration of equation (3) shows that

$$\phi = \phi_0 + (2e/\mathrm{h})Vt \tag{4}$$

If this value is substituted in equation (2), one obtains the result

$$I = I_c \sin (\omega_J t + \phi_0) \tag{5}$$

so there is an ac current at the frequency

$$f_J = \frac{\omega_J}{2\pi} = \left(\frac{1}{2\pi}\right) 2eV/\mathrm{h} = V/\Phi_0 \tag{6}$$

where $\Phi_0 = \frac{2\pi h}{2e} \cong 2.0678 \times 10^{-15}$ Wb is the magnetic flux quantum, and the coefficient in the last term in equation (6) is 483.59767×10^{12} Hz/V.

Certain SQUIDs are expected to sense magnetic flux in the ELF range from dc up to 1 kHz (ref. 5). Measurements of the electromagnetic field are based on changes in the magnetic field based on one flux quantum. A flux quantum is the amount of magnetic flux from the Earth's magnetic field that passes through an area the size of a human red blood cell.

If a constant biasing current is maintained in the SQUID, a change in phase at the junction oscillates the measured voltage. Counting these oscillations provides the change of flux through the sensor (refs. 3 and 4). Current applications using the SQUID sensor are submarine communication, the monitoring of brain wave activity, nondestructive testing, and earthquake prediction. Currently, this sensor is not used for the detection of SR, which presents researchers an opportunity to contribute to science. The major advantage of a SQUID antenna is its extremely high sensitivity, possible light weight, and portability. Some disadvantages of the SQUID antenna are that it has to be cryogenically cooled, it is highly susceptible to environmental interferences and noise, and the driving electronics are very complicated. However, High-Tc SQUIDS that use the superconductor YBCO (ibco) have been developed that are cooled at 77 to 90 K by liquid nitrogen, which has a lower cost than liquid helium and a boiling point of 4 K, which is used for niobium. A 77 K commercial cryocooler typically costs $40,000, is 10 × 3 × 3 in. (250 × 75 × 75 mm), and weighs 9 to 18 lb (4 to 8 kg). Furthermore, recent development of the Chip-Integrated Electrohydrodynamic (EHD)-Pumped Cryogenic Cooling System (by Advanced Thermal & Environmental Concepts, Inc.) could make SQUIDs extremely small and portable at 0.3 lb (0.140 kg), 1 × 1 × 0.2 in. (30 × 20 × 5 mm), and $500. Testing of the Micro Cryogenic Cooling system is now underway at Goddard Space Flight Center in the thermal vacuum chamber.

Coil Antenna

For magnetic field measurements, past professional researchers have employed very large search coils: 30 000 turns, 6 ft (1.8 m), and 88.2 lb (40 kg). The active coil antenna is made up of only 1000 turns of wire around a ferromagnetic core consisting of a 12 × 2 in. (305 × 5 mm) cylinder weighing 4 lb (2 kg). It has a sensitivity of 1 pT in the frequency range of less than 1 Hz to about 1 kHz. The coil antenna, with an active circuit developed by Dr. John Sutton (2002 retired NASA civil servant), uses negative resistance and negative inductance, causing the antenna circuit to act as a magnetic dipole field (ref. 6). This use allows the coil to act as an atom with increased capture cross section, in which the incoming plane wave will bend toward the much smaller coil, allowing the circuit to absorb energy from a large portion of the plane wave as shown in figure 4.

The coil antenna has been the most widely used antenna for detecting SR. Applying the active circuit to the antenna increases the sensitivity of signals in the ELF range, allowing for a decrease in antenna size. Researchers have not yet adopted this principle, even though it has proved effective for receiving SR. The advantages of using this receiver instead of the SQUID are that it is easier to fabricate and less expensive. A major advantage that the active antenna has over the SQUID is proven reception of SR signals, which are achieved with reasonable signal-to-noise ratio. Some of the receiver's disadvantages are that a coil antenna has less sensitivity than the SQUID, and the active coil antenna circuitry needs temperature compensation design and development. With improved permeable material such as METGLAS® and improved operational amplifiers, the sensitivity could be increased possibly to 0.1 pT. Using a Swiss screw machine and a laser to etch turns of evaporated gold wire around the METGLAS®,

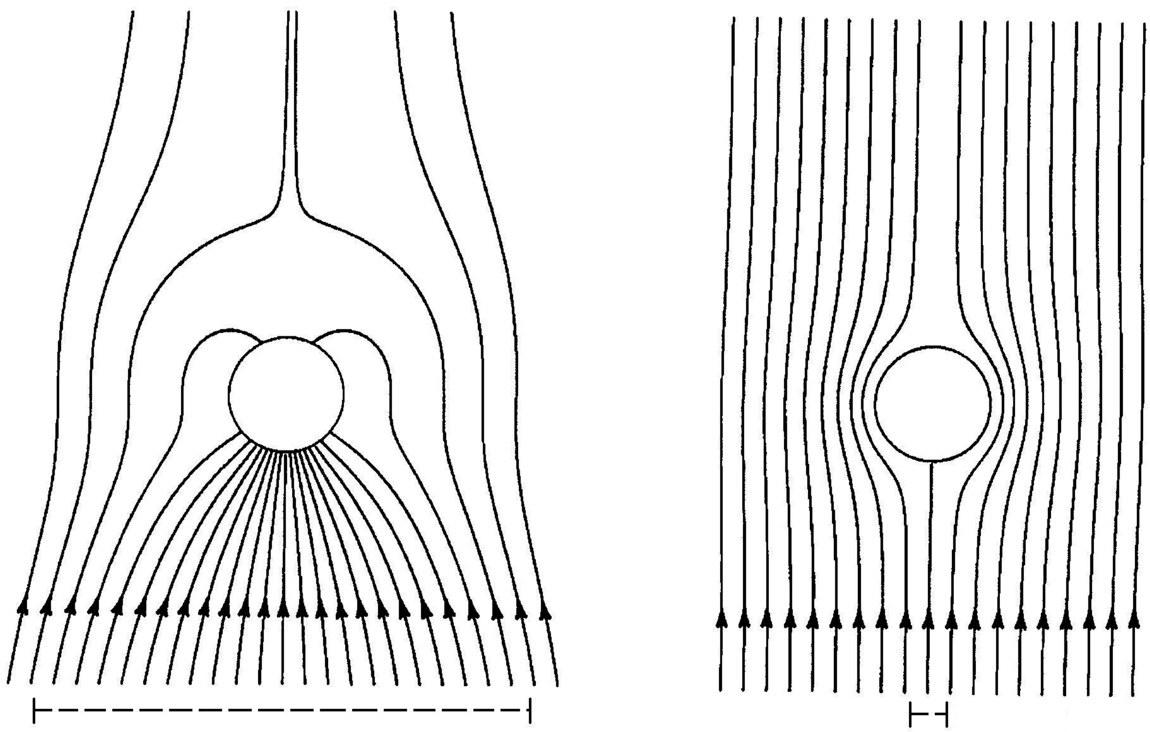

Figure 4. Flux lines shown at left from a regenerative feedback dipole have a greater capture cross section than flux lines at right without regenerative feedback (ref. 7). (Reprinted with permission of the American Association of Physics Teachers)

significant reduction in the cylinder coil area as well as increased sensitivity could be realized—if room for more coil turns is acceptable. This method and apparatus could miniaturize the size of the sensor coil to a couple of inches. Nanotechnology, using carbon nanotubes for wires, could be another option employed to reduce the cylinder coil area. Remaining work is required for the active circuitry to compensate for ambient conditions (i.e., temperature effects). A feedback loop or resistors with balancing, offsetting temperature coefficients will be considered.

Concluding Remarks

Atmospheric electrodynamics is an important area of research that is still in its early stage of discovery. Efficient and effective Schumann resonance (SR) receivers play a key enabling role in the maturity and advancement of atmospheric electrodynamics research and applications. Increased funding and priority from NASA headquarters, as well as creativity and interest from NASA engineers and scientists, are needed to explore and research the little known area of Schumann resonance.

References

1. Lonetree, Benjamin: *Seven Subtle Vibrations: A Scientific Study of Schumann Resonance, Geomagnetics, and Vortex Energy in Sedona*. July 2002. Received as an e-book side7@sidereal7.org Accessed 6-24-2003.

2. Bliokh, P. V.: *Schumannn Resonances in the Earth-Ionosphere Cavity*. Institution of Electrical Engineers, pp. 121–134, 1980.

3. Nave, Rod: SQUID Magnetometer. http://hyperphysics.phy-astr.gsu.edu/hbase/solids/squid.html#c1 Accessed 6-24-2003.

4. Van Duzer, Theodore; and Turner, Charles W.: Principles of Superconductive Devices and Circuits, Second Edition. ISBN: 0132627426, Prentice-Hall, Inc., 1998.

5. Kawai, Jun; Uehara, Gen; Kohrin, Toshiyuki; Ogata, Hisanao; and Kado, Hisashi: *Three Axis SQUID Magnetometer for Low-Frequency Geophysical Applications*. Applied Electronics Laboratory, Kanazawa Inst. of Technology, Japan. http://wwwr.kanazawa-it.ac.jp/~aelkit/ManuscriptCameraready(Rev).pdf Accessed 6-24-2003.

6. Sutton, John; and Spaniol, Craig: A Broadband Active Antenna for ELF Magnetic Fields. *Physics essays* 6, vol. 1, pp. 52–59, March 1993.

7. Bohren, Craig F.: How Can a Particle Absorb More Than the Light Incident on It?" *Am. J. Phys.*, vol. 51, no. 4, p. 323, April 1983.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01- 10 - 2003

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Investigations of Relatively Easy To Construct Antennas With Efficiency in Receiving Schumann Resonances

Preparations for a Miniaturized Reconfigurable ELF Receiver

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Farmer, Brian W.; and Hannan, Robert C.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
23-781-20-13

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-18332

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/TM-2003-212647

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 32
Availability: NASA CASI (301) 621-0390 Distribution: Nonstandard

13. SUPPLEMENTARY NOTES
Farmer and Hannan, Langley Research Center.
An electronic version can be found at http://techreports.larc.nasa.gov/ltrs/ or http://ntrs.nasa.gov

14. ABSTRACT
Relatively little is known about the cavity between the Earth and the ionosphere, which opens opportunities for technological advances and unique ideas. One effective means to study this cavity is with extremely low frequency (ELF) antennas. Possible applications of these antennas are global weather prediction, earthquake prediction, planetary exploration, communication, wireless transmission of power, or even a "free" energy source. The superconducting quantum interference device (SQUID) and the coil antenna are the two most acceptable receivers discovered for picking up ELF magnetic fields. Both antennas have the potential for size reduction, allowing them to be portable enough for access to space and even for personal ware. With improvements of these antennas and signal processing, insightful analysis of Schumann resonance (SR) can give the science community a band of radio frequency (RF) signals for improving life here on Earth and exploring beyond.

15. SUBJECT TERMS
Earth-ionosphere waveguide; Schumann resonances; ELF; Antenna; Coil antenna; SQUID

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	11	(301) 621-0390

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18