Towards a New Frontier in Radio Science:

Amateur - Professional Connections for Geospace Research

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HamSCI Meeting
NJ Institute of Technology
23 February 2018
Although radar has emerged from the war as a startling new discovery, its principles are not as new as they might appear to be at first hand. Radar was known and developed simultaneously in America, England, France and Germany during the early 1930s. Like every other electronic device, its development and improvement was predicated on the development and availability of tubes. The heart of any electronic device is a tube, whether it be a radio set, a radar, or an electronic counting device.

Very early radars were low-frequency devices which used enormous dual antennas and large, bulky transmitters and receivers. It was known at the time that radars capable of greater resolution and accuracy, as well as much smaller and lighter in weight, could be developed if tubes could be made available to generate power at the superhigh frequencies. Accordingly, the British Admiralty assigned the problem of developing a generator of microwaves to a research group at the University of Birmingham. The Birmingham group developed a practical form of cavity magnetron which, along with other developments, opened the possibility of obtaining satisfactory power output at extremely short wave lengths. In the latter part of 1940, a British technical mission visited the United States, and it was during this visit that the American contribution was made.

This type of package magnetron uses direct coupling from one of the magnetron cavities to a section of wave guide. The glass window on this section of guide acts as a matching transformer into the external wave guide. The glass boot around the heater leads is cut away to provide for forced cooling of the heater leads and seal, so as to permit to reach its objective and to be reflected.

Profound Thanks:

Dr. Bill Liles, NQ6Z
Dr. Ethan Miller, K8GU - Johns Hopkins APL
Ward Silver, N0AX - ARRL
Carl Luetzelschwab, K9LA
Prof. Nathaniel Frissell, W2NAF - NJIT
Dr. Terry Bullett, KD0ZWU - NOAA
Prof. J. M. Ruohoniemi, Virginia Tech
John Ackermann, N8UR
Rich Moseson, W2VU
José Nunes, CT1BOH
Will Rogers, KD4FOV - MIT Haystack
Skip Youngberg, K1NKR
Joe Dzekевич, K1YOW

Nashoba Valley Amateur Radio Club (NVARC)
American Radio Relay League

HamSCI Meeting  NJ Institute of Technology  23 February 2018
Early Influences

Hallicrafters SX-110 (1962)

6SG7 RF Amp, 6SA7 Converter, 6SG7 1st IF Amp, 6SK7 2nd IF Amp, 6SC7 Audio Amp/BFO, 6K6GT Audio Output, 6H6 Detector/ANL/AVC and 5Y3GT Rectifier.
Railway Express Agent
Stanley Skillen (left)

Operator and 2nd “trik” agent
Charles Reiss (middle)

P. J. Terni (right)
October 21, 1957
Millerton, NY

Harlem Valley RR
NY Central
When Langmuir arrived at the Laboratory, the director, Willis R. Whitney, told him to look around and see if there was anything he would like to “play with.” Whitney would often ask him, “Are you having any fun today?” One day, after three years of apparently unproductive research, Langmuir answered, “I’m having a lot of fun, but I really don’t know what good this is to the General Electric Company.” Whitney replied, “That’s not your worry. That’s mine.”
MIT Haystack Observatory Complex
Westford, Massachusetts
Established 1956

Radio Astronomy
Atmospheric Science
Space Surveillance
Radio Science
Education and Public Outreach

Haystack Observatory
Millstone Hill Observatory
Millstone Hill Radar
Firepond Optical Facility
Amateur Radio’s Influence on Science and Technology
Edwin Howard Armstrong
1890-1954

Regeneration
Superregeneration
FM Modulation

A New Method for the Reception of Weak Signals at Short Wave Lengths

By Edwin H. Armstrong, E. E.*

THE problem of receiving weak signals of short wave length in a practical manner has become of great importance in recent years. This is especially true in connection with direction finding work where the receiver must respond to a very small fraction of the energy which can be picked up by a loop antenna.

The problem may be summed up in the following words: construct a receiver for undamped, modulated continuous and damped oscillations which is substantially equally sensitive over a range of wave length from 50-600 meters; which is capable of rapid adjustment from one wave to another, and which does not distort or lose any characteristic note or the resulting low frequency current. Two limitations at once present themselves, one inherent in low frequency amplifiers and the other inherent in all known rectifiers. The limitation in the amplifier is the residual noise which makes it impractical to use effectively more than two stages of amplification. The second limitation lies in the characteristic of the detector or rectifier. All rectifiers have a characteristic such that the rectified or low frequency current is roughly proportional to the square of the impressed high frequency E. M. F. Hence the efficiency of rectification becomes increasingly poorer, the weaker the signal until a point is reached below which the detector practically ceases to respond.

*President, Radio Club of America.
A METHOD OF REDUCING DISTURBANCES IN RADIO SIGNALING BY A SYSTEM OF FREQUENCY MODULATION

By Edwin H. Armstrong

Summary—A new method of reducing the effects of all kinds of disturbances is described. The transmitting and receiving arrangements of the system, which makes use of frequency modulation, are shown in detail. The theory of the process by which tone reduction is obtained is discussed and an account is given of the practical realization of it in transmissions during the past year from the National Broadcasting Company’s experimental station on the Empire State Building in New York City to West Hempstead, Long Island, and Hudsonfield, New Jersey. Finally, methods of multiplying and the results obtained in those tests are reported.

PART I

It is the purpose of this paper to describe some recent developments in the art of transmitting and receiving intelligence by the modulation of the frequency of the transmitted wave. It is the further purpose of the paper to describe a new method of reducing interference in radio signaling and to show how these developments may be utilized to produce a very great reduction in the effects of the various disturbances to which radio signaling is subject.
Prior to the opening ceremony of WJZ in NYC, Armstrong climbed up the transmitter. Sarnoff was not amused.
Tom Clark K3IO
Leading authority on Very Long Baseline Interferometry; amateur satellite pioneer, president of AMSAT, digital communications pioneer.

Owen Garriott W5LFL
Pioneered the use of ham radio from Earth orbit during his "spare time" on shuttle flight STS-9 / Spacelab November 1983
(proposed doing this earlier during Skylab 3 July 1973)
Father of Richard Garriott W5KWQ
Soyuz TMA-3 October 2008
Al Gross W8PAL
Invented handheld radio transceiver (walkie-talkie), telephone pager, and cordless telephone

George Jacobs W3ASK
Amateur satellite pioneer. HF broadcast engineering expert, developed Voice of America’s worldwide broadcasting system

Left: holding OSCAR 1, 1961.
Phil Karn KA9Q
Developed basis for wireless internet communications by adapting Internet communications protocol (TCP/IP) for radio use

John Kraus W8JK
Radio astronomy pioneer
The “Big Ear” Radio Observatory (Ohio)
Ernst Krenkel   RAEM
Polar explorer, expedition communicator,
Russian radio hero, made first Arctic-Antarctic
radio contact

Grote Reber W9FGZ
“Father” of radio astronomy

Ernst Krenkel   RAEM
Polar explorer, expedition communicator,
Russian radio hero, made first Arctic-Antarctic
radio contact
Eugene Senti WØROW
As engineer for Collins Radio, invented the radio transceiver (transmitter and receiver in a single package, with shared circuitry)

Paul Baran W3KAS
Invented packet switching, basis of Internet and other modern communication networks; developed first telemetry equipment for NASA
Harold Beverage  W2BML
Inventor, Beverage antenna

Bob Bruninga WB4APR
Developer of APRS (Automatic Position Reporting System)
Joe Taylor K1JT
Steve Franke K9AN

Developers of weak signal HF communications modes (JT65, JT9, FT8)

Taylor: radio astronomer
Nobel Prize, Physics
Binary pulsar discovery (with Russell Hulse)
William Eitel W6UF
Co-founder, Eimac, with Jack McCullough, W6CHE

Sam Harris W1FZJ
VHF pioneer, QST columnist; made first EME contact, engineered Arecibo radiotelescope
Chuck Towns K6LFH
Amateur satellite pioneer; OSCARs I & II built in his garage

Antonio Elias KA1LLM
Executive Vice President and General Manager for Advanced Sciences, Orbital Sciences Corp
Led technical team that designed and built the air-launched Pegasus booster as well as the X-34 hypersonic research vehicle
Bob Rouleau VE2PY
First to modify commercial digital communications protocol for amateur use, leading to development of amateur packet radio

Oswald Garrison “Mike” Villard, Jr. W6QYT
SSB pioneer, meteor scatter pioneer, invented over-the-horizon radar, developed “stealth” technology
Ivan “Sonny” Harrison W5HBE
Developed the “Carterphone” phone patch to connect radios to the telephone network, leading to the U.S. Supreme Court’s “Carterphone” decision, which opened the door for connecting all sorts of devices, including computers and modems, to the telephone network. This paved the way for widespread internet and e-mail access via “dialup” connections.

Phillip Smith 1ANB
Inventor of the Smith Chart for determining transmission-line impedances
Loyd Sigmon W6LQ
Developed first radio traffic alert system, “SigAlert,” in Los Angeles; precursor of today’s radio traffic reports.

Marshall Ensor W9BSP
Helped track down German “Wolf Pack” submarines during WW II by refining radio direction-finding (RDF) techniques.
Reginald Fessenden VP9F
Father of radiotelephony; first wireless radio broadcasts (1906)

Hazard “Buzz” Reeves K2GL
President, Cinerama; developed method of affixing strip of magnetic oxide to movie film, making it possible to record pictures and sound simultaneously on one piece of film.
James Hillier ex-VE3SH
Co-inventor of scanning electron microscope; former head of RCA Labs.

John Kanzius K3TUP
Inventor of possible cure for cancer using RF energy; process for possible use of seawater as fuel.

William Bridges W6FA
Laser pioneer; developed first “noble gas” lasers (argon, krypton, xenon) and the dominant modulation system for feeding data into fiber-optic cables
George Smith AA2EJ
Inventor of the CCD (charge-coupled device) sensor, which revolutionized digital imaging; co-recipient of the 2009 Nobel Prize in Physics.

E. King Stodola W2AXO
Pioneer of EME (Earth-Moon-Earth communications).
Pioneer in development of radar; scientific director of Project Diana (Earth-moon radar signals in 1946; proof that radio could transit the ionosphere in both directions). Foundations of communication satellites and radio astronomy advances.
Clifford Berry W9TIJ
Co-inventor of the Atanasoff-Berry computer (or ABC), the precursor to virtually all electronic computers

Paul Laughton N6BVH
Apple’s disk operating system; Atari’s operating system

Steve Wozniak ex-WV6VLY and ex-WA6BND
Co-founder of Apple Computers.
Matt Ettus N2MJI
Software defined radio pioneer; developed first Universal Software Radio Peripheral (USRP) with GNU radio software support

Terry Fox N4TLF
Packet radio pioneer; primary developer of AX.25 amateur packet protocol (also used in many cubesat radios)
Recording by Roy Welch
Dallas, TX
Feb 11, 1958

Discovery of the Radiation Belts
Explorer 1 1958
James Van Allen

(Sven Grahn)
Future Shock:
Modern (and Disruptive) RF Technology
Hardware and Software
**KITS: 20M WSPR-Pi (QRPi)**

<table>
<thead>
<tr>
<th>Popular</th>
</tr>
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<tbody>
<tr>
<td>HackRF One</td>
</tr>
<tr>
<td>HPSDR - TR-Plus</td>
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<tr>
<td>Raspberry Pi WSPR TX module</td>
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<tr>
<td>Pulse Puppy</td>
</tr>
<tr>
<td>TASS - Coax Relay System</td>
</tr>
<tr>
<td>TICC</td>
</tr>
<tr>
<td>TNS-BUF</td>
</tr>
</tbody>
</table>

### Raspberry Pi QRP TX Shield for WSPR on 20 Meters

Nowadays, one of the most impressive QRP modes is Joe Taylor, K1JT’s WSPR (pronounced "WSPR") mode. WSPR stands for "Weak Signal Propagation Reporter." Programs written for WSPR mode allow users to send and receive low-power transmissions to test propagation paths on the MF, HF and VHF bands. Users with Internet access can watch results in real time at wsrtnet.org.

The QRPi board (or shield as referred by the community today) is an inexpensive way of turning a Raspberry Pi single-board computer into a QRP transmitter.

Traditionally, a LPF removes harmonics from a transmitter output, but leaves any broadband noise that is not filtered by a BPF.

To protect the clock generator output stage of the Pi, a buffer amp is provided for isolating the circuit.

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**Leo Bodnar electronics**

**Precision Frequency Reference (GPS Clock)**

**Price: 150.00GBP**

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**QRP Labs**

**Si5351A Synthesizer**

**Hans Summers G0UPL**

**QRP Labs Shop**

**Click here for Shop!**

---

**Disruptive Hardware: RF Tools of the Trade**

---

**Click!**

**Shop order $7.75**
Blurring the Hardware/Software Line for RF Transducers
Reverse Beacon Network

- Volunteer Network
- ~130 Nodes
- Data back to 2009
Big Data – Other Ham Networks

<table>
<thead>
<tr>
<th>Network</th>
<th>Start Year</th>
<th># Spots</th>
<th>DB Size</th>
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<td>2008</td>
<td>535,000,000</td>
<td>44 GB</td>
</tr>
<tr>
<td>RBN</td>
<td>2009</td>
<td>578,000,000</td>
<td>36 GB</td>
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<tr>
<td>PSKReporter</td>
<td>2013</td>
<td>1,000,000,000</td>
<td>100 GB</td>
</tr>
</tbody>
</table>

• There is A LOT of data.
• This is not a “traditional” experiment.
• How do we analyze this?
Citizen Science: Early Forays
The Story of the Transatlantics

By The Editor

The signals of some thirty-odd American amateur radio stations, working on the short wave lengths and low power permitted amateurs, were heard across the Atlantic Ocean in the second series of Transatlantic Sending Tests conducted by the American Radio Relay League in December, 1921. This is a story of that achievement.

The First Attempt

The possibilities of transatlantic tests were first presented to the amateur world in 1920 by Mr. M. B. Sleeper, at that time radio editor of "Everyday Engineering". It is a subject that intrigues the amateur—his greatest desire in life is to get "distance" with his equipment. It has wondered and we even made the boast in print that if a dyed-in-the-wool American ham could be sent across the water with a good American regenerator we knew signals could be copied; in fact, we bet our new spring hat on it. Ever since then we have been answering inquiries from England as to just what a "ham" is, particularly one who has been dyed while still in the wool. But we're used to questions.

To Try Again

And so the matter of additional tests was taken up with Mr. Philip R. Coursey, assistant editor of "The Radio Review", London, who had managed the British end of the first tests, and he, finding British amateurs desirous of giving the game a

The following table lists the entrants in the finals:

<table>
<thead>
<tr>
<th>Call</th>
<th>Location</th>
<th>Type</th>
<th>Wave</th>
<th>Cypher</th>
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<td>200</td>
<td>YLPMV</td>
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<td>C.W.</td>
<td>200</td>
<td>BPUSC</td>
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<td>C.W.</td>
<td>200</td>
<td>CQVTD</td>
</tr>
<tr>
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<td>Spk.</td>
<td>210</td>
<td>DRWUF</td>
</tr>
<tr>
<td>1BCG</td>
<td>Greenwich, Conn.</td>
<td>C.W.</td>
<td>230</td>
<td>GODLY</td>
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<tr>
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<td>C.W.</td>
<td>200</td>
<td>FSXVG</td>
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<tr>
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<td>C.W.</td>
<td>200</td>
<td>GTYWH</td>
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<tr>
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<td>Brooklyn</td>
<td>C.W.</td>
<td>200</td>
<td>HUXJX</td>
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<tr>
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<td>200</td>
<td>JVAJK</td>
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<td>200</td>
<td>KVBZL</td>
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<td>C.W.</td>
<td>210</td>
<td>LXCAM</td>
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<td>C.W.</td>
<td>200</td>
<td>MYDBM</td>
</tr>
<tr>
<td>3BP</td>
<td>Newmarket, Ont.</td>
<td>Spk.</td>
<td>200</td>
<td>NZZCO</td>
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<tr>
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<td>200</td>
<td>OAGDF</td>
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<tr>
<td>9KO</td>
<td>St. Louis, Mo.</td>
<td>Spk.</td>
<td>200</td>
<td>PBHFG</td>
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<tr>
<td>9AW</td>
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<td>C.W.</td>
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<td>QCIJR</td>
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<td>12E</td>
<td>Marion, Mass.</td>
<td>C.W.</td>
<td>375</td>
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<td>C.W.</td>
<td>360</td>
<td>UHNLV</td>
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<td>Blackwell, Okla.</td>
<td>Spk.</td>
<td>375</td>
<td>YJOMW</td>
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<td>C.W.</td>
<td>375</td>
<td>WKPNX</td>
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<td>Spk.</td>
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<td>Minneapolis, C. W.</td>
<td>300</td>
<td>SFLJT</td>
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</table>
CQ Magazine sponsored
Radio Amateur Scientific Observations VHF project
late 1940s - early 1950s

- Sponsored by CQ in coordination with the U.S. Air Force Geophysical Research Division
- Investigated ionospheric phenomena at 50 MHz
- Ran from May 1949 to May 1952 and involved over 500 registered amateurs in the western hemisphere
- More than 100,000 observations collected by CQ and forwarded to the Air Force
- All amateur participants were issued certificates of appreciation by the U.S. Air Force

Findings included:
- Prevalence of Trans-Equatorial propagation
- Frequent VHF openings between North and South America
- Connections to Sporadic E
Interconnections: Science, Commercial, Radio Physics

Jicamarca Radio Observatory
Jicamarca, Perú
50 MHz phased array
late 1950s construction
US National Bureau of Standards
Radio Amateur Scientific Observations

Contributions to scientific research fully credited to amateur radio as a means of perpetuating the hobby, is the motivating force behind this non-profit CQ activity.

For well over one year, the staffs of CQ magazine has been giving serious thought to the future of amateur radio. All of us, at one time or another, have been told that being an amateur radio operator is a privilege and is something that must be earned. Unfortunately, once earning the privilege does not ensure its continuance for years to come. Instead, the desirability of allowing amateur radio to continue is always under scrutiny. This surveillance has been much greater in the postwar years and it is for the benefit of many radio amateurs that a few have exerted considerable effort to cast the hobby in a favorable light. The public and emergency services performed by radio amateurs are well known. In addition, the international aspects of the art should always be borne in mind, and only within the past few years have the experimental circuit developments of amateur radio lagged behind the commercial laboratories. But expansion of any of these was not the problem facing this staff. Rather, how could amateur radio most benefit the present scientific trends in adjacent fields?

A study showed that the collaboration between "Vic" Dawson, W3XZB, our V.H.F. Editor, and "Perry" Perrell, our Assistant Editor, in the field of wide wave propagation above 50 mc has uncovered several distinct phenomena. It was felt that if sufficiently accurate data were at hand we would find that the surface has only been scratched. As a result, several informal talks were held with various Governmental laboratories which might be interested in following up the suggested line of research. At the same time (i.e. last summer) a test run of the proposed 30-mc project was made. The response, although not as great as had been expected, was nevertheless large enough to aid in furthering its full-scale project, provided more amateurs cooperated. Believing in the intrinsic good judgment of a very large majority of the amateurs, this organization began negotiations with the Western Laboratories, Air Material Command, U.S.A.F., for the purposes of obtaining a cost-reimbursement non-profit contract to supply certain amateur radio observations to the Geophysical Research Division of the Western Laboratories.

The program as outlined in the negotiations was for Radio Magazines, Inc., to establish a separate section within its business organisation, and to carry forth a project of collecting Radio Amateur Scientific Observations. The Scientific Observations section would be directed by Mr. Perrell and would initially collect suitably data on the prevalence, distribution and intensity of radio waves propagated by means of sporadic-E ionized clouds, or by other means. Also, the Scientific Observations section would screen all data to insure their accuracy and reliability for use in further scientific investigations. Working on this basis, negotiations were completed and a formal contract for services and data was signed between the Government of the United States of America and Radio Magazines, Inc. on May 26, 1949.

By arbitrary definition, scientific observations in this project would consist for the present of any and all reports of reception of radio signals above 50 mc and beyond the limit of the Tropospheric Wave. Thus, no special tests or equipment are required in this project. The 6-meter band is ideally suited in the radio spectrum to detect and observe certain forms of sporadic-E ionization. Also, the most consistently active 6-meter operators are individuals who have been fascinated by the peculiar openings and the opportunity to work DX under pretty much unpredictable circumstances.

...Here the need is to resolve theoretical concepts with observed phenomena.

Today there is an absolute need for competent observations of various effects in the very high frequency radio spectrum. Such observations are needed to fill in many gaps in the theoretical basis of radio wave propagation. The number of observations needed is far greater than the facilities of even the well organized government research establishments can provide.

...Observations by amateurs when properly gathered, screened, and tabulated are very likely to prove one of the most valuable instruments that the scientists have at hand.
The Geospace Environment: Much Left to Discover..
Earth’s Ionosphere and Its Relation To The Atmosphere

Our planet’s neutral atmosphere.

Earth’s Ionosphere and Its Relation To The Atmosphere

.. is the source for the ionosphere.

Sun’s EUV rays ionize the neutral gas.

Ionosphere Vertical Structure

The F2 region varies by 3-5X diurnally, highest just after noon, lowest before dawn.

The F1 region and E region dissipate at night.

The D region is present only during daytime and in times of high activity.

Ionosondes Measure Up To $H_{\text{max}}$
Ionosphere Vertical Structure

(varies in altitude: space weather

(red = more electrons, blue = less; log scale!)

Varies in Altitude: Space Weather

Millstone Hill (eastern USA)
Ionosphere Horizontal Structure

(red = more electrons, blue = less; log scale!)

Geodetic median vertical TEC from 2017-07-04 00:00:00 to 2017-07-04 00:20:00

Varies in Space, Time: Space Weather

© 2017 MIT Haystack Observatory
Ionosphere Has Lots of Traveling Waves

ΔVTEC
2015-03-17 06:00:00

Varies in Space, Time: **Space Weather**

Vierinen, Rideout, Coster
MIT Haystack
Observations during an eclipse offer a special opportunity for studying both the solar ionizing radiations and the earth’s ionosphere. They are not ideal for this purpose. The ionospheric physicist might wish that the sun could be regarded as a constant, uniform source of ionizing radiation; but investigations of the sun show that it is not. The solar physicist would like to regard the ionosphere as a detector for ionizing radiation. But the ionosphere does not meet the basic requirements of a good detector: straightforward operation, reproducibility, and a linear or other convenient type of response.
Ionosphere Is Strongly Magnetized!

The Three Types of Motion of Charged Particles

Electrons cannot just go anywhere.
Gravity AND magnetic field direction are important

Study of this phenomena = Magnetoionic Propagation
This adds complexity to HF propagation predictions.
Ionospheric Radio: Effects of Magnetic Field

Two different indexes of refraction.. just like a birefringent crystal.

(Ethan Miller, JHU/APL)
Ray-Tracing Shows Complexity of HF Paths

2012-Sep-20 at 00:00 UT (~16:54 LT) (IRI-2012) SAS beam 5; freq 11.0MHz

SuperDARN HF Radar Network

(J. M. Ruohoniemi)
HF Propagation & The Ionosphere

BKS Beam 15

15.0 MHz

16 Nov 2015
0000 UT

10.0 MHz

16 Nov 2015
0000 UT
Geospace Environment: Complexity, Interconnectedness

The Space Weather Environment of the Earth
Ionosphere, Plasmasphere, Magnetosphere
Neutral Atmosphere Below, Heliosphere Above

(Grebowsky / NASA GSFC)
Juicy Science Examples
(many more possible..)
2017-09-06 Solar Flares at Geosynchronous Orbit

GOES X-ray Flux (1 minute data)

Begin: 2017 Sep 06 0900 UTC

Updated 2017 Sep 6 1407 UTC

NOAA/SWPC Boulder, CO USA
D Layer absorption affects lower freqs more than higher freqs.
Fades rapidly after sunset.

(Tom Carrigan, NE1R)
2017-09-06 Solar Flares: D Region Absorption

We need good worldwide coverage!
2017-09-05 Normal Conditions: Wallops, VA Ionosonde

No Flare

(Terry Bullett)
2017-09-06 Flare Effects: Wallops, VA Ionosonde

X9.3 flare 12 UTC (Terry Bullet)

(Terry Bullet)
CW Contest Op Hears A Flare’s HF Wipeout in Action..

X4.0 Solar Flare Arrival at 1638 UTC

José Nunes, CT1BOH
(QTH = Portugal)


CQ WW CW contest
26 November 2000
1636 - 1702 UTC

Call = P40E at the time
QTH = Aruba
June 13, 2016 6 Meter Double Hop Trans Atlantic Es DX Map

The VHF Gods Were Smiling on us this Day!

(QST Dec 2017)
Total Solar Eclipses
Citizen Science: SWL Eclipse Observations

Shortwave Signal Propagation 2017 Eclipse

Collected by J. S. Erickson Schenectady, NY

Eclipse Local Max

Totality location at time of max effect

WWV TX 10, 15 MHz

United States

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Propagation Estimates (Carl Luetzelschwab K9LA)

WWV 10.0 MHz to JSE SWL
August 21, 2017 at 1830 UTC
2618 km, o-wave
elevation angle = 26.0°

MUF = 17.0 MHz
absorption = 28.5 dB

WWV

from Proplab Pro V3

Collected by
J. S. Erickson
Schenectady, NY
Eclipse
Local Max

Non-eclipse ionosphere

WWV 15.0 MHz to JSE SWL
August 21, 2017 at 1830 UTC
2618 km, o-wave
elevation angle = 11.4°

MUF = 17.0 MHz
absorption = 13.5 dB

JSE SWL
We are in an exciting discovery period

Remember (and mine) what has gone before

Think about best tool use for science results

Great geospace science awaits.

Thanks.

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