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UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

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AUTUMN COURSE ON GEOMAGNETISM, THE IONOSPHERE
AND MAGNETOSPHERE

(21 September - 12 November 1982)

LECTURE 3: Choosing of Operational Frequencies and Transmitter Powers for a given HF-Link.

LECTURE 4: The Concept and Practice of Ionospheric Predictions.
A Glossary of Ionospheric Terminology.

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HF Link Test cases.

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Choosing of operational frequencies and transmitter powers for a given HF-Link

The various steps involved in choosing the right operating frequencies and transmitter power to obtain a predetermined signal above the noise level (or grade of service) for any given point-to-point link are the following:

Step 1. Estimate the probable modes of communication for the link depending on the path length.

Step 2. Determine the elevation angles for the chosen modes. Use information on height of the layer [in terms of M (3000)F_2] in computing the angles.

Step 3. Determine the E-region (and E_s layer, if necessary) penetration frequencies at the points of E-region entry using foE at the point of entry and incident angle of the chosen mode at 100km.

Step 4. A radio frequency one each for day time and night time are chosen from the computed MUFs for a mode based on predicted parameters for a given month and solar activity levels. The chosen MUFs should be lower than lower deciles but higher than LUFs if the mode availability is to be atleast for 90% of time. Care has to be taken to check that chosen MUFs is higher than E-region screening frequency (step 3) in case of day time frequencies.

Step 5. Finalize a frequency for day time i.e. to be operated between ∼ 0700 hrs (L.T) to ∼ 1800 hrs (L.T) and determine the Time Availability of that frequency for the entire period using median (f_m) and lower decile (f_ℓ) MUF values.

Time Availability (percentage)

$$Q = 130 - \frac{80}{1 + \dfrac{(1-f/f_m)}{(1-f_\ell/f_m)}}$$

Step 6. Compute the System Loss using CCIR formula

a) Calculation of System Loss L_s involves computation of several loss and gain terms involved in the propagation.

b) Important loss and gain factors are:

(i) Free space loss = Lbf

(ii) Ionospheric Absorption Loss = La

(iii) Polarisation coupling loss = L_c

(iv) Ground reflection loss for multiple-hops = L_g

(v) Horizon focus gain = G_f

(vi) Transmitter and Receiver antenna gain= G_t and G_r

System Loss $= L_s{}_{(dB)} = L_{bf} + L_a + L_c + L_g - (G_f + G_t + G_r)$

c) $L_{bf} = 20 \log_{10} (4\pi d/\lambda) = 32.4 + 20 \log_{10} f + Lf$

where $Lf = 20 \log_{10} \left[2R \sum^{n} \frac{\sin d\gamma}{2R} / \cos\left(\Delta r' + \frac{d\gamma}{2R}\right) \right]$

$$La = \frac{\Phi_n (f_v/foE)\, A_T(0,0)F(\alpha)(1+0.0067R_{12}) \sec i_{100}}{(f + f_L)^2}$$

L_c = Important for East-West circuits

$L_g = 10 \log \left(\frac{R_H^2 + R_V^2}{2}\right)$ where $R_H = \frac{\sin\Delta - \sqrt{(n^2 - \cos^2\Delta)}}{\sin\Delta + \sqrt{(n^2 - \cos^2\Delta)}}$

$$R_V = \frac{n^2 \sin\Delta - \sqrt{(n^2 - \cos^2\Delta)}}{n^2 \sin\Delta + \sqrt{(n^2 - \cos^2\Delta)}}$$

n^2 = Refractive index = $K - j \frac{1800 \times \sigma}{f}$

G_f = Use the plot (CCIR), important for low elevation angle circuits.

G_t and G_r = Depends on the type of antennas

d) Details of some of the parameters used in these computations

d = great circle path

λ = Wave length (Km) of the radio frequency

f = Radio frequency in MHz

R = Radius of earth, 6371 km

d_r = Hop distance

$\Delta r'$ = Elevation angle of for the hop

f_v = Equivalent vertical frequency at the point of Reflection. Calculated using CCIR methods.

f_oE = E region critical frequency at the point of Reflection.

f_oF_2 = F region critical frequency at the point of Reflection.

f_L = Gyro frequency

ϕ (f_v/f_oE) = A function calculated using CCIR methods

$A_T(0,0)$ = A factor dependent on month and modified dip angle involved in Ionospheric absorption.

$F(\chi) = \cos^p (0.881\,\chi)$ A function depending on zenith angle (χ), modified dip latitude and month (CCIR plots to be used)

R_{12} = Zurich smoothed sunspot number

i_{100} = Angle of incidence at 100 km level for a given circuit

$i_{100} = \arcsin (0.985 \cos \Delta)$

Δ = Elevation Angle

σ = Ground conductivity in mhos/m

K = Dielectric constant

Step 7. Determine radio noise level at the receiver location from the maps (Saxena & Ghosh). The values (E) read from the maps in dB above 1µV/m for 1 KHz band width at 5 MHz should be converted into radio noise power (R_n) in dBW for required radio frequency and band width.

a) $$R_n \text{ (dBW)} = \frac{A_r \times E^2}{Z_o}$$

where $A_r = \lambda^2 \; G/4\pi$

λ = wavelength of radio wave (meters)

and Z_o = Impedance of receiving antenna (Ohm)

b) $N_1 - N_2 = -12 \log (f1/f2)$

$N_1^1 - N_2^1 = 10 \log (B_1/B_2)$

where N_1 and N_2 are noise levels at frequencies f1 and f2 for a given band width and N_1' and N_2' at Band widths B_1 and B_2 for a given frequency.

Step 8. Determination of required transmitter power (P_T) for a desired S/N

$$P_T \text{ (dBW)} - L_s \text{ (dB)} = R_n \text{ (dBw)} + S/N \text{ (dB)}$$

Test Case

DELHI	TRIVANDRUM
(28.6°N, 77.2°E)	(8.55°N, 76.87°E)

Great circle path -- 2240 km

August R_{12} -- 40

Day Time Frequency

Step 1. 1F and 2F modes of propagation are considered.

Step 2.		1F	2F
	Elevation angle	11.85°	28.82°
	i_{100}	74.58°	59.65°
Step 3.	E-region penetration frequency at noon	13.6 MHz	7.1 MHz
Step 4.	Lower Decile at noon	18.0 MHz	9.0 MHz
	MUF should be between	13.6 MHz and 18.0 MHz	7.1 MHz and 9.0 MHz

In addition the day time frequency in general is expected to be valid from 0700 or 0800 hours onwards upto to 1800 hours local time. The link frequency for day time should be prefarably lower than the lower decile at 0700 or 0800 hours.

Lower decile	15.5 MHz (~0800 hrs)	8.8MHz (~0700 hrs)
Day time frequency for Delhi-Trivandrum link	15.0 MHz	8.0 MHz

		1F mode	2F mode
	f =	15.0 MHz	8.0 MHz
Step 5	Time availability		
	0800 hrs	91.7%	95.5%
	1000 "	91.1%	93.5%
	1200 "	98.9%	95.2%
	1400 "	102.4%	98.2%
Step 6	(i) Basic free space Loss= Lbf = 20log $(4\pi d/\lambda)$	123.5dB	119.0dB
	(ii) Ionospheric loss		

$$L_a = \phi\left(\frac{f_v}{f_oE}\right) A_T(0,0)F(x)(1+0.0067R_{12})\ \sec i_{100}/(f+f_L)^2$$

	1F mode	2F mode
χ :	~5°	~5°
f	15 MHz	8 MHz
f_oE (noon)	3.59 MHz	3.61 MHz
critical frequency f_oF_2(noon)	10.80 MHz	8.09 MHz
f_v	4.72 MHz	2.46 MHz
(fv/f_oE)	1.25	0.90
fl	1 MHz	1 MHz
modified dip latitude	23.27°	12°
P	1.58	1.6
i_{100}	74.58°	59.65°
A_T	330	275
$F(\chi)=\cos^p(0.881\chi)$	0.9953	0.9952
$(1+0.0067 \times R_{12})$	1.265	1.265
La	7.60dB	13.70dB

		1F	2F
(iii)	Polarization coupling loss = Lc	neglected	neglected
(iv)	Ground reflection loss = Lg	None	5.5dB
(v)	Horizon focus gain=Gf	2.5dB	2.0dB
(vi)	Transmitter antenna gain = G_t	10 dB	10dB
	Receiver antenna gain = G_r	10dB	10dB

	1F	2F
$L_s = L_{bf} + L_a + L_c + L_g - (G_f + G_t + G_r)$	108.6dB	116.2dB
To account for day to day variability in Ionosphere = add 9dB loss	117.6dB	125.2dB
Step 7. Atmospheric Radio Noise at Delhi (Receiver)	-125dBW	-125dBW
Step8. Transmitter power when S/N = 20 dB	18 watts	100 watts
when no antenna gains are included	2.3 KW	100 KW

Atmospheric radio noise field strength in dBW at 1 KHz band width for various frequencies obtained from measured values in dB above 1 $\mu V/m$ at 5 MHz.

dB above 1uV/m at 5 MHz	dBW 5MHz	dBW 8MHz	dBW 10MHz	dBW 15MHz	dBW 20MHz	dBW 25MHz
-15	-129.2	-135.73	-138.83	-144.45	-148.94	-152.11
-13	-127.2	-133.75	-136.85	-142.51	-146.94	-149.57
-11	-125.10	-131.75	-134.67	-140.49	-145.00	-147.57
-9	-123.20	-129.74	-132.63	-138.47	-142.99	-145.55
-7	-121.20	-127.75	-130.8	-136.45	-140.97	-143.54
-5	-119.20	-125.75	-128.8	-134.44	-138.94	-141.55
-3	-117.20	-123.75	-126.8	-132.45	-136.95	-139.56
-1	-115.20	-121.75	-124.8	-130.45	-134.96	-137.55
+1	-113.20	-119.75	-122.8	-128.45	-132.94	-135.55
3	-111.20	-117.75	-120.8	-126.44	-130.95	-133.54
5	-109.20	-115.75	-118.8	-124.45	-128.94	-131.54
7	-107.20	-113.75	-116.8	-122.45	-126.93	-129.53
9	-105.20	-111.75	-114.8	-121.44	-124.93	-127.57
11	-103.20	-109.75	-112.8	-119.25	-123.00	-125.55
13	-101.12	-107.75	-110.8	-117.25	120.95	-123.55
15	-99.12	-105.75	-108.8	-115.25	-118.95	-121.55

WORKSHOP ON RADIO COMMUNICATIONS IN TROPICS

(Trieste, November 1982)

The Concept and Practice of Ionospheric Predictions
A Glossary of Ionospheric Terminology

Absorption:

Absorption losses are next only to the free space loss in HF communication and the large diurnal variability in absorption is partly responsible for the large diurnal variations in the received field strength. Ionospheric absorption is of two kinds: (a) Non-deviative absorption: As the radio wave passes through the ionosphere the ambient electrons are set into oscillation by the electric vector of the radiowave. The electrons reradiate secondary wavelets and in the absence of any collisions, the total strength of the wave is not attenuated. However, the oscillating electrons do collide with heavier particles, such as the ions and the neutral molecules and there is irretrievable loss of energy. These collisions are highest in the lowest region of the ionosphere because of the dense neutral atmosphere and hence the non-deviative absorption occurs essentially in the D-region. (b) Deviative absorption: In the process of the radio wave undergoing a reflection in the ionosphere, the group velocity of the waves decreases in the region where the refractive index is much lesser than unity. Because

of this, considerable slowing down of the movement of the wave train occurs and hence the absorption increases. The deviative absorption is important only when the operating frequency is very close to the MUF. Thus, in high reliability HF links, where the frequency is considerably lower than MUF deviative absorption is not particularly important.

D-region: This region is the lowest layer of the ionosphere extending from about 60 km to 90 km. This layer is essentially a daytime feature with a maximum electron density of over 10^3 per c.c (with orders of magnitude higher negative ion densities). While this layer can reflect LF and VLF waves, it acts merely as an absorbing region for the HF band because of the high collisional frequencies of the electrons in the dense neutral atmosphere. The D-region can also support VHF communications by forward scatter.

E-region: This layer extends from 90 km to approximately 140 km and undergoes large day-to-night variation. The daytime parameters of the E region bear a definite relationship with the solar zenith angle and are hence easily predictable. This region is of utmost importance for HF communications over short and medium distances, especially during daytime. The daytime electron densities are around 10^5 per c.c.

F-region: The F-region of the ionosphere formed by the photo ionization of atomic oxygen has the most important layer for long distance HF communication. This region extending from 140 km to more than 1000 km has a maximum charged particle concentration around 350 km though the production maximum is far below, at 160 km. The

F region splits into F_1 and F_2 regions during daytime especially during the hours when the solar zenith angle is low, especially during high solar activity period.

f_oF_2: The single most important ionospheric parameter in HF communication is foF_2. This is the highest frequency that can just be reflected vertically backwards from F_2 region of the ionosphere. The suffic 'o' indicates that the value refers to the ordinary component of the composite wave. Likewise f_oE and f_oF_1 indicate the critical penetration frequencies (ordinary wave component) for the E and F_1 regions respectively.

h_mF_2: This is the height of the peak density of the F_2 layer, in fact, of the ionosphere. This value may vary between 230 km and 350 km depending upon the season, local time, latitude and solar activity. This is the second most important parameter in HF communications.

Ionosphere: The ionosphere for practical purposes starts at an altitude of 60 km and extends to altitudes of more than 1000 km. The ionosphere is formed by the interaction of the solar extreme-ultraviolet radiations and X-rays with the terrestrial neutral atmosphere. In addition, production by solar particles is also important at very high latitudes. The concentration of free electrons or ions may vary from a few tens per cc at 60 km to more than a million per cc at about 350 km, beyond which the charged particle density decreases again.

Magnetic Storms: Following a solar flare, high energy particles, also known as solar plasma emitted by the sun travel outward with velocities ranging from several hundred to more than two thousand kms per sec, and are diverted by the earth's magnetic field to high latitudes. Through a complicated injection mechanism, these particles are trapped by the earth's magnetic field and form a loop of current around the earth apparently decreasing the terrestrial magnetic field. These magnetic storms are associated with absorption at polar latitudes because of particle precipitation and also with electron density changes in the F region of the ionosphere. During the main phase of the magnetic storm, MUF values are decreased at middle and high latitudes; the changes in MUFs at low latitudes however, are only marginal.

MUF: The maximum usable frequency for any circuit, abbreviated as MUF, is usually a function of f_oF_2 and h_mF_2. If the operating frequency exceeds the MUF the radiowave simply penetrates the ionosphere and is totally lost into space. Hence MUF is an indication of the maximum frequency ionosphere can support for a given path.

Mode: The path that a radiowave takes in its passage from transmitter to the receiver can be described by the mode of propagation. For example a 1E mode means that the radiowave undergoes a single reflection at the E region between the transmitter and the receiver while a 2E mode means that it undergoes two reflections at the E region with an intermediate reflection on the ground. Likewise 1F, 2F, 3F modes mean that the radiowave undergoes single, double and treble reflections at the F region with 0, 1 and 2 reflections on ground.

OWF: The optimum working frequency (OWF) of a circuit is less than the MUF of the circuits because the MUF usually is based on the median values of the F region parameters and thus the ionosphere can support the MUF only for 50% of the time. By reducing the MUF by about 15%, the ionospheric support for communication can be assured for atleast 90% of the time. This percentage support of the ionosphere increases as the frequency is decreased further.

Photoionization: This is the process of removal of an electron from a neutral atom or a molecule by the action of a photon usually of solar EUV on X-rays. For example, the strong Lyman-produces ionization in the D region by interacting with the Nitric oxide while the E region is produced because of the action of X-rays on oxygen and nitrogen. The F region is produced by the action of the 304 Å line from the solar helium ion on atomic oxygen.

Polarisation: In an ionised medium with an ambient magnetic field a radiowave splits itself into two independent circularly polarised components. These two components are known as the ordinary (O) and extraordinary (x) waves. The partition of the wave energy between these two components is a function of the angle between the direction of propagation and the earth's magnetic field. The differential attenuation of these two waves and also the polarization coupling loss are extremely relevant to radio communication.

Radio Noise: The radio noise is broadly classified into two areas: (a) Internal noise is generated in the antenna, transmission lines and in the receiver itself. This noise has the characteristics of thermal noise and can be determined mathematically to a high degree of precision. (b) External noise consists of mainly atmospheric, galactic and man-made noise. For HF communications, the most dominant external noise source is atmospheric noise produced by cloud discharges, while the galactic noise can for all purposes be neglected. The manmade noise source is important only in highly industrialised areas. The atmospheric noise, especially at the lowest band of the HF spectrum can be the deciding factor in restricting the reliability in some seasons at low latitudes.

Reflection: As radiowaves penetrate upwards through the ionosphere they encounter successively increasing electron densities. The process makes the waves bend downwards, which could also be called refraction. This refraction is a function of the electron density gradient in the ray path. For a given electron density and angle of incidence of the ray on the ionosphere, a particular frequency can be totally reflected backwards. It is this quality of the ionosphere that is responsible for the long distance propagation of the HF radiowaves.

Skip zone: For any particular operating frequency there is a minimum angle of incidence upon the ionosphere below which the wave will not be reflected back. For example, for frequencies below f_oF_2 this minimum angle is 0^o. As the frequency of operation increases beyond foF2, this angle increases and there is a distance called skip distance beyond which the reflected signals are received on the earth. In the immediate vicinity of the transmitter there is usually a small circular zone within which the ground waves and the direct space waves are received. The annular link between these two zones is known as skip zone in which HF communication is not possible.

<u>SWF</u>: A shortwave fadeout is caused because of enhanced solarflare radiations at X-ray and extreme ultraviolet wavelengths which produce increased ionization in the lower radiowaves. This phenomenon which is limited to daylight hours only restricts the reliability of HF links, especially during high solar activity period when solarflares are more frequent.