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SECOND COLLEGE ON THEORETICAL AND EXPERIMENTAL RADIOPROPAGATION PHYSICS

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ROLE OF IONOSPHERE IN MODERN COMMUNICATIONS SYSTEMS

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B M REDDY PART A

INTRODUCTION:

Ionosphere-reflected propagation provided the first mode of long distance radio broadcasting and led to exhaustive studies to document spatial and temporal morphology of the ionosphere to aid optimum exploitation. Other lectures deal with the topic of conventional HF communications including predictions for frequency planning etc. However, the role of ionosphere in Modern communication systems would deal with more recent developments with contemporary and future interests. If I fill up my time, by merely listing all the present day and future roles of ionospheric medium it will be not only monotonous, but functionally unproductive. Instead, I will pick up those examples, that will easily reach a majority of my audience, often trading technical accuracy, for better comprehension.

Five decades ago, long distance propagation was essentially restricted to the ionospheric mode. This encouraged a tremendous amount of research activity on the ionospheric medium. Due to our desire for greater band-width, and higher reliability, and aided by new techniques to generate higher radio frequencies, a host of new systems in VHF, UHF and microwave communications came in. The problem of over coming the Earth's curvature remained, until passive satellites (of course to be followed by active satellites) were launched to bounce back the radio waves. Some kind of marginal extensions beyond the horizon were possible, with terrestrial microwave systems using tall towers, or tropo scatter techniques. It should be noted that the ionospheric medium, with its reflecting layers located between 100 to 400KM, serves as a canopy of passive satellites to overcome the Earth's curvature.

Radio Spectrum Applications:

I will merely mention the most common uses of the Radio spectrum as of today through a couple of Tables. (Table I and Table II). The basic aim of these two tables is to draw your attention to the role played by ionosphere in almost all the bands of the frequency spectrum. ELF, VLF and LF used in navigation, Maritime Communications, T & F transmissions etc. propagate as ground waves, but also through ionospheric reflections. The uses of MF for broadcasting and HF for broadcasts and communication links are well known. The VLF system (OMEGA) operation is based on a world-wide network of eight transmitters (Norway, Liberia, USA, Argentina, Australia, Japan) at 10.2 11.5, 11.333 & 13.6 KHz. These frequencies are synthesised from a common source in the exact ratio of 1 13/12 ,10/9, and 4/3.

Phase coherence and emission timings are carefully controlled. Diurnal & Seasonal Variations and Transient ionospheric disturbances affect the accuracy and should be properly accounted for.

LF is still used in certain European countries for urban broadcasting.

ELF is tipped as a future hope for communicating (one way) with submarines cruising at patrol depths around the world (40-80 Hz).

Table II shows VHF and beyond. These are all basically LOS systems, including TV broadcasts and satellite systems - except the Troposcatter system and the VHF scatter systems using meteor trails and D-region irregularities. In the VHF band, ionospheric role is dominant on three counts. Firstly, the ionosphere is a nuisance in satellite systems. Secondly, again as a nuisance in TV receptionbecause of ionospheric support to VHF under special conditions- and we will discuss this in some detail later. The third is the intentional use of ionosphere for VHF scatter systems. Similarly, satelite systems in UHF and even in SHF arenot immune to ionospheric degradation. These other bands at 60 GHz and 90GHz are listed for the sake of completeness, but irrelevant to my presentation. Only a word in passing as this has emerged as a powerful secure system of NATO. This 60 GHz corresponds to the resonant absorption by molecular oxygen. And molecular oxygen density is invariant. So one can design a short link of say 10 to 20 KM with a sharp cut off and high directivity. We can communicate with the border patrol for example and see that there is no signal spill over even 500m beyond.

phased HF will remain useful, if not powerful for quite some time in future. It was once thought that with more reliable techniques emerging, HF will be [illegible] out. But the unabated increase in the pressure on HF spectrum belied such expectations. The reasons of course are not far to seek. With new space weapons, satellites have become vulnerable-they can be maimed and even killed. All high reliability systems have back up HFlinks. Also, HF systems are orders of magnitude cheaper.

HF Communications in Tropics:

In the tropics, because of low solar zenith angles, we have simply greater solar spectral irradiance per unit area including the energy in the EUV and X-rays, leading to greater electron production. So, during day, we have high Ne values facilitating higher operating frequencies. Those of you in HF business know what a great advantage it is - More Band width, less absorption, lesser atmospheric noise and simpler antennas. Secondly - the high latitude mag. field lines are almost vertical and open up in space. Solar particles make easy entry. Also, the ring current particles find their graveyards at high latitudes because that is where they penetrate to lowest altitudes. The result is a host ofparticle events which cause heavy HF attenuation, the worst being the so called

PCA events.

There are of course induced effects of these particle events, the magnetic storms, which manifest with different sets of time delays. Quite naturally, the high latitude and the mid latitude ionospheres are troubled with these storm effects, plunging the MUF values far below the predicted median values. Fortunately, the tropics are shielded by the horizontal mag field lines from the invasions of these particle events and their resultant ionospheric storms. by the same token however, as a result of low zenith angles, the tropics receive a good dose of the solar x-rays and are more vulnerable to SWF events. Also during night time, the ionosphere collapses rapidly near the geomag equator, forcing the operational frequencies downward where the Atmospheric Noise is high. But over all, the advantages in the Tropics for out weight the disadvantages and Ionospheric communications will remain attractive.Recently, some services in India, especially police wireless, have introduced digital HF modems. We were asked to prescribe the maximum band width each channel can handle at different seasons and times of day. But unfortunately, we cannot do a good job of it now, as it requires more knowledge of the fine structure merphology of the ionosphere. In fact this is an example, where very high reliability is possible in HF digital links, if some of the latest high-tech Ionosondes are deployed.

HF Radar:

In recent years, HF over-the Horizon Radar has emerged as a powerful technique for remote study of ocean state, snow/ice cover over mountains and of couse as a long range ground based surveillance system. One would wonder why an expensive, perhaps less accurate HF radar system in present hi-tech era. As early as in sixties, the IDSCP of USA launched 26 satellites operating between 7 to 8 GHz - and were doing well. The NNSS (5 sat, circumpolar and 600nm, a fix of 0.1n. mile). Navstar or GPS with 24 satellites worked very well. But now, the space weapons hovering over the horizon will end the monopoly of satellite surveillance. A conventional microwave radar, which of necessity should be located near the border, is susceptible for physical, and electronic offence. HF radio which will be deep in our own territory has certain distinct strategic adantages. Fig.1 shows a rough sketch of a HF radar in operation. A sample spectrum for different sea waves is also shown below the sketch. The HF radar operates with a typical beam width of 1°, a range of 600 to 3000 km (more in multihop system) and with 30 to 40 Km width of a cell and similar dimension in range. Though this look area of say 1000 to 2000KM looks likea large area, the relative uncertainity in position is of the same order as in a microwave radar. Doppler processing of the radar signal requires that the transmitted signal be phase-coherent on a pulse to pulse basis, that is the phase of the signal be the same from one pulse to the next. A series of such pulse returns for each of a set of time delays is stored in memory and then the Foureir transform of the series is taken. The Doppler spectrum, that is signal amplitude versus Doppler freuency, (shown below) is derived , and this gives cross section versus target velocity. But now, such an exercise requires, an input to the computer, regarding the maximum coherent integration time permissible for a given set of ionospheric conditions. As you know, the Ionosphere is beset with a host of dynamic phenomena that ruin the fidelity, and separation of targets from clutter in the Doppler spectrum is difficult - unless a real time prediction of optimum integration times are continuously fed to the system. Our present knowledge of the Ionosphere is to be updated with more finestructure studies to take full advantage of this technique.

Angular Refraction:

An important parameter critical for GPS systems is Angular refraction. The Ionospheric Refractive Index (less than unity) bends the radio waves from the satellite away from the geometric path. This depends on the frequency, TEC, elevation angle and the height of the centroid of TEC distribution. Fig.2 shows the error calculated for Delhi for summer months of 1989. Winter errors will be higher because winter TEC values at Delhi are higher due to the winter anomaly (1.5° at 100 MHz, for low angle).

Ionospheric Modification:

Ionospheric modificationby high power radio waves leads to a number of thermal and parametric interactions. The observed phenomena include appearance of density striations and spread F,, enhanced plasma waves, extra-thermal electron fluxes, self focussing and scattering of e m waves. Artificial modification is a distinct possibility in near future to create a high density ionosphere that can support VHF or even UHF propagation - as shown in Fig.3a. It is now known that VHF TV transmissions are received, from more than 3 or 4 thousand kilometers, through F region, modified by certain short wave transmitters, operating near the critical frequency. Fig. 3b shows the SPS (Satellite Power Systems) concept which is now on the drawing board as a future possibility for collecting solar power from geostationary satellites.

The satellite with super large solar panels converts the energy into microwave power that can be beamed to earth over a 10KM diameter. The large power (5 to10 GW) penetrating through the ionosphere would heat it by ohmic inter-actions between the power beam and the electrons, ions and neutrals.

The phenomenon of Ionospheric scintillations and the consequent degradations to satellite-based radio systems are discussed separately in more detail in Part B of this paper. Fig. 4 is a sample of constraints imposed by scintillations on satellite communication

RADIO SPECTRUM UTILISATION TODAY

T A B L E I

ELF (UPTO 3KHz) VLF (3 TO 30 KHz) LF (30 TO 300KHz)	NAVIGATION, MARITIME COMMUNICATIONS TIME & FREQ. TRANSMISSION, PROPAGATION THROUGH GROUND WAVE & EARTH - IONOSPHERE WAVE GUIDE.
MF (300 TO 3000KHz)	BROADCASTS & SURVIVAL COMMN. SYSTEMS. PROPAGATION THROUGH GROUND WAVE DURING DAY, BUT E-REFLECTIONS DURING NIGHT OVER LONG DISTANCES.
HF (3 TO 30MHz)	LONG DISTANCE BROADCASTS AND COMMN. LINKS. PROPAGATION THROUGH E AND F LAYER REFLECTIONS.

T A B L E II

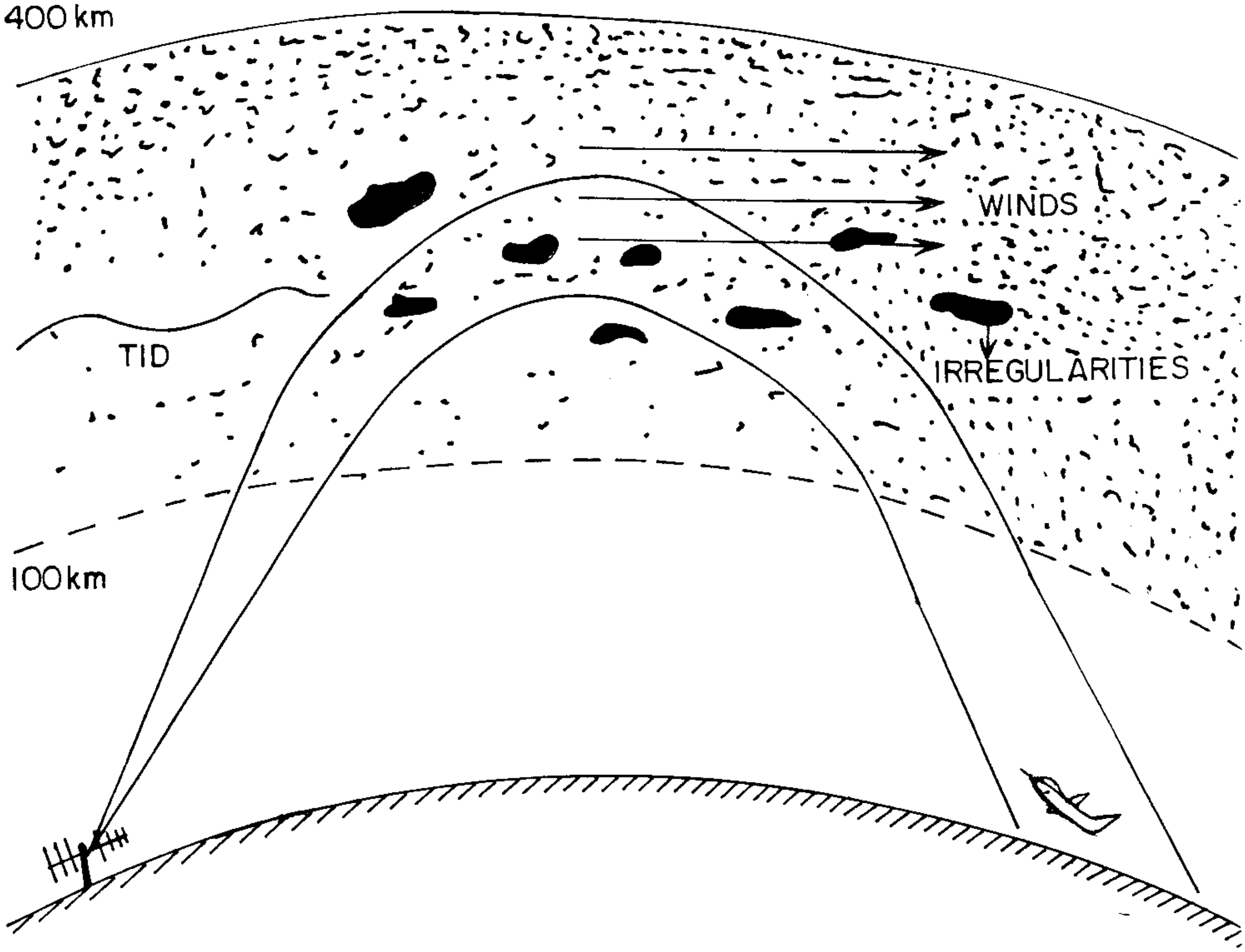
VHF (30 TO 300 MHz)	TV, LOS LINKS, SCATTER COMMS. SATELLITE SYSTEMS.
UHF (300 TO 3000MHz)	TROPOSCATTER LINKS, SAT. COMMNS, TV AND LOS.
SHF (3 TO 30 Ghz)	SATELLITE RADIO SYSTEMS, LOS TROPOSCATTER, MOBILE COMMNS.

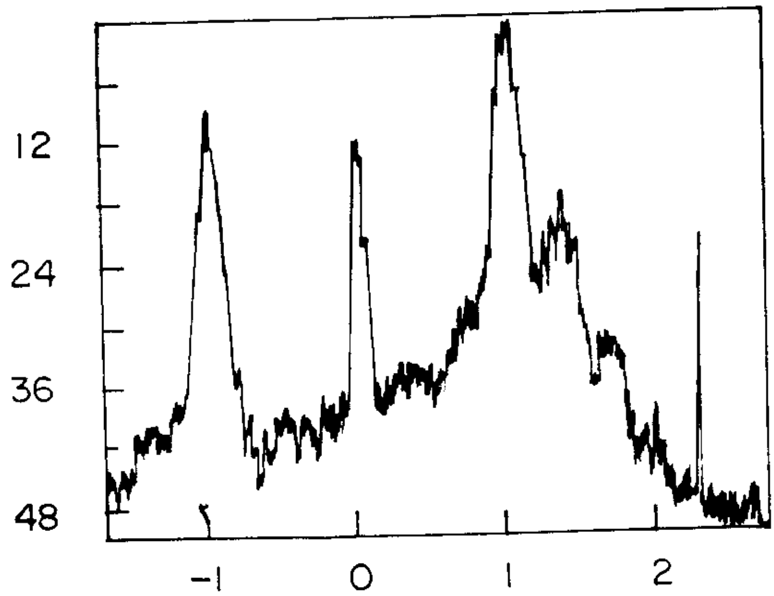
OTHER SPECIAL BANDS

60GHz	SECURE COMMN. SYSTEMS.
90 GHz	MISSILE GUIDANCE

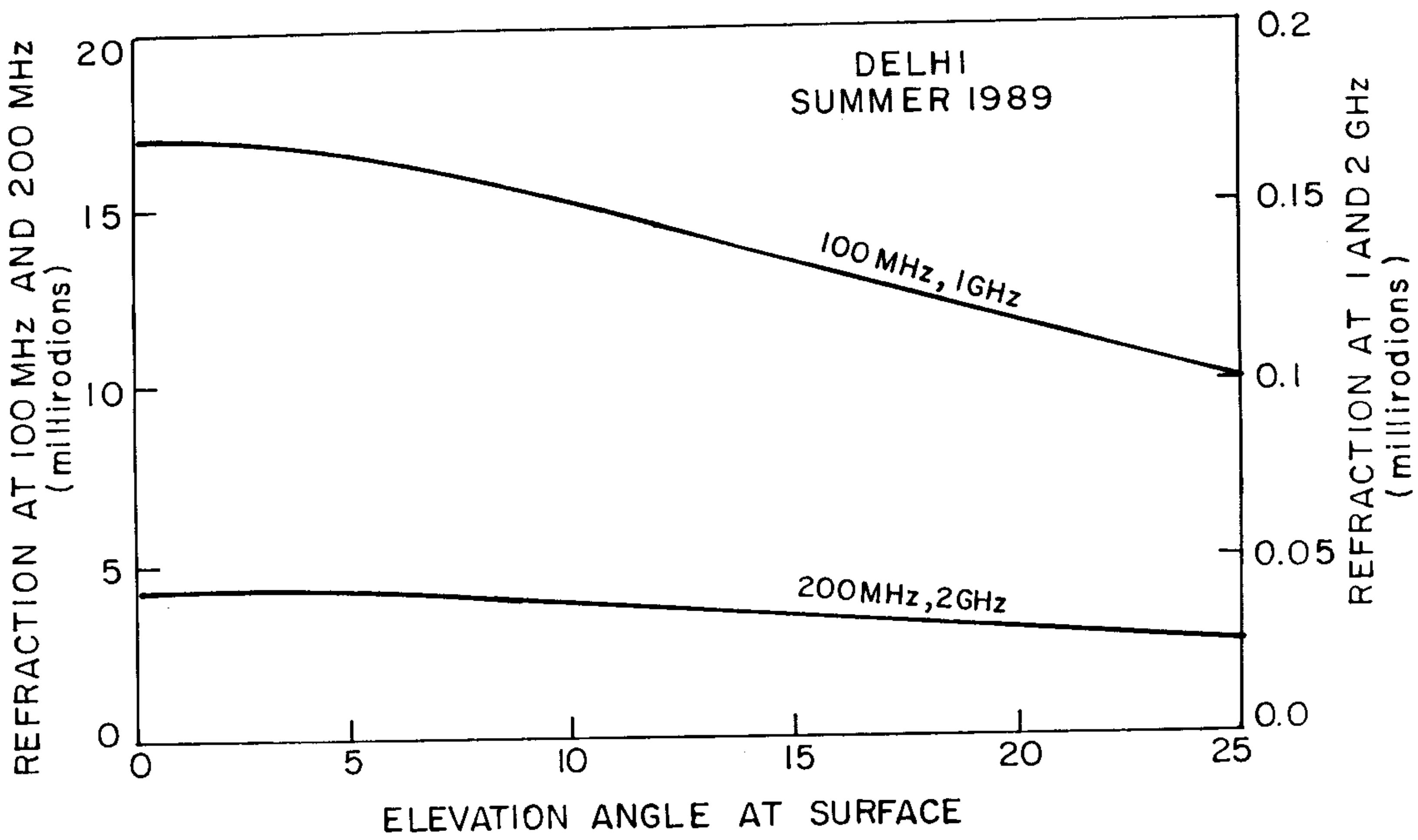
FIG. 1

ROLE OF IONOSPHERE-HF RADAR



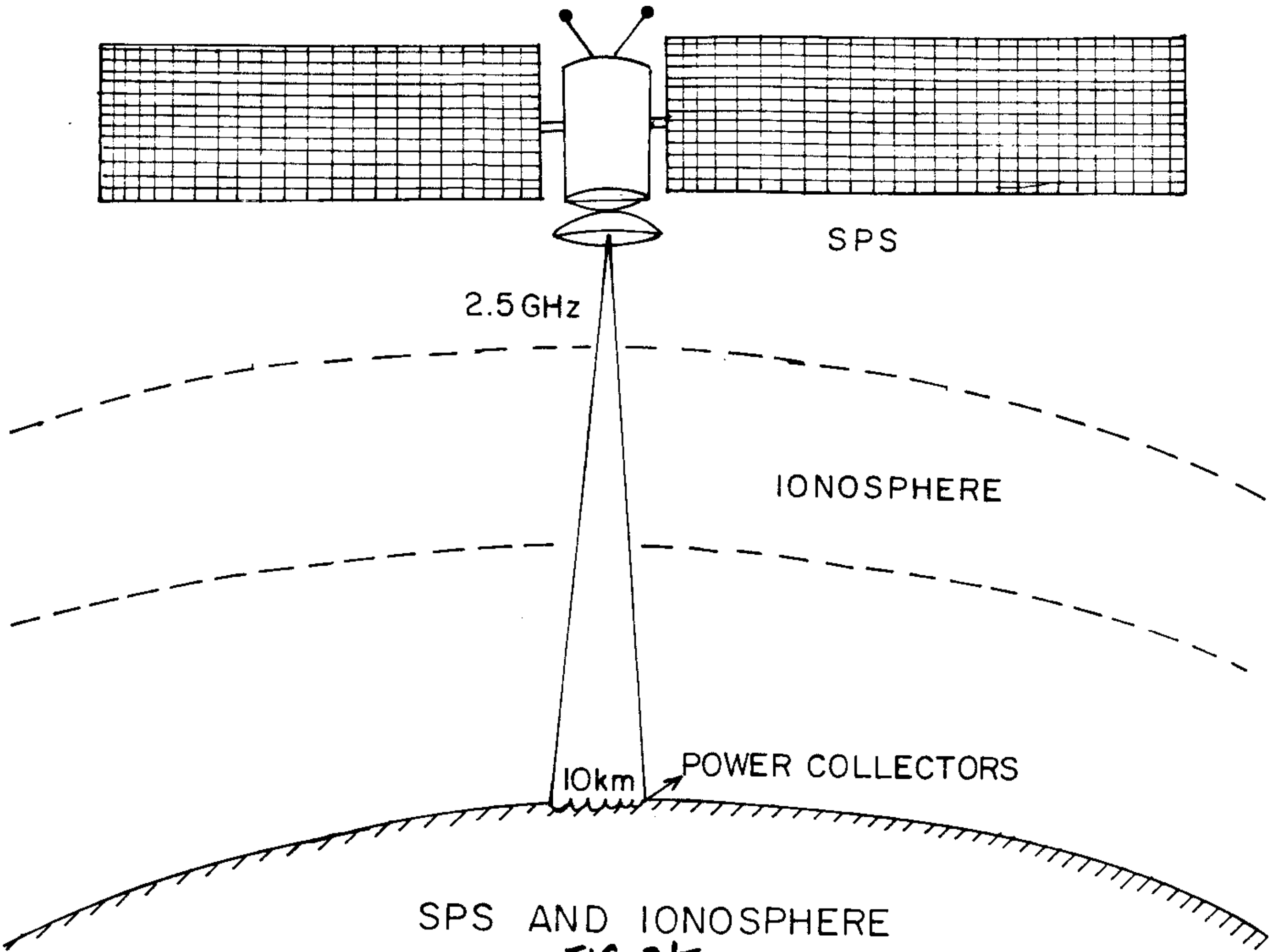


AMPLITUDE-DOPPLER SPECTRUM
(FOR SEA WAVES)



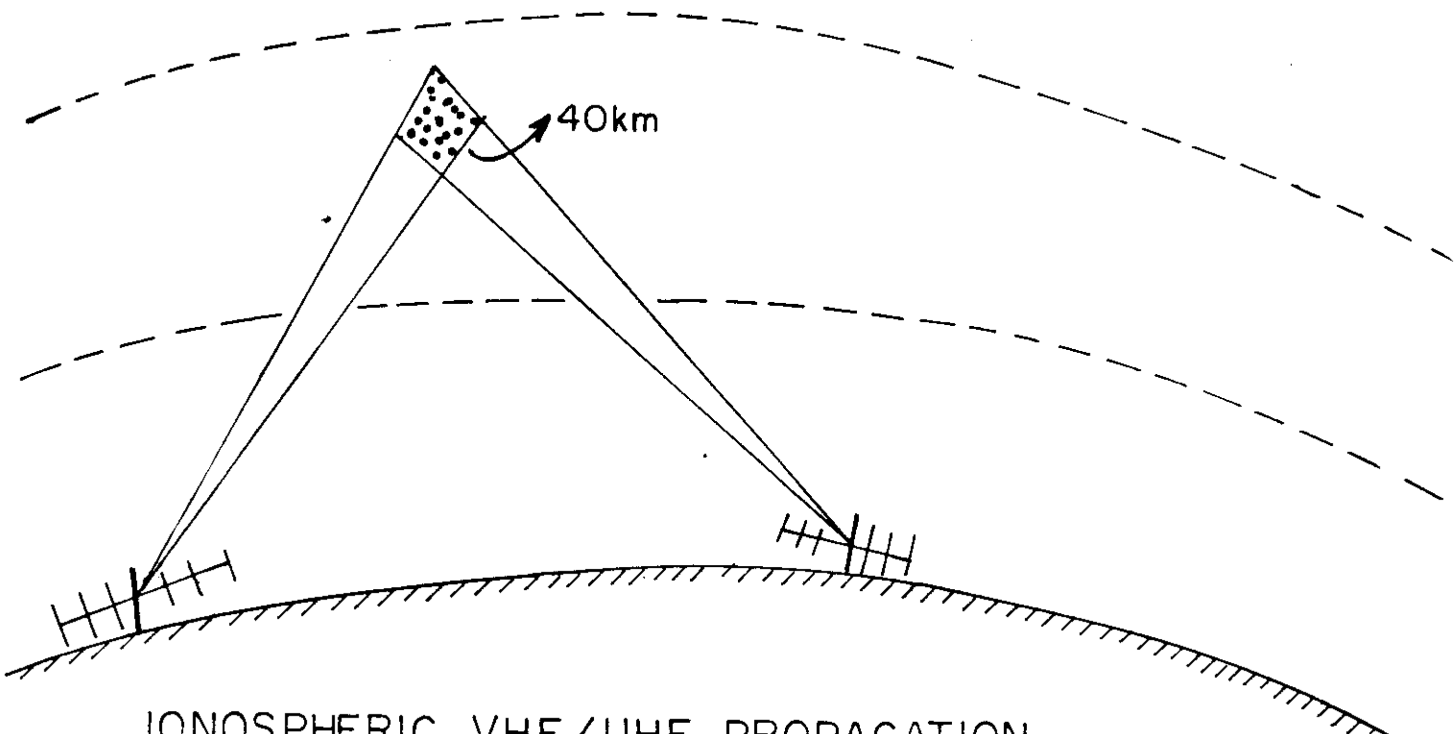
REFRACTION AT 100 MHz AND 200 MHz
(millirodions)
20
15
10
5
0
DELHI
SUMMER 1989
100 MHz, 1GHz
200MHz, 2GHz
0
5
10
15
20
25
ELEVATION ANGLE AT SURFACE
0.2
0.15
0.1
0.05
0.0
REFRACTION AT 1 AND 2 GHz
(millirodions)

FIG. 2



SPS AND IONOSPHERE

FIG. 3b



IONOSPHERIC VHF/UHF PROPAGATION

FIG. 3a

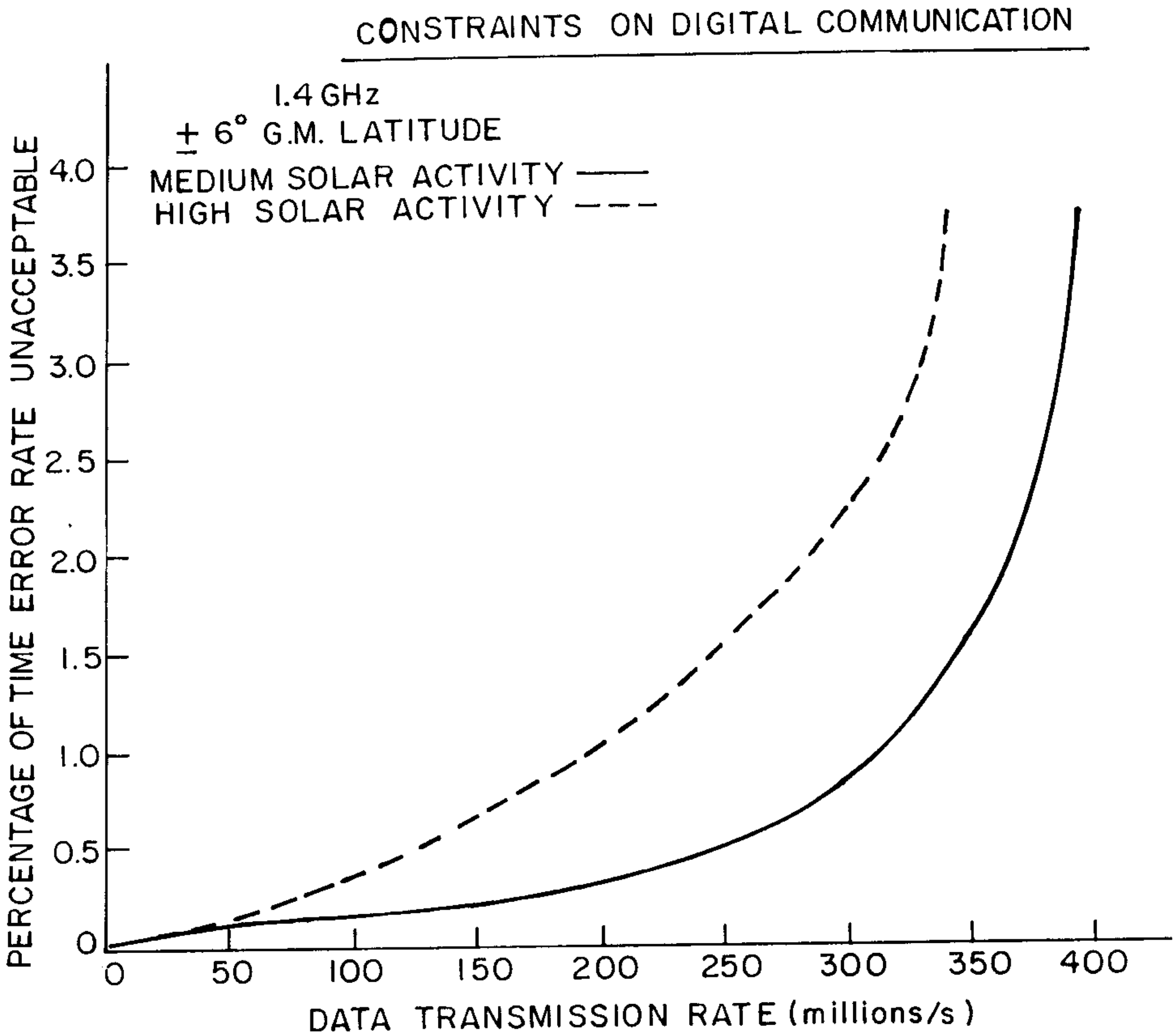

CONSTRAINTS ON DIGITAL COMMUNICATION
1.4 GHz
± 6° G.M. LATITUDE
MEDIUM SOLAR ACTIVITY
HIGH SOLAR ACTIVITY
PERCENTAGE OF TIME ERROR RATE UNACCEPTABLE
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
50
100
150
200
250
300
350
400
DATA TRANSMISSION RATE (millions/s)

Fig. 4