Seeing the Ozone

Finding the needle in the haystack

The MOSAIC System

- The MOSAIC system consists of two parts
  - The front-end receiver
  - The back-end electronics and software
- MOSAIC is pointed into the sky, where it detects radio signals emitted by Ozone molecules in the Mesosphere
- One frequency emitted by Ozone is 11.0724545 GHz (let’s call it 11 GHz)

How do we know that?

- Amazingly, we are looking right through the Ozone in the Stratosphere and Troposphere. How?
- Asymmetric molecules emit microwave radiation at specific frequencies (see Radio Sources presentation)
- In a gas, spectral lines can spread around the center frequency for two reasons:
  - Doppler broadening due to gas turbulence
  - Pressure broadening

Pressure Broadening

- Collisions cause a homogeneous spreading or broadening of the nominal 11 GHz spectral line
- The atmosphere increases in density and pressure as you get closer to the ground
  - The denser the gas, the more frequent the collisions
- The 11 GHz line will broaden by
  - about 2 – 3 GHz near ground level
  - about 2 – 3 MHz in the Stratosphere
  - very little in the Mesosphere

Doppler Broadening

- Gas molecules are always moving, some of them will be moving toward you, others will be moving away from you (turbulence)
- This effect would contribute about 18 kHz of broadening for Mesospheric Ozone
  - the dominant broadening of Mesospheric Ozone
- Could still use the Doppler Shift (not broadening) of the center frequency (11.0724545 GHz) to measure an aggregate velocity of the Ozone

MOSAIC front-end receiver

- The front-end of the MOSAIC system is a standard Direct TV set-up designed for operation in Europe.
- There are two parts to the front-end
  - An 18” offset parabolic dish
  - A low-noise amplifier block (LNB)

The LNB

- The LNB (aka LNBF) is located at the focal point of the offset parabola
  - Sometimes called the “feed” or the “horn” (these are microwave engineering terms)
- The LNB bandwidth is important
  - Detects signals between 10.7 – 11.7 GHz

Pointing MOSAIC

- Analysis yields an optimal pointing angle of 8º above the horizon
  - Thickest slice of Mesospheric Ozone
  - Least amount of ground clutter into side lobes
- Be careful not to point MOSAIC toward European satellites in geosynchronous orbits (~ 35,800 km altitude)

Why an offset parabola?

- The LNB and its support are located outside of the path of the incoming energy
- Increases antenna efficiency to ~80% (versus 40% - 70% for other set-ups)

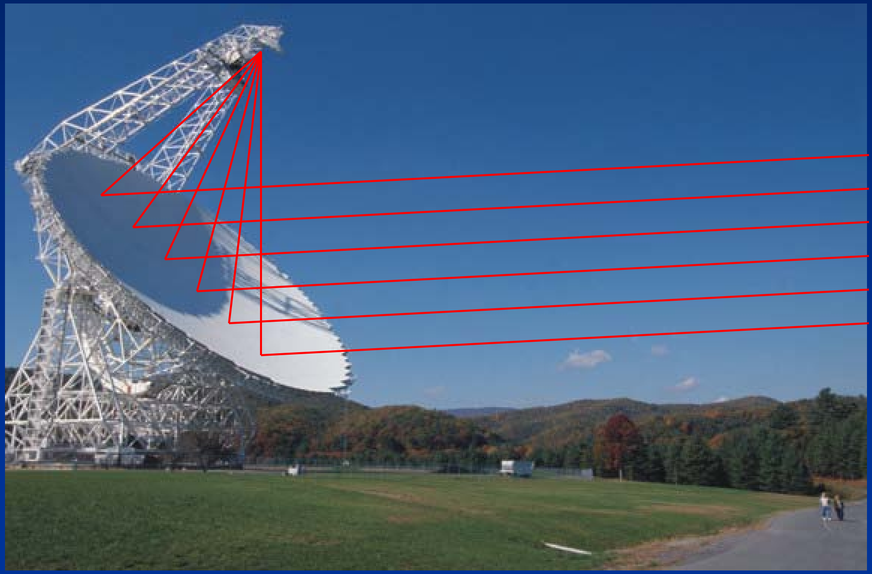


Image from NRAO / AUI / NSF

Dish Gain

- The dish will focus incoming radio waves
- Dish gain depends on three factors
  - Surface area
    - Gain goes up linearly with area
  - Signal frequency
    - Gain goes up as the square of frequency
  - Smoothness of surface
    - Imperfections to the parabola decrease gain

Beamwidth and Side Lobes

- The full width of the main lobe at half power is the beamwidth of the dish (MOSAIC ~ 4º)
- Not all energy reaching the LNB comes from along the primary axis of the parabola
- All antennae have parasitic "leakage" from off-axis sources (side lobes)

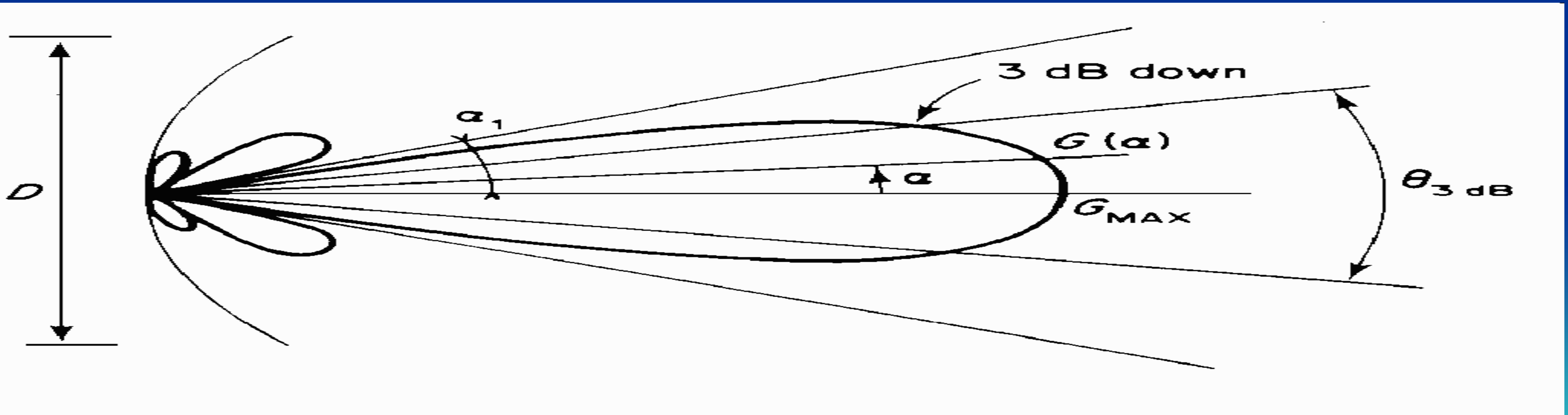


Image from the Australian Department of Communications and the Arts

Down Conversion

- The signal output of the LNB is in the range of 10.7 – 11.7 GHz
- This is “mixed” with a local oscillator (LO) to convert (shift) the signal to a more manageable 950 – 1950 MHz
- This signal is easier to transport over the cable to the back-end electronics

Cabling

- High frequency signals require specialized cabling
- Your telephone is run throughout your house over a twisted-pair of conductors
- MOSAIC requires shielded coaxial cables to carry the signals from the LNB to the back-end electronics
- Shielding inhibits the injection of noise from other sources during signal transport

Signal to Noise

- The signal from Mesospheric Ozone will be in the vicinity of $\sim 10^{-25}$ W or ~10 mK
- Such a tiny signal would be lost if the LNB contributes too much thermal noise
- The incoming signal will be summed over enough time (*integrated*) to build up significant samples
- If system noise is truly random, integration will suppress that noise

Calibrating MOSAIC

- The radio receiver is manually calibrated by placing an absorbing material in front of the antenna
- Frequency drift in the LO of the LNB is corrected by injecting a stable calibrated oven crystal oscillator signal about once every 90 seconds

The MOSAIC back-end

- Atmospheric Ozone does not transmit a clean, crisp signal for displaying on a TV
- The output of the LNB must be processed further
- Another down conversion takes place before the data enters the ADC (Analog-to-Digital Converter) inside of the PC

12-bit ADC

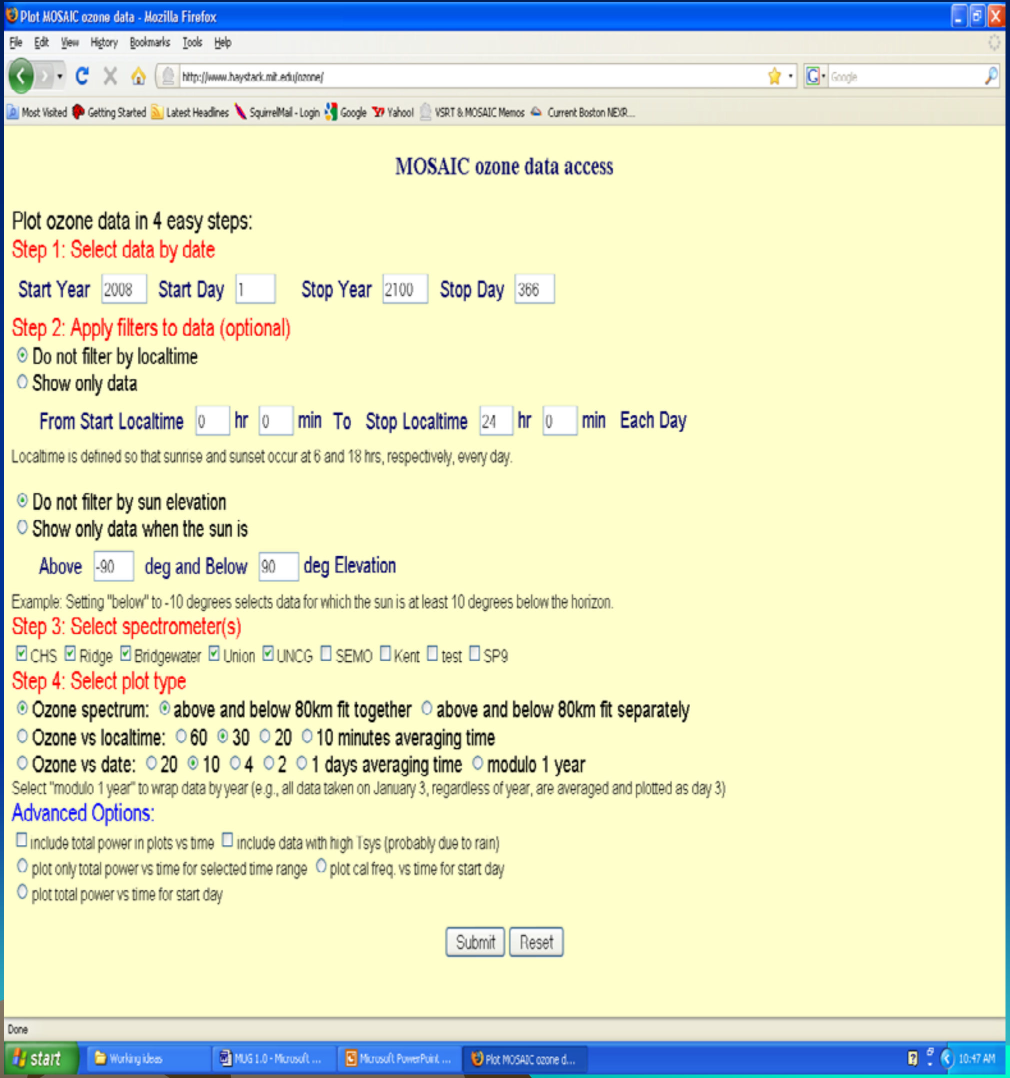
- One of the most expensive components in the MOSAIC system is the Analog-to-Digital Converter (ADC), an option board which is installed into a high-end PC
- The ADC is taking 12-bit samples at a rate of 20 million samples per second

MOSAIC Host Software

- The PC to which the MOSAIC antenna is attached will run a handful of scripts
  - Place data from ADC into files
  - Inject 10 MHz crystal into signal path
  - Upload files once a day
  - Check local PC clock
- You could run a spectrum at the Host location for that antenna's output

Signal Processing

- Access to real-time data and a GUI has been provided on the Haystack website
- Data files from the MOSAIC units are uploaded once every day



http://www.haystack.mit.edu/ozone/

The MOSAIC GUI

- The MOSAIC User's Guide will provide detailed instructions for the use of MOSAIC data
- The GUI will invoke Java/C programs on the server for data analysis and plotting
- The data files are also available for student storage and future use

Data Files

- The data file format is described in the Mosaic User Guide (MUG)
  – Basically a tab-delineated text file
- Advanced students could perform further analysis by importing into Excel or commercial software, such as MATLAB

GNU Octave

- GNU Octave is a high-level computer language primarily intended for numerical computations
- Octave is free software
  - – restrictions apply, see www.octave.org
- It is mostly compatible with the commercial software product MATLAB
  - – MOSAIC Memo #054 shows an example

Fourier Transform

- Signals captured in the time domain may be converted to the frequency domain by a mathematical process called Fourier Transformation
- The algorithm used on most computers is called the Fast Fourier Transform (FFT)
- The PC can handle other tasks, such as filtering and smoothing algorithms

FFT & Filtering Details

- MOSAIC software uses 4096 samples to derive a 10 MHz wide spectrum with 4.9 kHz resolution
- This is further smoothed to 9.8 kHz resolution, and only the central 1.25 MHz bandwidth is used for the Ozone line

MOSAIC Summary

- The MIT Haystack website hosts a GUI which allows students anywhere in the world to access real-time MOSAIC data
- Programs have been written to plot the O_3 center frequency, diurnal variations, and seasonal variations
- Access to the data is also provided for students who might wish to write their own processing programs via Excel or MATLAB
- A MOSAIC User's Guide (MUG) is available

Primary Source

- Many memos have been published by the Haystack staff regarding MOSAIC

http://www.haystack.mit.edu/edu/undergrad/VSRT/VSRT_Memos/memoindex.htm