Title

NVIS Frequency Selection at Mid-Latitudes

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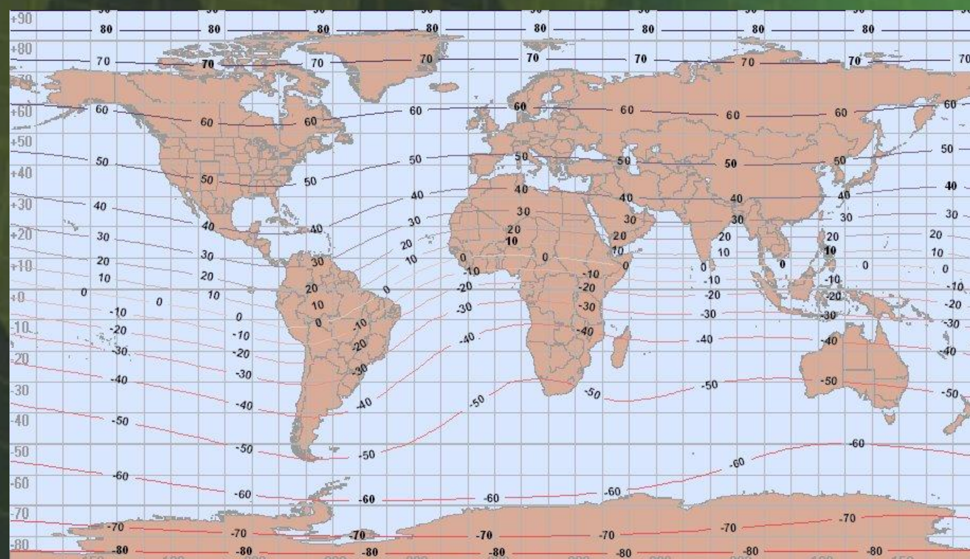
Target Audience

- HF user of NVIS communications techniques:
  - Military
  - Military Auxiliary Radio System (MARS)
  - Humanitarian
  - Amateur radio

Target Area

- Mid-latitude locations (between ~30-60° geomagnetic latitude, north or south)
- Map of modified DIP latitude

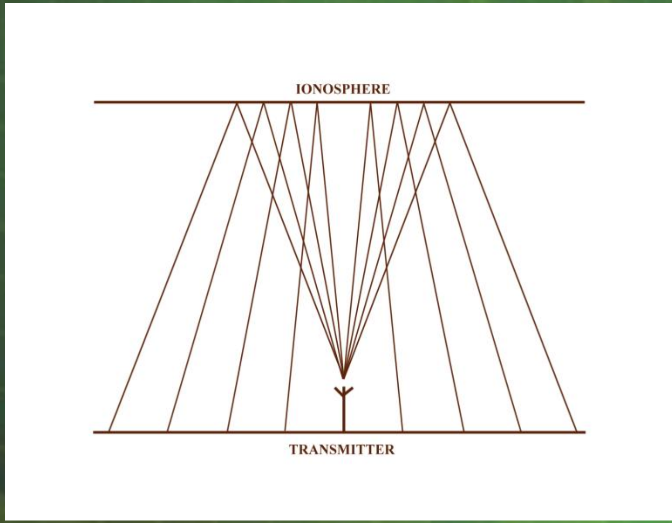


Outline of Presentation

- Introduction
- Some currently observed, incorrect NVIS guidelines
- Measurements (ionosonde and beacon)
- Propagation prediction software
- Frequency terms
- Other considerations (absorption, polarisation, noise)
- Summary

Introduction

- NVIS: Near-Vertical Incidence Skywave
- HF ionospheric propagation technique
- Low HF frequencies (2-10 MHz)
- High angle radiation
- Short ranges (up to 500 km)
- No skip zone
- Terrain insensitive



Some Currently Observed, Practical NVIS Guidelines for Frequency Selection

- *foF2* is maximum frequency supported by ionosphere at vertical incidence (INCORRECT)

  Observed in some practical HF system literature for professional applications

- FOT ≈ 85% of *foF2* (INCORRECT)

  Frequently observed in amateur/MARS literature

Some Current Practical NVIS Guidelines for Frequency Selection ($foF2$)

- $foF2$ is maximum frequency supported by ionosphere at vertical incidence (INCORRECT)
- Consider:

  Magnetoionic theory

  Ionosonde measurements (ionogram)

  UK NVIS measurements at 5 MHz

Magnetoionic Theory – Characteristic Waves in Ionosphere

- Existence of two characteristic waves in ionosphere:

  Ordinary wave (o-wave)

  Extraordinary wave (x-wave)

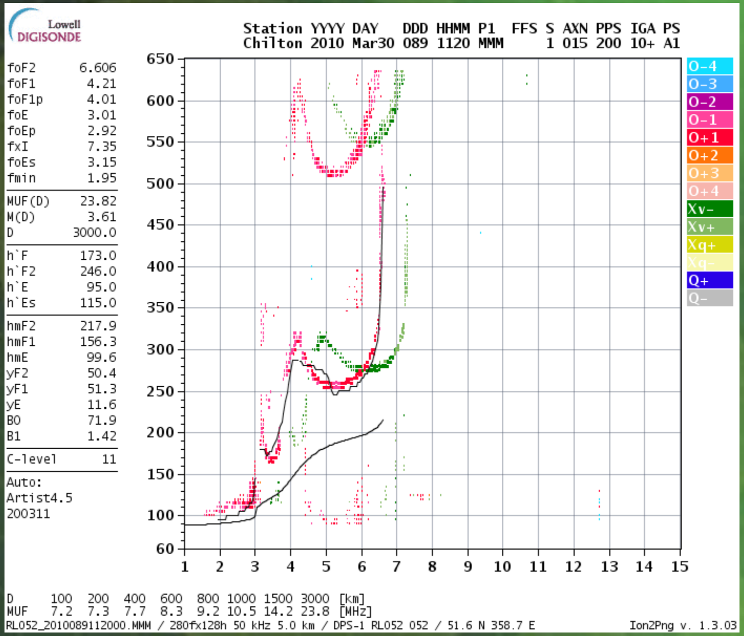
- Different critical frequencies related through electron gyrofrequency:

  $fxF2 - foF2 \approx f_H/2$

- Over UK, f_H ~1.2 MHz at 300 km altitude

Ionosonde Measurements – Chilton, UK

- Both o-wave and x-wave seen in ionogram
- *foF2*: o-wave critical frequency
- *fxF2*: x-wave critical frequency
- *fxI*: good approximation for *fxF2*



- *fxF2* is maximum frequency supported by ionosphere at vertical incidence

UK NVIS Measurements

- ‘The 5 MHz Experiment’
- UK amateur radio measurements
- Network of beacon transmitters
- Database available for analysis
- Good quality data
- Professional relevance

Beacon Transmitter Locations

- GB3RAL

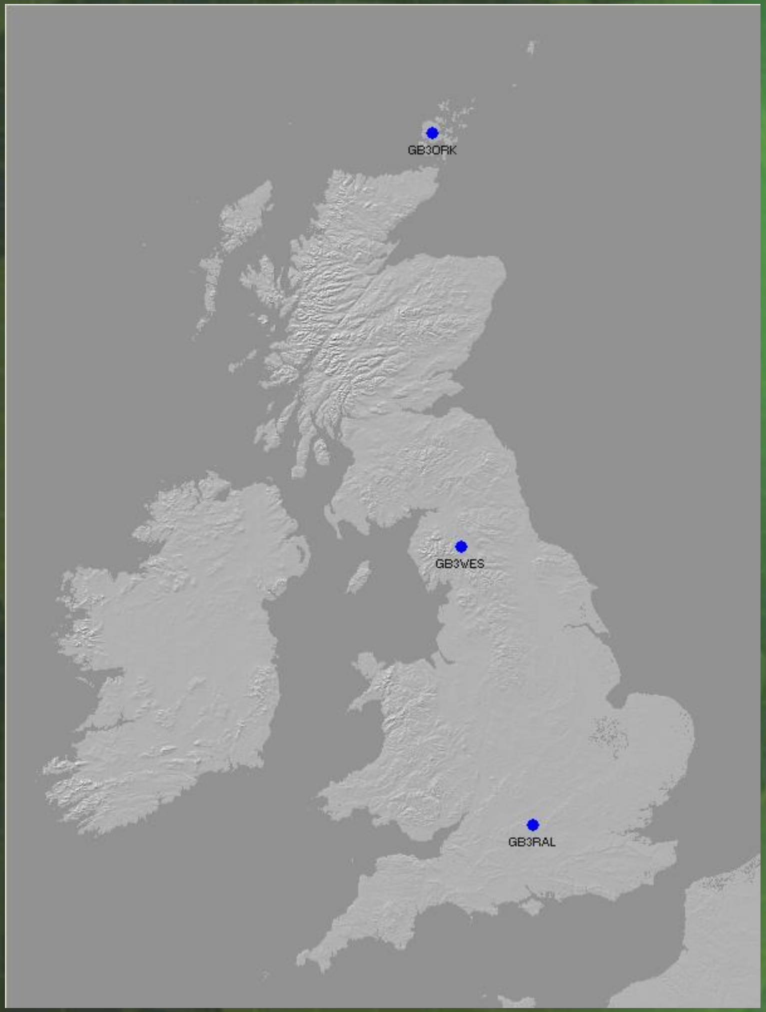
  Chilton

- GB3WES

  Cumbria

- GB3ORK

  Orkney



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Beacon Transmitters

- Frequency: 5.290 MHz
- Time and frequency-locked to GPS
- Transmit every 15 minutes

GB3RAL:	00, 15, 30, 45
GB3WES:	01, 16, 31, 46
GB3ORK:	02, 17, 32, 47

- Peak conducted power: 10 W
- Antenna: Inverted-V dipole

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Receiving Station Equipment

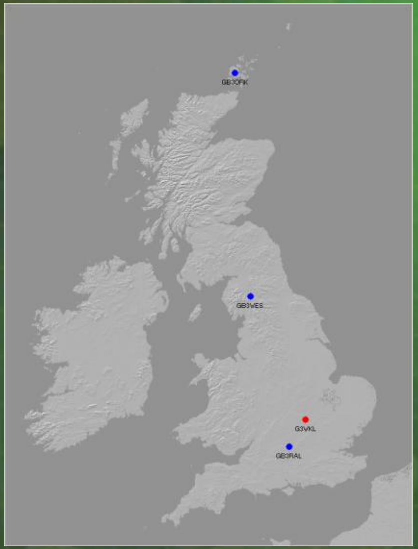
- Direct conversion (zero-IF) receivers
- No automatic gain control (AGC)
- Audio frequency output sampled by PC soundcard
- Measure peak signal and average noise
- Receivers calibrated

  Commercial signal generator
  Low-level crystal oscillator

Analysis for this Presentation

- Reception of GB3RAL (Chilton) at G3WKL
- Link range / bearing

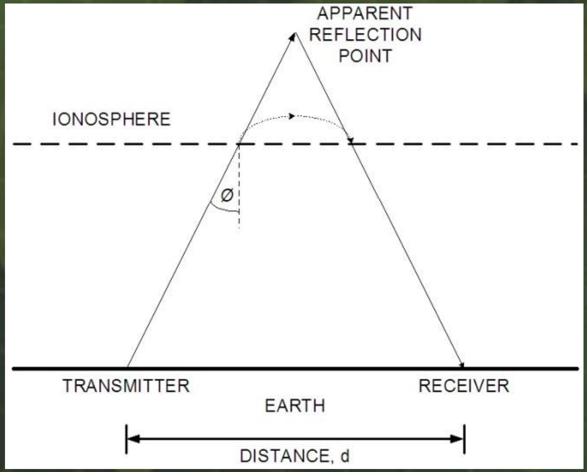
    70 km / 35°



- Correlate with ionosonde critical frequencies adjusted for secant law

Secant Law

- Ionosphere supports higher frequency at oblique incidence than normal incidence



$$f_{obl} = f_{vert} \sec(\phi) = \frac{f_{vert}}{\cos(\phi)}$$

$$f_{obl} = f_{vert} \sqrt{1 + \left(\frac{d}{2h'}\right)^2}$$

- Use critical frequencies *foF2* and *fxF2* in place of f_{vert}

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Secant Law Assumptions / Simplification

- Plane earth and plane ionosphere
- For simplicity, author has used *hmF2* instead of *h'*, which introduces error

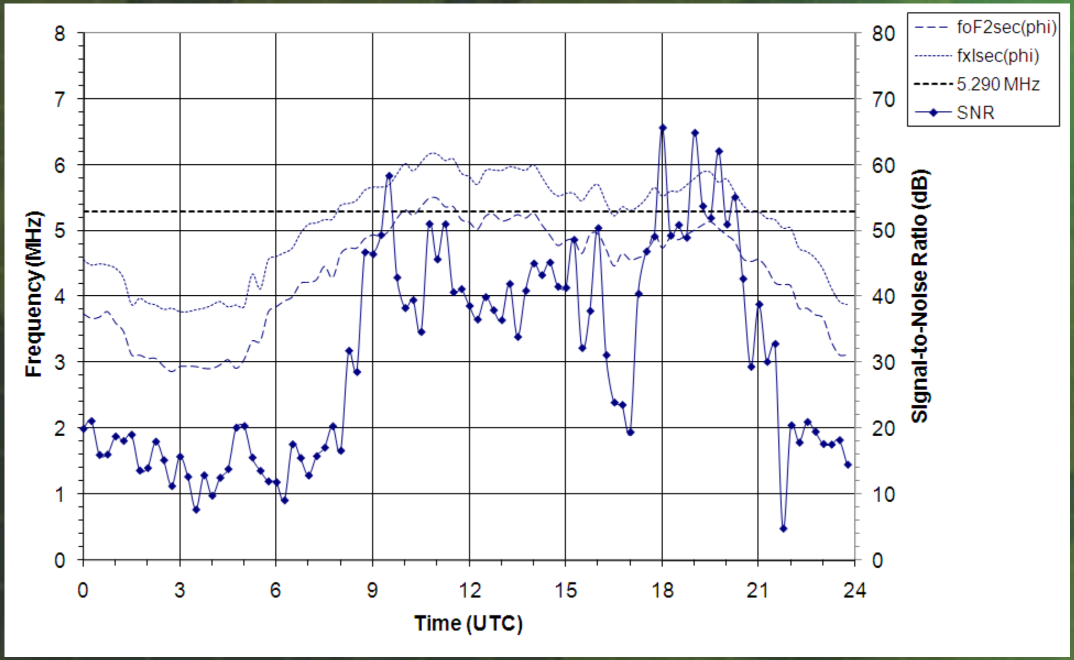
$$f_{obl} = f_{vert}\sqrt{1+\left(\frac{d}{2h'}\right)^2}$$

$$\frac{\partial f_{obl}}{\partial h'} = -f_{vert}\left(\frac{d}{2}\right)^2 \frac{1}{h'^3} \frac{1}{\sqrt{1+\left(\frac{d}{2h'}\right)^2}}$$

- Error small for short-range propagation via F2-region (i.e. NVIS propagation)
- Use ionosonde *fxI* parameter in place of *fxF2*

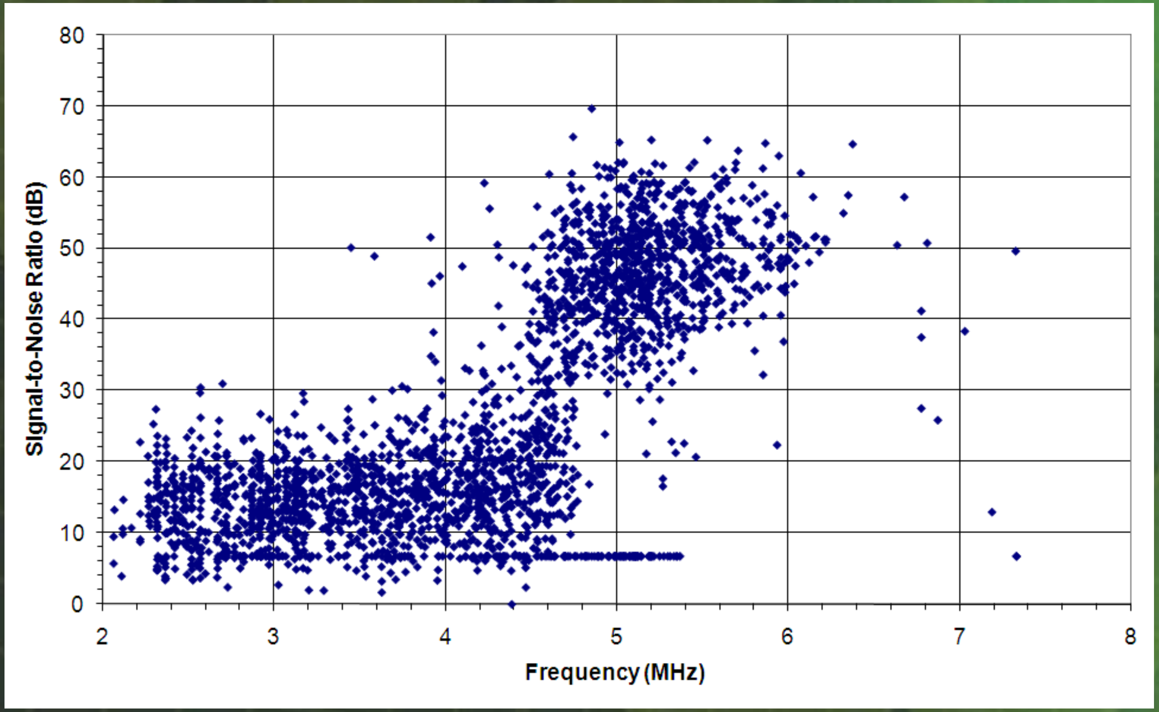
GB3RAL SNR at G3WKL
4th September 2007

- Compare SNR with Chilton $foF2\sec(\varphi)$ and $fxI\sec(\varphi)$
- Beacon reception when $fxI\sec(\varphi)$ > 5.290 MHz



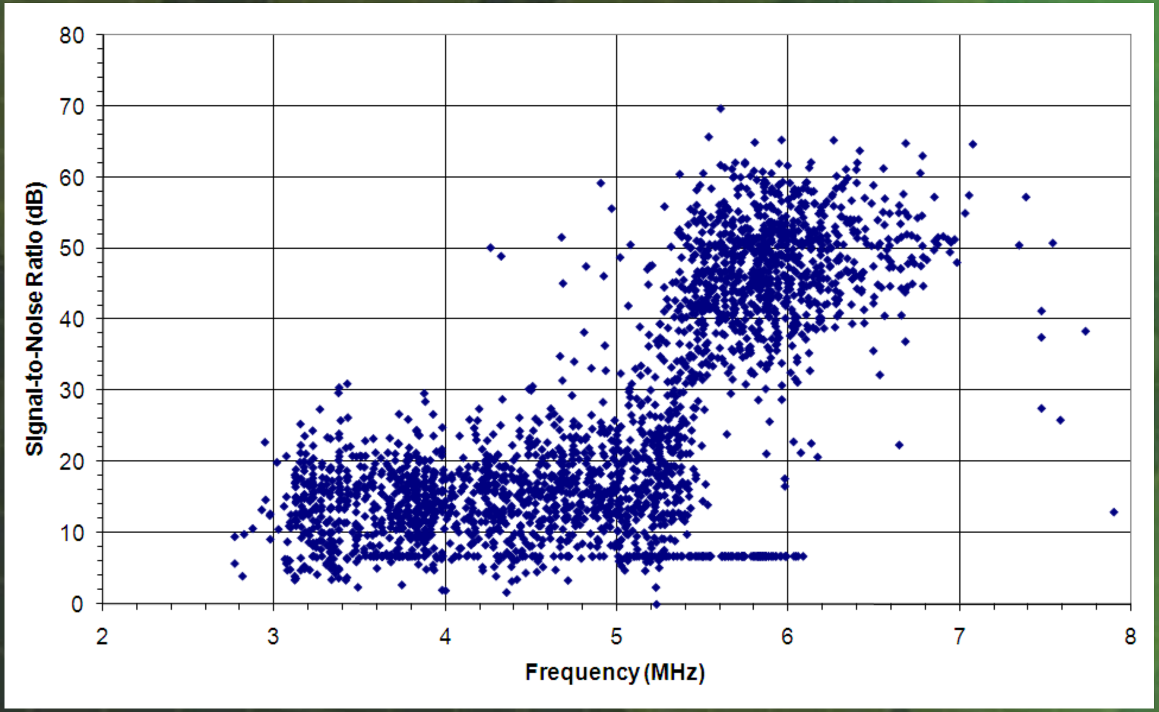
GB3RAL SNR at G3WKL Versus $foF2\sec(\varphi)$ September 2007

- Propagation supported when $foF2\sec(\varphi)$ < 5.290 MHz
- Contradicts NVIS $foF2$ maximum frequency guideline



GB3RAL SNR at G3WKL Versus *fxI*sec(φ) September 2007

- Propagation supported when *fxI*sec(φ) > 5.290 MHz
- Maximum NVIS frequency related to *fxF2*



Propagation Prediction Software (1)

- VOACAP: Voice of America Coverage Analysis Program
- ICEPAC: Ionospheric Communications Enhanced Profile Analysis and Circuit

Both based on IONCAP

Development dating back to Second World War (CRPL)

MUF calculation for F2-region based on x-wave component

Propagation Prediction Software (2)

- ITU-R REC533

  Half electron gyrofrequency included in MUF term for zero ground distance

- ASAPS: Advanced Stand Alone Prediction System

  Based on REC533

  fxF2 used for NVIS MUF calculation

Electron Gyrofrequency

- Equations for ionosphere critical frequencies depend on electron gyrofrequency

Exact: $$foF2^2 = fxF2^2 - fxF2\, f_H$$

Approximation: $$fxF2 - foF2 \approx \frac{f_H}{2}$$

- Electron gyrofrequency depends on Earth's magnetic field

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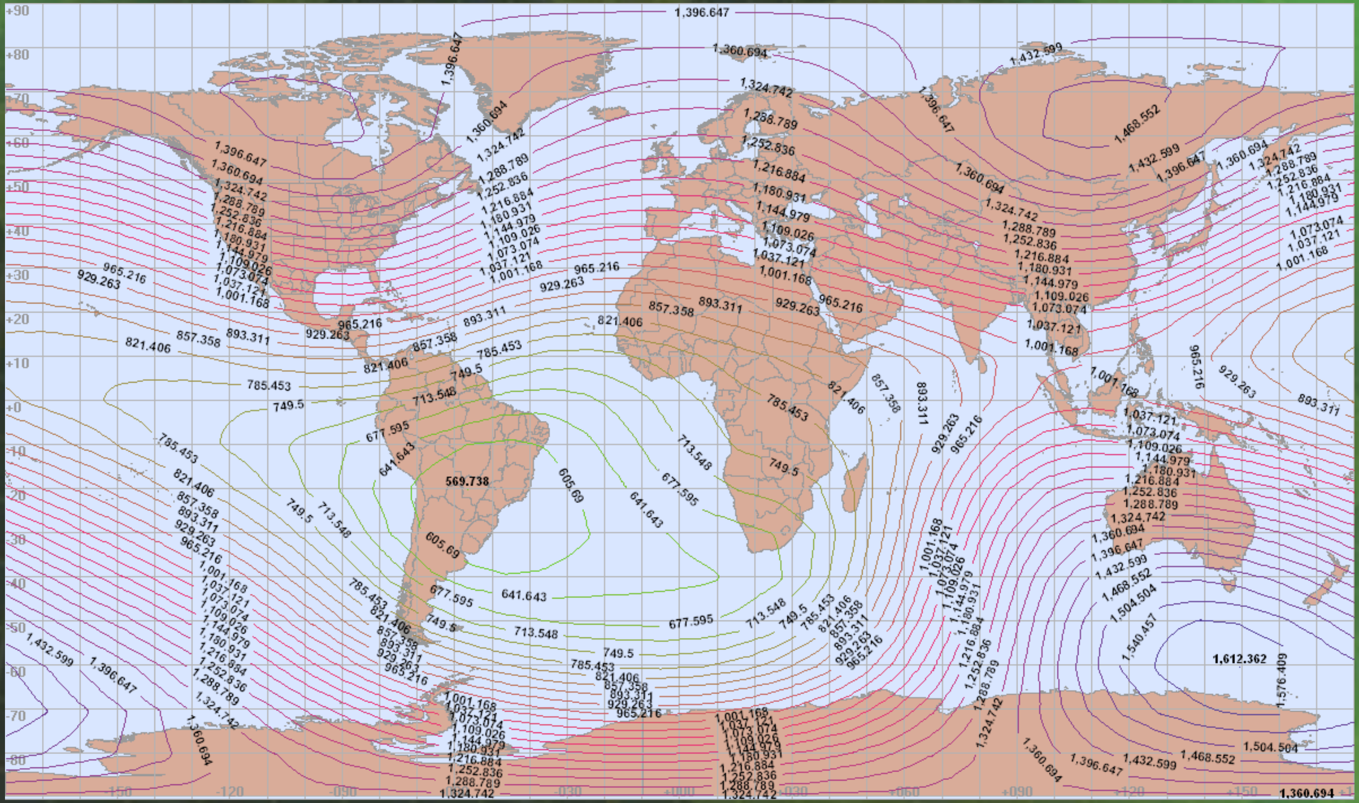
Electron Gyrofrequency Map

- At 300 km altitude (IGRF-10 model)



Some Current Practical NVIS Guidelines for Frequency Selection (FOT)

- FOT ≈ 85% of *foF2* (INCORRECT)
- Consider context
- Note *foF2* is a single measurement at a given time on a given day

Frequency Terms

- Variety of terms relating to frequency

  e.g. MUF, MOF, FOT, OWF, HPF

- MUF and MOF terms sometimes used interchangeably

- Meaning depends on context

MUF

- MUF: Maximum Useable Frequency

  (1) Daily maximum at a given time. Also Maximum Observed Frequency (MOF)

  (2) Monthly median of daily MOF at a given time

- MUF in propagation prediction tools (e.g. VOACAP) is monthly-median MOF

- Daily MOF exceeds MUF (monthly-median MOF) on 50% of days in month

HPF

- HPF: Highest Probable Frequency
- Context: Monthly-median predictions
- Daily MOF exceeds HPF on 10% of days in month

FOT (1)

- FOT: 1) Fréquence Optimum de Travail

  2) Frequency of Optimum Traffic
- OWF: Optimum Working Frequency
- Context: Monthly-median predictions

FOT (2)

- Daily MOF exceeds FOT on 90% of days in month
- FOT ≈ 85% of MUF (monthly-median MOF)
- Note daily MOF for NVIS propagation related to *fxF2*

FOT (3)

- FOT considered a ‘safe’ frequency that should usually work during the month
- Choose FOT if you have to choose only one frequency for a given link at a given time for the duration of the month
- Is FOT still relevant when multiple frequencies available (i.e. ALE)?

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ALE Frequency Scan List

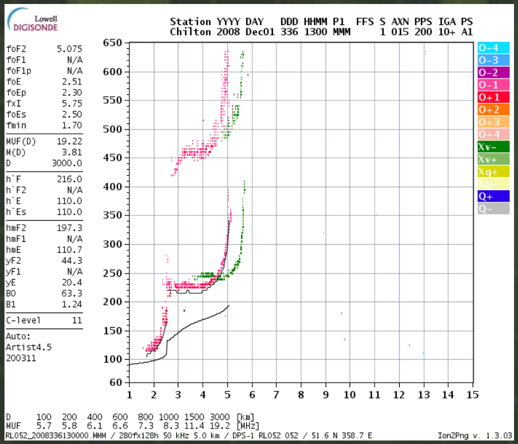
- ALE: Automatic Link Establishment
- Daily MOF can exceed MUF on 50% of days in month
- Frequency scan list should cover:
    - Diurnal MOF variation
    - Close to maximum HPF
    - Below minimum FOT

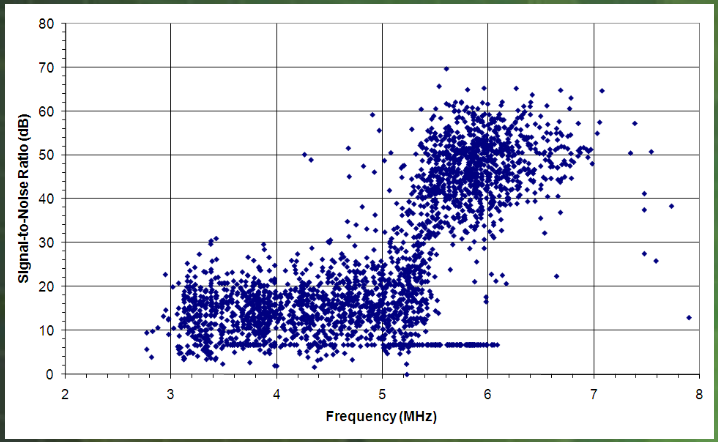
Some Other Considerations

- Absorption
- Polarisation
- Noise

Absorption

- Non-deviative
  - Greater loss at LF for x-wave (below ~3-4 MHz)
- Deviative
  - Greater loss near critical frequency





Wave Polarisation at Vertical Incidence (1)

- Elliptical polarisation at mid-latitudes
    - Very elliptical at MF
    - Circular at HF
    - Power divided evenly between o- and x-waves
    - Polarisation fading with linearly-polarised antenna
- Circular polarisation at magnetic dip pole

Wave Polarisation at Vertical Incidence (2)

- Linear polarisation at magnetic dip equator

  Ionosondes use linearly-polarised antennas to differentiate o- and x-waves

  US military used horizontal dipoles aligned N-S during Vietnam War

  N-S alignment for o-wave

  Minimise risk to communications due to x-wave absorption at low HF? Another story!

Noise

- External noise at HF dominates over receiver noise

    Low noise figure not needed

- Noise level generally decreases with increasing frequency
- Signal-noise ratio (SNR) might be better at higher frequencies

Significance of Guideline Corrections

- *fxF2* is ~14% greater than *foF2* at 5 MHz over UK
- ‘FOT ≈ 85% of *foF2*’ guideline forces operation on even lower frequencies
- Greater selection of frequencies available
- Important for NVIS frequency selection:

  Mid-latitude locations
  Daylight hours
  Solar-cycle minimum

Summary

- Extraordinary wave important for NVIS communications at mid-latitude locations
- *fxF2* defines maximum vertical frequency supported by ionosphere
- Agreement with established ionospheric theory and HF propagation prediction methods
- May not be obvious to the HF NVIS user

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