Synchrotron Radiation at 50 MHz: A Tool for Monitoring Radiation Belts?

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http://space-env.esa.int/index.php/ESA-ESTEC-Space-Environment-TEC-EES.html

Inner Belt Variability
(Baker et al., Geophys Res. Lett., 2007)
Radiation Belt fluxes for various energy thresholds
(Starfish corrected)
(Singley and Vette, 1972)

“inner” belt

“outer” belt
Summary---Inner Belt Electrons

largely steady-state compared to outer belt (slow time constant associated with radial diffusion)

Occasional injection events affect $L<2$, especially
  --trapping of solar energetic electrons
  --magnetospheric compression-induced radial transport

solar cycle variation

Need for baseline (e.g., in case of artificial injection)
Relativistic synchrotron radiation:

- beamed perpendicular to magnetic field
- approximately linearly polarized EW at equator
- $\gamma > 4$ (>2 MeV) $\Rightarrow$ radiation up to >50 MHz

Angle gets smaller with increasing energy:
Smaller angle $\Rightarrow$ shorter pulses at observer $\Rightarrow$ broader spectrum
Schwinger (1949) formula:

\[
P_n = \frac{e^2}{8\pi^2\varepsilon_0 c} \frac{n^2\omega_{ce}^2 \beta \sin^2 \alpha}{(1-\beta \cos \alpha \cos \psi)^4} \left\{ [J'_n(z_n)]^2 + \frac{\beta \cos \alpha - \cos \psi}{\beta \sin \alpha \sin \psi} J_n^2(z_n) \right\}
\]

where:
\[P_n = \text{power per electron}\]
\[n = \text{harmonic number}\]
\[\beta = \frac{v}{c}\]
\[\omega_{ce} = \text{electron gyrofrequency}\]
\[\alpha = \text{pitch angle}\]
\[\psi = \text{observation angle}\]

Dyce and Nakada (1959), Peterson and Hower (1963), Peng et al. (1974)
Matthews, LaBelle

\[P_n \sim 10^{-30} \text{ W Hz}^{-1}\text{ster}^{-1}\]
Power = $P_n \frac{A}{h^2} \left( h \frac{\lambda}{L} \right)^2 \Delta h \frac{\text{flux}}{c}$

$P_n \sim 10^{-30}$ W Hz$^{-1}$ ster$^{-1}$ (power per electron)

$A = L^2 = (300 \text{ m})^2$ (Jicamarca)

$\lambda = 6 \text{ m} = 600 \text{ cm}$ (50 MHz)

$\Delta h \sim 2000 \times 10^5 \text{ cm}$ (.3 R$_E$)

flux $\sim 10^5$ electrons/cm$^2$s (AE-8 model, Starfish corrected)

$c = 3 \times 10^{10} \text{ cm/s}$

Power per Hz $\sim 2 \times 10^{-22}$ W/Hz $\sim 10^0$K

(Detailed modelling by
Dyce & Nakada, others, get $\sim 13^0$K)

Observable?
Galactic background ~ 4000°K

--- high sample rate/long integration ~10^6 spectra
--- Dicke radiometer scheme (temperature controlled noise source)
--- **Polarization discrimination:**

  synchrotron radiation linearly polarized (EW plane)
  galactic background unpolarized

\[\text{Both experience Faraday rotation through ionosphere}\]

use Jicamarca pencil beam---look 3° off mag zenith

\[\text{Angle for which daytime Faraday rotation differs from nighttime by 180°}\]

desired signal rotates 180° in ~ 20 minutes across dawn
undesired signal does not rotate.
Jicamarca observation of synchrotron radiation from Starfish nuclear test (1963)

Peak about 20 min after atmospheric nuclear test at Johnston Atoll

Brightness Temp $\sim 4500^0\text{K}$

Exponential decay

(from Ochs et al., 1963)
--- Random noise $\sim 5^\circ$ K
--- No effect seen on three nights of observation
--- Some kind of systematic error not understood

Real part of cross spectrum, bins 480-580, July 25, 2006
Summary---Detection Scheme:

-- Separate EW from NS antennas

-- Detect with Dicke Radiometer

-- Sample for approximately 1-2 hrs across dawn

-- Discriminate component of signal which Faraday rotates (requires extremely low cross-talk between EW and NS signals)