Description of Research Project

Form 442 Confirmation Number: EL893840
Form 442 File Number: 1067-EX-CN-2019

An Experimental License is required to allow transmission of signals as part of an observation time grant awarded by the Long Wavelength Array radio observatory. This facility can receive terrestrial and celestial signals in the 4-88 MHz range, is located in the Sevilleta National Wildlife Refuge, New Mexico, and is operated by the University of New Mexico as part of the University Radio Observatory Program supported by the National Science Foundation.

The purpose is to measure properties of the ionosphere using the 256-element Long Wavelength Array in New Mexico to receive signals from a terrestrial transmitter just outside ground wave distance via near vertical incidence skywave (NVIS).

The transmitter will emit both continuous waves and linear frequency sweeps up to 70 KHz wide at a rate of 0.1-10 sweeps per second over a 4 hour period on center frequencies suitable for NVIS in the range 4-10 MHz at a 100 watt power level.

The data from each of the 256 elements will be processed digitally to create time-varying images of the ionosphere that can be interpreted to detect earth-disturbing events such as earthquakes.

The pages below are

1. the coversheet and detailed proposal to the Long Wavelength Array Time Allocation Committee
2. the award letter granting observation time in 2020
3. the STA grant used in 2019 for the observations done in 2019

PROPOSAL COVER SHEET

V5.0

Cycle 8 Call for Proposals: LWA1 Radio Observatory

Submit to: lwa@unm.edu by November 1, 2019

Long Wavelength Array

Project title: LWA observations of earth-disturbing events and atmospheric parameters using phase images of the ionosphere obtained by bottom-side sounding

Project Summary (please do not write beyond this space):

We are applying for LWA observation time in 2020 to continue our observations made in 2019 (project LD010) to image Earth. One mode images waves in the ionosphere caused by Earth-disturbing events (big weather systems, earthquakes, lightning strikes, forest fires, etc.) and the other mode images atmospheric parameters in 3D. Both modes create phase images using radio signals transmitted from the Earth's surface upwards to ionization layers where they are reflected/refracted back to Earth's surface and captured by the LWA. A Fourier transform of the phase image separates all the Earth ionization layer's waves of different amplitudes and frequencies (wavevectors), providing valuable information about the Earth-disturbing event that created the wave. These LWA observations will provide new information about the power, energy and location of occurrence of Earth-disturbing events, as well as the three-dimensional measurement of the Earth atmosphere's temperature, pressure and composition (water and aerosols) necessary to help understand and monitor climate change.
The proposal text includes preliminary results from our 2019 observations.

Project Investigators:

	Name	Affiliation	Email
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Co-I	Bill Junor	Los Alamos National Lab	bjunor@lanl.gov
Co-I			

PI Contact Information

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Victoria, B.C. V8W 2Y2, Canada

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Requested mode(s): Backend(s) for each requested mode:

☐ LWA1 only — ☐ DRX ☐ TBN ☐ TBW ☐ DR-Spec

☒ LWA-SV only — ☐ DRX ☒ TBN ☐ TBF ☐ DR-Spec ☐ BIM

☐ LWA1+SV Interferometer — ☐ DRX

Observing Request Information (leave fields that do not apply to your setup empty):

LWA1 only time request:	hrs/beam:		nr of beams:	
LWA-SV only time request:	hrs/beam:		nr of beams:	
LWA1+SV interferometer time request:	hrs:		–	–
Repeated observations: length of each block (hrs):	4 hours LWA-SV			
frequency of blocks (or when):	Twice a month			
Restrictions in observing time (time of day):	Near noon and near midnight			
Restrictions in observing time (time of year):	All 4 seasons			

LWA observations of earth-disturbing events and atmospheric parameters using phase images of the ionosphere obtained by bottom-side sounding

We are applying to continue the observations for which we were awarded time in CFP7 as project LD010, so much of this proposal text is identical to our CFP7 proposal. The objective remains as in CFP7: to image Earth in ways not before possible in two modes. One mode images Earth-disturbing events and the other mode images atmospheric parameters in 3D. Both modes create images using radio waves transmitted from Earth's surface upwards to Earth's ionization layers where they are reflected back to Earth's surface and captured by the LWA. The LWA observations with the raw data option enables a measurement of the phase and the arrival time of the radio wave at each antenna, which is different at each antenna due to waves existing in the Earth's ionization layers. Earth has four ionization layers. It has been determined that 80% of the waves existing in the Earth's ionization layers are created by Earth disturbing events such as big weather systems, earthquakes, lightning strikes, forest fires, etc and 20% are created by solar events such as the sun's solar flares, solar wind, pulsars **[1].** Knowledge enabled by the LWA observations will provide new information about the Earth enabling the power, energy and location of occurrence of the Earth disturbing events, as well as, the three-dimensional measurement of the Earth's atmosphere's temperature, pressure and compositions (water and aerosols) necessary to monitor climate change.

The raw data would be obtained in TBN mode from LWA-SV at center frequencies near 4, 5, 7, 10, 12 and 15 MHz with bandwidth of 100 KHz in 4 hour sessions. The data management plan with the raw data option is to supply LWA with 5 hard drives in the appropriate form factor to record the raw IQ data from each antenna as per LWA memo 177.

At time of writing, we have only very preliminary results from two sets of LWA-SV observations made in May and October 2018.

The first data set observed terrestrial broadcast carrier waves at 5 and 10 MHz that were processed to obtain a phase image. We created movies of 1952 frames where each frame averaged the phase values from 512 samples of the 100 KHz TBN data for each antenna and color coded the phase value at each antenna location. The videos show a steady wave pattern alternating with patterns without waves with transitions between patterns on the order of seconds to 10s of seconds. Two frames of that data are shown on page 4. Also shown are estimates of ionospheric height from plane wave geometry.

For the second data set, we arranged for a local 100 watt transmitter about 50 miles away in Santa Fe operated by Bill Junor of LANL to illuminate the ionosphere at near vertical incidence. We obtained an FCC STA to authorize transmission of sweep as well as carrier waveforms. Propagation predictions showed a skywave path at 4, 5 and 7 MHz. The sweep waveforms were designed for an initial test in discrete steps of 100 Hz and of time duration 50 msec to 1 second. However, these stepped sweeps did not correlate because of random phase shifts in the transmitter frequency synthesizer. Unfortunately, the LWA center frequencies did not match our SDF and transmission schedule except at 7 MHz, so the only useful data was the 7 MHz carrier. We plan more observing sessions in the remainder of out CFP7 time using a software generated sweep waveform to receive data at 4, 5 and 10 MHz as well as 7 MHz.

More data is needed to progress towards the goals in our CFP7 proposal, hence we are applying for more observation time in 2020.

One idea for outreach that arose from our initial data analysis: provide TBN data at a 96 KHz (instead of 100 KHz) sampling rate, because 96 KHz is compatible with standard audio signal processing applications and also make an LWATV-style audio channel available on the website.

What follows is text from the CFP7 proposal with a few updates. Earth's ionization layers have two superlative qualities. They are the most sensitive Earth entity being lighter than air. They are also Earth's largest sensor to disturbances whether from space or from Earth itself. The waves existing on their surface have been monitored in ionosondes [**2**], equivalent to having one pixel in an image insufficient to determine the properties of the ionization layer's waves.

Importantly, the waves in the Earth's ionization produce pre-earthquake signatures one to five days before big earthquakes occurs [3][4]. The LWA observations can determine the location of these pre-earthquakes signatures possibly providing warnings of days, whereas, the current method (laser interferometry) provides just 30 seconds.

Rayleigh waves created by earthquakes have been detected by HF Doppler radar [5] and Over the Horizon radar [5][6]. Earthquake signatures measured by Doppler radar sounder and Over-The-Horizon Radar are converted via a transfer function into the correspondent ground displacement in order to compare it with classic seismometers [5][6]. However, radio wave imaging based on Doppler does not have much sensitivity and can only measure disturbances above Richter scale magnitude 7 [5]. Ionospheric waves have been imaged using the Murchison widefield array and EISCAT but at much higher frequencies 80-300 MHz. There are attempts to characterize Earth's ionization layers using multiple satellites [7], however being spread out and looking at Earth from different altitudes and positions loses the coherence of the wave information. A passive radar system using LWA and a terrestrial transmitter is used to locate that transmitter [8] and probe ionospheric structure.

The LWA TBN data provides means to produce the phase images of the waves of the Earth's ionization layers. The difference in arrival time and phase shift difference between each antenna is caused by the radio wave traveling difference distances when reflected off the peaks and valleys of the waves on the surface of Earth's ionization layers. The amplitude of the waves are believed to be 100s of meters sufficiently large to be observed [**9**]. The waves on the surface of the Earth's ionization layers have many amplitudes, frequencies and travel directions (wave vectors). They represent many Earth disturbing events that have different power, energy and location. A Fourier transform of the phase image separates all the Earth ionization layer's waves of different amplitudes and frequencies (wavevectors), providing valuable information about an earth-disturbing event that created the wave. The Fourier transformed phase image is then analyzed using deep learning techniques and used to train classifiers to identify rare events including earthquake and pre-earthquake signatures [10].

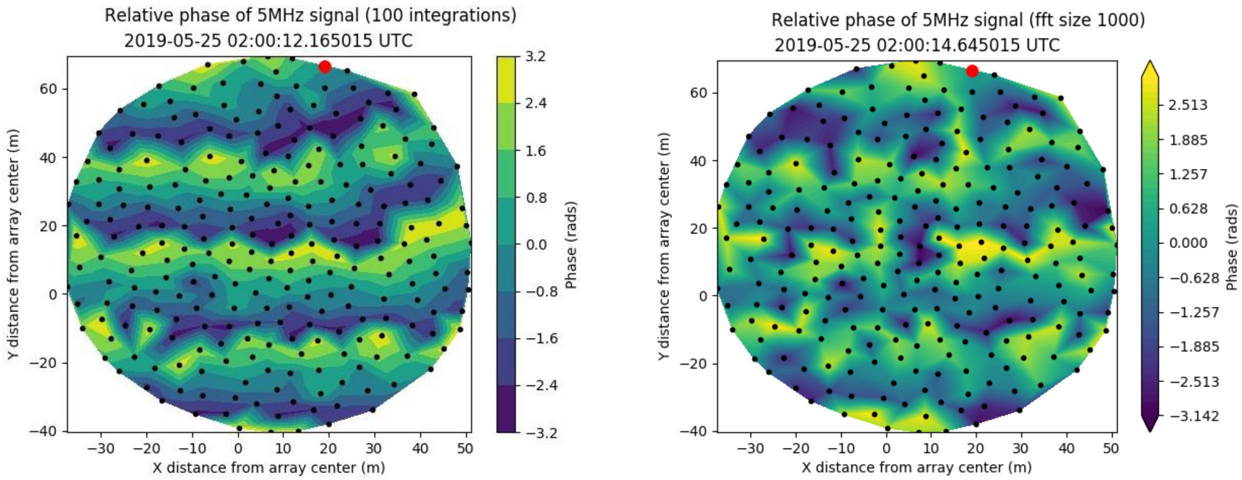
A second mode of processing the LWA observation data does not use the waves on the surface of the ionization layer. Instead, a low pass filter is used to remove the signals associated with the waves providing a signal representative of a flat surface on the Earth's ionization layers. This flat surface signal is used to measure the refractive index of the Earth's atmosphere, which decreases exponentially, very slowly from the Earth's surface up to the ionization layers. The exponential dependency is made linear using a Fourier transform resulting in a transfer function of the Earth's atmosphere's refractive index as a function of altitude. All boundary conditions and constants associated with this transfer function are determinable using refractive index measurements on the surface of the Earth and balloon data that is made once per day at many locals. The Earth has four ionization layers that reflect the radio waves at different frequencies providing four equations to solve for four unknowns of the atmosphere such as its pressure, temperature and compositions (water and aerosol contents). Additionally, Earth's four ionization layers reflect the radio waves at different points or locations within Earth's atmosphere providing four different viewpoints of Earth's atmosphere enabling 3D imaging/measurements of Earth's temperature, pressure and compositions by tomography methods. Additionally, since the Earth's atmosphere is not stationary and is composed of shifting clouds that consist of granulated ice (hail), water droplets and snowflakes, the LWA observation data can be processed using 3D confocal imaging to obtain their sizes, shapes, concentrations as a function of altitude within the clouds. As the clouds float by the LWA, they can be scanned from their lowest altitude to their highest altitude enabling determination of the densities of the granulated ice, water droplets and snowflakes providing much needed data for Earth Atmosphere's modelers who are still grappling with simulating the reflectance of radiation of the clouds and aerosols from space and Earth [**11**].

The proposed LWA observations to image the waves require a local transmitter at a carrier frequency and distance from the LWA such that near vertical incidence signals (NVIS) are dominant. Our team includes Bill Junor with NVIS antennas in Santa Fe, transmitting under an FCC STA. The transmitting frequency will be selected between the D-layer absorption frequency and the foF2 NVIS critical frequency based on current NVIS radio propagation forecasts [12]. If possible, we plan to change transmitting frequency once or twice during the 4 hour observation period to follow the changes in the absorption and critical frequencies as the sun moves.

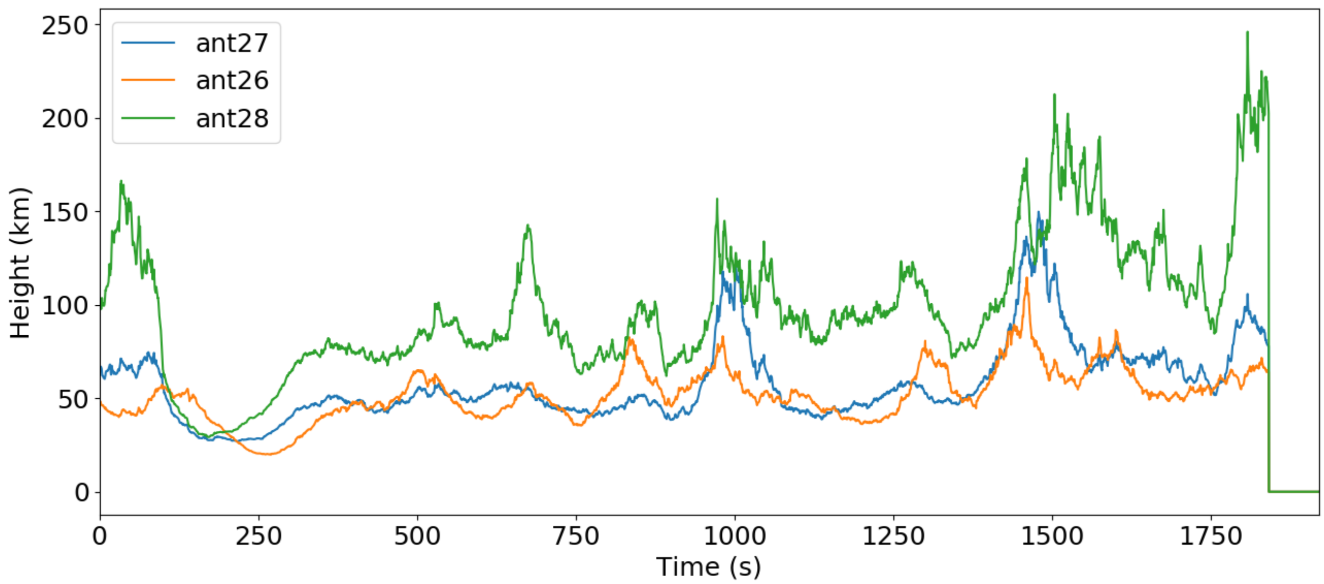
For the second mode of data processing, we wish to observe signals that arrive over a range of angles from vertical to near-horizontal. To that end, we will also make LWA observations of short wave broadcast and time standard transmitters [13] located well beyond NVIS distance but within single hop propagation distance of up to 3200 km at frequencies near 5, 7, 10, 12 and 15 MHz.

A detailed observation plan with specific frequencies will be made based on HF propagation forecasts [14] once the scheduled observation days and times are known, see example on page 4. For both modes, we request to have the PASI data available if possible for comparison with our TBN data processing.

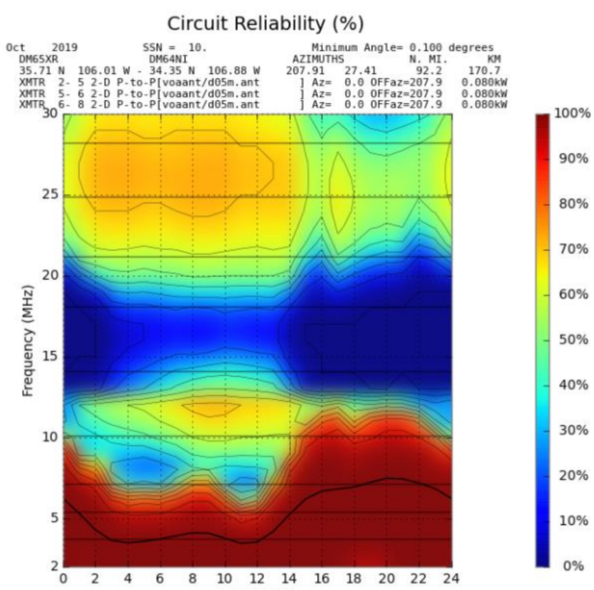
1. H. Rishbeth,"F-region links with the lower atmosphere?" J. Atmosphere and Solar-Terrestrial Physics, Vol. 68, Issue 3-5 (2006) 469-478.
2. Tuna, Hakan, Orhan Arikan, and Feza Arikan. "Model based Computerized Ionospheric Tomography in space and time." *Advances in Space Research* 61.8 (2018): 2057-2073.
3. Chen, Y.I., Liu, J.Y., Tsai, Y.B., Chen, C.S., 2004. Statistical tests for pre-earthquake ionospheric anomaly. Terrestrial, Atmospheric and Oceanic Sciences 15, 385–396.
4. Petraki et al, Electromagnetic Pre-earthquake Precursors: Mechanisms, Data and Models-A Review, J. Earth Science & Climatic Change 6 1 2015.
5. S. Pulinets, D. Ouzounov, A.Karelin, and D.Davidenko, "LithosphereAtmosphere–Ionosphere–Magnetosphere Coupling—A Concept for Pre-Earthquake Signals Generation", Chapter 6 in *Pre-Earthquake Processes A Multidisciplinary Approach to Earthquake Prediction Studies*, Geophysical Monograph 234, Wiley, 2018, pp. 79-98.
6. Occhipinti, Giovanni, et al. "Surface waves magnitude estimation from ionospheric signature of Rayleigh waves measured by Doppler sounder and OTH radar." *Scientific reports* 8.1 (2018): 1555.
7. Tuna, Hakan, Orhan Arikan, and Feza Arikan. "Model based Computerized Ionospheric Tomography in space and time." *Advances in Space Research* 61.8 (2018): 2057-2073.
8. Helmboldt, J. F., et al. "Passive all-sky imaging radar in the HF regime with WWV and the first station of the Long Wavelength Array." *Radio Science* 48.5 (2013): 491-512.
9. Lognonné et al, Seismic waves in the ionosphere, europhysicsnews 4 37 pg. 11.
10. Goodfellow, Ian, et al. *Deep learning*. Vol. 1. Cambridge: MIT press, 2016.
11. Knut von Salzen et al, (2013) The Canadian Fourth Generation Atmospheric Global Climate Model (CanAM4). Representation of Physical Processes, Atmosphere-Ocean, 51:1, 104-125.
12. http://www.idahoares.info/tutorial_hf_nvis_band_selection.shtml
13. https://short-wave.info/
14. http://www.voacap.com/overview.html



Relative phase of LWA antennas using WWV 5 MHz signal



Estimated Ionosphere Height



VOACAP propagation forecast for October 2019 for circuit from Sante Fe to LWA-SV

Gmail

Peter Driessen <uvic00@gmail.com>

LWA CFP8 TAC results

10 messages

Ylva M Pihlstrom <ylva@unm.edu> Mon, Dec 16, 2019 at 2:07 PM
To: "peter@ece.uvic.ca" <peter@ece.uvic.ca>
Cc: Jayce Dowell <jdowell@unm.edu>, Gregory Taylor <gbtaylor@unm.edu>

Dear Dr. Driessen,

Your project 'LWA observations of earth-disturbing events and atmospheric parameters' (LWA project ID LD015) has been accepted for observing with 96 LWA-SV TBN hours allocated. In the end of this email you will find the average referee grade for your project together with comments from the review process. For LWA CFP8, the oversubsricption rate measured in beam hours at the LWA1/LWA-SV combined was about 2.

CFP8 observations will begin on January 1st, 2020, and we encourage users with time allocated to begin submitting their observing schedules as soon as possible, as Session Definition Files (SDFs). Prepared SDFs should be submitted via the validator (http://fornax.phys.unm.edu/lwa/validator/index.html).

For information on how to prepare your SDF, please consult the following web pages available under the LWA Astronomer web page:

http://www.phys.unm.edu/~lwa/obssched.html (main observing web page)
http://www.phys.unm.edu/~lwa/astro/currentissues.html (currently known constraints and issues with LWA1)
http://www.phys.unm.edu/~lwa/astro/scheds/schedhints.html (Hints on how to prepare your SDF)

For inquiries, please email lwa@unm.edu.

Regards,
The LWA CFP8 TAC

LD015 Time Allocation Summary

Average grade: 4.2 (scale 1-5)
Time allocated: 96 LWA-SV TBN hours

TAC referee comments:
The TAC supports this project, and interesting work has been done during 2019 for LD010.

Individual referee comments:

* Continuation of a project aiming to understand how the ionosphere is affected by Earth-related events. The project is well planned and there is an ongoing collaboration with LANL and FCC for required transmissions. Not suitable for interruptions as there must be coordination with transmissions.

* The team carried out three campaigns in 2019 using both signals of opportunity like WWV and also a 100 W transmitter in Santa Fe. The results seem interesting with a possible detection of some sort of wave over LWA-SV. Investigations of bottomside ionospheric structure have been carried out before, but there is still much to learn and it is worthwhile to have another team working in this area. The proposed observations look doable

To: Peter Driessen
E-Mail: peterdri@gmail.com
From: OET Systems Administration (Batch Processing) OET Systems Administration (Batch Processing)
Date: May 07, 2019

Subject: OET Experimental License Grant Notification, Call Sign: WO9XIX File Number: 0690-EX-ST-2019

Message:

This is notification that the filing associated with callsign WO9XIX and file number 0690-EX-ST-2019 has been granted. It will remain in effect until its scheduled expiration date of 01/01/2020.

To view this grant, please visit the OET Experimental Licensing Branch Electronic Filing Site.

This is an automated message. Please do not reply to this e-mail.

Peter Driessen, P.O. Box EOW 448, 3800 Finnerty Road, Victoria, V8P5C2, Canada

United States of America
FEDERAL COMMUNICATIONS COMMISSION
EXPERIMENTAL
SPECIAL TEMPORARY AUTHORIZATION

EXPERIMENTAL
(Nature of Service)

WO9XIX
(Call Sign)

XT   FX
(Class of Station)

0690-EX-ST-2019
(File Number)

NAME Peter Driessen

This Special Temporary Authorization is granted upon the express condition that it may be terminated by the Commission at any time without advance notice or hearing if in its discretion the need for such action arises. Nothing contained herein shall be construed as a finding by the Commission that the authority herein granted is or will be in the public interest beyond the express terms hereof.

This Special Temporary Authorization shall not vest in the grantee any right to operate the station nor any right in the use of the frequencies designated in the authorization beyond the term hereof, nor in any other manner than authorized herein. Neither the authorization nor the right granted hereunder shall be assigned or otherwise transferred in violation of the Communications Act of 1934. This authorization is subject to the right of use of control the Government of the United States conferred by Section 706 of the Communications Act of 1934.

Special Temporary Authority is hereby granted to operate the apparatus described below:

Purpose Of Operation:
The purpose is to measure properties of the ionosphere using the 256-element Long Wavelength Array in New Mexico to receive signals from a terrestrial transmitter just outside ground wave

Station Locations
(1) Santa Fe (SANTA FE), NM - NL 35-42-41; WL 106-00-30

35.71139 106.0083

Frequency Information

LWA SV 34.349268 106.88426

Santa Fe (SANTA FE), NM - NL 35-42-41; WL 106-00-30

Frequency	Station Class	Emission Designator	Authorized Power	Frequency Tolerance (+/-)
4000 kHz	FX	1H00A0 75K0A1A	100 W (ERP)	1 %
5300-5375 kHz	FX	1H00A0 75K0A1A	100 W (ERP)	1 %
5351.5 kHz	FX	1H00A0	100 W (ERP)	1 %

This authorization effective July 01, 2019 and will expire 3:00 A.M. EST January 01, 2020

FEDERAL COMMUNICATIONS COMMISSION

Frequency Information

Santa Fe (SANTA FE), NM - NL 35-42-41; WL 106-00-30

Frequency	Station Class	Emission Designator	Authorized Power	Frequency Tolerance (+/-)
5351.5 kHz	FX	1H00A0 75K0A1A	100 W (ERP)	1 %
7050-7125 kHz	FX	1H00A0 75K0A1A	100 W (ERP)	1 %

Special Conditions:

(1) Licensee should be aware that other stations may be licensed on these frequencies and if any interference occurs, the licensee of this authorization will be subject to immediate shut down.

(2) In lieu of frequency tolerance, the occupied bandwidth of the emission shall not extend beyond the band limits set forth above.