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COLLEGE ON THEORETICAL AND EXPERIMENTAL RADIOPROPAGATION SCIENCE

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THE IMPORTANCE OF THE IONOSPHERE IN MODERN SATELLITE COMMUNICATIONS

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The Dispersion Formula

$$n^2 = 1 - \frac{\tilde{X}(1-\tilde{X})}{1 - \tilde{X} - \tilde{Y}_T^2/2 \pm \sqrt{\tilde{Y}_T^4/4 + \tilde{Y}_L^2(1-\tilde{X})^2}}$$

with $\tilde{Y}_L = \tilde{Y}|\cos\Theta|$ (longitudinal component),

$\tilde{Y}_T = \tilde{Y}\sin\Theta$ (transversal component)

$$\tilde{X} = \frac{X}{1+jZ} \qquad \tilde{Y} = \frac{Y}{1+jZ} \qquad j = \sqrt{-1}$$

Conventional acronyms:

$$X = \frac{f_p^2}{f^2} \qquad Y = \frac{f_g}{f} \qquad Z = \frac{\nu}{2\pi f}$$

f_p : plasma frequency, $(2\pi f_p)^2 = \dfrac{e^2 N}{m\epsilon_o}$ $\quad AN = f_p^2$

N : electron density, e : electron charge,

m : electron mass, ϵ_o : permittivity of free space

S.I.–units: $A = 80.6$

f_g : electron gyrofrequency, $2\pi f_g = \dfrac{e}{m}B$

B : geomagn. induction

ν : effective collision frequency for electrons

High frequency approximation ($f > 100$ MHz)

Quasi-longitudinal approximation (Q. L.)

$$n_{1,2}^2 = 1 - \frac{X}{1 \pm Y_L}$$

magnetic Northern hemisphere:

+–sign: lefthand circular polarization,

––sign: righthand circular polarization.

Linear polarization at satellite antenna ⟶ righthand and lefthand circular components.

Phase difference at receiving antenna:

(= Faraday effect)

$$\varphi = \frac{2\pi f}{c}\int_S^R (n_1 - n_2)\, ds \qquad ds : \text{phase path element}$$

c : free space velocity of light

$$n_1 - n_2 = \frac{n_1^2 - n_2^2}{n_1 + n_2} \doteq \frac{XY_L}{1 - Y_L^2} \doteq XY|\cos\Theta|$$

$$\varphi = \frac{2\pi f}{c} \int_S^R \frac{A}{f^3} N f_g |\cos\Theta| \, ds \doteq \frac{C_F M}{f^2} \int_0^{h_{lim}} N \, dh$$

straight line instead of ray path:

$$ds = -\frac{dh}{\cos\chi} \qquad (dh: \text{ height element,}$$

$\chi(h)$: zenith angle of satellite in height h)

$$C_F = \frac{e^3}{8\pi^2 \epsilon_o m^2 c} \quad \text{Faraday constant}$$

$$M = \overline{\frac{B|\cos\Theta|}{\cos\chi}}$$

(the average is usually replaced by the value in a "mean ionospheric height" h_i of 350 or 400 km)

Geostationary satellites: $h_{lim} \doteq 2000$ km

$\int_0^{h_{lim}} N \, dh$ <u>ionospheric</u> electron content

Two signal components,
widely spaced in frequencies
and transmitted phase coherently $\longrightarrow$
Differential Doppler effect
(ionospheric influence on carrier phase)

$f_1 = pf, \quad f_2 = qf \qquad p,\ q$: integer numbers

$$\Psi = \frac{\varphi_2}{q} - \frac{\varphi_1}{p} \doteq \frac{\pi f}{c} \int_S^R (X_1 - X_2) \, ds =$$

$$= \frac{\pi A}{cf} \left(\frac{1}{p^2} - \frac{1}{q^2}\right) \int_S^R N \, ds$$

(ray paths replaced by straight line)

projection from slant to vertical:

$$\Psi = \frac{C_D}{f} \left(\frac{1}{p^2} - \frac{1}{q^2}\right) \overline{\left(\frac{1}{\cos\chi}\right)} \int_0^{h_s} N \, dh$$

(C_D: Diff. Doppler constant, h_s: height of satellite)

Range Error, Group Delay

phase path $\rho = \int_S^R n\, ds = \rho_o - \frac{A}{2f^2} \int_S^R N\, ds$

Range Error $\Delta\rho = \frac{A}{2f^2} \int_S^R N\, ds$

(proportional to slant electron content)

Group refractive index $n_g \doteq 1 + \frac{1}{2}X = 1 + \frac{AN}{2f^2}$

Group travel time $t = \frac{1}{c} \int_S^R n_g\, ds = \frac{\rho_o}{c} + \frac{1}{c} \int_S^R \frac{1}{2} X\, ds$

Group Delay $\Delta t = \frac{1}{c} \int_S^R \frac{1}{2} X\, ds = \frac{1}{2} \frac{A}{c f^2} \int_S^R N\, ds$

Beacon Satellite Group

= Working Group G.2 of URSI

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- Mailing list
- Symposia (next: Tucuman, Argentine, March 1990)
  Spring 1992: Boston, USA

Main Subject Areas:
1) Electron Content (TEC)
2) Scintillations

Science:
Ionospheric Physics
Solar-Terrestrial Relations
Ionosphere - Magnetosphere
Ionosphere - Neutral Atmosphere

a) Case Studies
(e.g., Magnetic Storms)
b) Longterm Studies
(e.g., Modelling of Ionospheric Regions)

Applications:
Scientific:
Geodesy
Radio Astronomy
Technological:
Satellite Communications
Navigation Systems
Time Dissemination from Satellites
Satellite Orbit Determination
Space Probe Navigation

"Propagation Errors"
Systems Limitations because of "Scintillations"

System Analysis and Planning
Error Assessment and Correction

Satellites

1) Geostationary:
   VHF-Beacons for Faraday
2) Low Orbiting:
   Dual Frequency Beacons for Differential
   Doppler (e.g., 150/400 MHz NNSS)
3) High orbits:
   e.g., GPS: Coherent L-Band
   (Diff.-Doppler + Group Delay)

Cooperation with Space Geodesy
(NNSS, possibly GPS)