All you should know about riometers

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*)true

*)false
RIO-meter

= Relative Ionospheric Opacity meter

(aka: absorption method A2)
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\[ P_N = kT_s B_n \]

- \( P_N \) ... noise power, W
- \( k \) ... Boltzmann constant
- \( T_s \) ... noise temperature, K
- \( B_N \) ... bandwidth, Hz

2nd HEPPA Conference, Boulder, October 6th, 2009
(wo)man-made:  - discrete frequencies
- harmonics of 50/60 Hz (fall off with frequency)

natural:  
- various extraterrestrial sources in the sky

preferred frequencies:  
- too low: can not penetrate $F$-region peak
- too high: not sensitive
- *e.g.* 38.2 MHz internationally reserved
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looking to the celestial north pole

sky noise temperature (in 1000 K) measured at 30 MHz in different co-ordinate systems (Cane, 1978)
Sky noise between the equator and the north pole. Sidereal midnight at the top.

Received power at 70°N over a sidereal day (power - theoretically - constant when pointed to pole star)
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Red circles represent antenna opening angles between ±5 to ±30°

Received power at 70°N over a sidereal day for different antenna opening angles

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Antenna opening angle from diurnal power ratio
(for 70°N)

theoretical QDC (3)
Received power is a function of:

- geographic latitude
- sidereal time
- antenna opening angle
- look direction
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\[ k_L = \frac{1}{\mu} \frac{e^2}{2 \varepsilon_0 m c} \frac{N_e \nu}{(\omega \pm \omega_c)^2 + \nu^2} \]

(absorption per unit path element; quasi-longitudinal propagation, “classical“ theory)

**in other words:**

- there are two modes (x-mode a little more absorbed)
- absorption is \( \sim N_e \times \nu \)
- absorption is \( \sim f^2 \) (for \( \omega >> \omega_c \) and \( \omega >> \nu \))

since \( \nu \sim p \Rightarrow 

- absorption is \( \sim N_e \times p \)
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\[ L_i = \text{const.} \int_{x=0}^{\infty} N_e p \, dx \]

\textit{const.} = \text{function of:}

- frequency,
- magnetic field,
- propagation direction.
Large absorption events tend to originate in the lower ionosphere (notably PCA‘s due to protons)
received power

absorption = QDC - received power

► exact QDC is crucial!
note:

► even the “normal“ (quiet) ionosphere absorbs \((L_Q)\)

► a riometer measures *additional* absorption \((L_R)\)

► absorption calculated from measured \(N_e\) is integral absorption \((L_i)\)

\[
L_R = L_i - L_Q
\]
three ways to obtain $L_Q$:

- (1) $QDC_{\text{winter}} - QDC_{\text{summer}} = L_Q(\chi)$
- (2) $L_i(\text{calculated}) - L_R(\text{measured}) = L_Q$
- (3) determine True Quiet $N_e$ from envelop of all $N_e$ and calculate $L_Q$
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Winter-Summer difference vs. solar zenith angle $\chi$

- requires extremely stable riometer
- can still not determine $L_Q$ at night

$L_Q (1)$

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- subtract measured $L_R$ from calculated $L_i$
- only few cases with sufficient height coverage!
- huge scatter!
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Using True Quiet $N_e$

Assimilate envelope by Chapman-layer $\Rightarrow TQ-N_e$

$$N_e = N_o (\cos \chi)^n$$

Calculate $L_i$

Assimilate absorption by

$$L_Q = L_o (\cos \chi)^n$$

$\text{day} \quad \text{night}$

$L_Q (3)$
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for $\omega \gg \omega_c$

$\Rightarrow L \sim \omega^{-2}$

measure $L_1$

$\Rightarrow$ ABEX on NittanySat

and subtract $L_R$

frequencies $f_1, f_2$

absorption $L_1$ and $L_2$

$\Rightarrow L_2 = L_1 (f_1/f_2)^2$

measured quantity: $\Delta L = L_1 - L_2$

$\Rightarrow L_1 = \Delta L [1 - (f_2/f_1)^2]$

for $f_2 \gg f_1$

$\Rightarrow L_1 \approx \Delta L$
check the QDC (at night when $L_Q$ is negligible)

check the QDC (during the day using established $L_Q$)
for vertical and oblique beams ($\Rightarrow$ imaging riometers)

establish $L_Q$ during the day (when $L_Q$ can be appreciable)

provide electron density estimates based on empirical model
the receiving antenna generally does not point to the ground station
- stabilise the satellite by magnet (always along the Earth’s $B$-field)
- gravity gradient stabilisation ("bottom" always points earthward)

residual antenna misalignment emulates absorption
- feed all receivers from the same antenna (same “pseudo“ absorption)

the polarisation can have any orientation at the satellite (Faraday rotation)
- transmit circularly polarised waves

the satellite has a velocity component in propagation direction (Doppler)
- transmit to the satellite with the expected frequency offset
- sweep frequency enough to safely cover any Doppler shift
- identify Doppler shift and adjust ground transmitters in real-time
transmitters for each frequency and location (with or without riometer)

- ≥100 W, but switch off regularly to check background power
- switch to low power for linearity check of receivers
- track the expected Doppler shift
- crossed dipoles for each frequency, phased for x-mode

choose frequency high enough to always penetrate the ionosphere

- max. 70° off zenith (most oblique beam of an imaging riometer)
- for \( f_0 F_2 = 10 \text{ MHz at } 300 \text{ km} \Rightarrow 22.6 \text{ MHz} \)

choose frequencies low enough to be more sensitive than the riometer

- e.g. 10 MHz is \((38.2/10)^2 = 16.6\) more sensitive than IRIS

telemetry and telecommand

- for each location for real-time download, or
- at Penn State only.
receivers for each frequency
  ► narrow band (to cover Doppler shift would unduly increase the noise)
  ► sensitivity 1 to 10 µV full scale
  ► one (electrically short) antenna for all receivers
some mechanism to activate receivers when within reach of ground station
  ► coded signal on the higher frequency
  ► activated from internal memory, or
  ► leave them on all the time.
Realistically $L_Q$ can only be determined by simulation using TQ-$N_e$

Absorption $L_Q$ is a function of:
- solar zenith angle $\chi$
- solar activity

Approximation of $L_Q$ by $L_o(\cos \chi)^n$; at night $L_Q = L_n$

<table>
<thead>
<tr>
<th></th>
<th>Low solar activity (67 Jy)</th>
<th>High solar activity (200 Jy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_o$, dB</td>
<td>0.140</td>
<td>0.191</td>
</tr>
<tr>
<td>$n$</td>
<td>0.570</td>
<td>0.546</td>
</tr>
<tr>
<td>$L_n$, dB</td>
<td>0.012</td>
<td>0.012</td>
</tr>
</tbody>
</table>

Table of annual means
(27.6 MHz, x-mode)
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IRIS imaging riometer at Kilpisjärvi, Finland
(69.1°N, 20.8°E)

- 64 antennas
- circularly polarised (x-mode)
- forming 49 beams
- central (vertical) beam ± 5.6°
- most oblique beam (69° off) ± 6.2°
- beam # 50: single antenna (wide beam)
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Why does the wide beam consistently “see“ more absorption?

November 2001
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… because contributions from the side have a longer path through the absorbing ionosphere.

wide vs. narrow beam (2)

calculation for a ±30° antenna, absorption at 90 km
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![Correction vs. Vertical (dB)](image_url)

- additional absorption (<20 %) due to oblique noise contributions
- reduced effective opening angle for large absorption (collimation)

Calculation for a ±30° antenna, absorption at 90 km

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wide beam data

corrected to emulate vertical pencil beam

November 4 to 12, 2001

correction works to better than 20%
\( L_R = 0.1 \text{ dB} \) is significant at night (i.e., \( 93 \cdot L_i \), vs. only \( 1.8 \cdot L_i \) during the day)

\( L_R \) not significant in the \( E \)-region (during the day)

median results of the empirical model IMAZ
(McKinnell and Friedrich, 2007)
\( K_p = 3, \chi = 60^\circ, 100^\circ, \) local noon / mid-night, mid April
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large $L_R$ is always associated with high $K_p$.

but high $K_p$ can occur without large $L_R$. 

best fit (not a good fit!)

$can L_R be replaced by K_p$?
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⇒ for quantitative or synoptic studies (involving different riometers) check:
  ⇒ the operating frequencies
  ⇒ the opening angles
  ⇒ the mode (o-, x-, or both)
⇒ can riometer absorption be replaced by a geomagnetic disturbance index?
  ⇒ definitely not
⇒ does, e.g., 0.1 dB mean a significantly different electron density?
  ⇒ yes at night, but not during the day
⇒ can, say, 0.1 dB be measured?
  ⇒ it can be resolved, but not (reliably) measured (QDC!)
⇒ is $L_R$ a clue to the shape of the profile?
  ⇒ to some extent: larger $L_R$ generally mean $N_e$ bulges at lower altitudes
Harrich, M:
Empirical Modelling of Electron Densities in the High Latitude Mesosphere,

Egger, G.:
Empirical Model of the Polar Cap Ionosphere,

Steiner, R.J.:
Novel Procedures for Modelling the High-Latitude Ionosphere,
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Cain, H.V.:
A 30 MHz Map of the Whole Sky,

Friedrich, M., M. Harrich, R.J. Steiner, K.M. Torkar, and F.-J. Lübken:
The Quiet Auroral Ionosphere and its Neutral Background,

Friedrich, M., M. Harrich, K.M. Torkar, and P. Stauning:
Quantitative Measurements with Wide-Beam Riometers,

Harrich, M., M. Friedrich, S.R. Marple, and K.M. Torkar:
The Background Absorption at High Latitudes,

McKinnell, L.A. and M. Friedrich:
A Neural Network Based Ionospheric Model for the Auroral Zone,

Schwentek, H. and E.H. Gruschwitz:
Measurement of Absorption in the Ionosphere on 27.6 MHz at 52°N by Means of a Riometer and a Corner Reflector Antenna Directed to the Pole Star,

Nittanysat – A Student Satellite Mission for D-Region Study and Calibration of Riometers,