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Tropospheric Water Vapour Measurement By Microwave Radiometer and to Configure Millimeter Wave Communication System for Antarctica

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Abstract

The common means of communication between India and Antarctica is through satellite which provides telephone, telex and telefax facilities. However, although highly reliable, this is very expensive way of keeping in touch with the mainland. As an alternative, low cost HF communication is also in use which gets frequently interrupted due to ionospheric disturbances. During the eleventh Indian expedition to Antarctica, possibility of communicating in the millimeter wave band and related problems were explored. The results of this study have been encouraging which are discussed in this paper.

Introduction

Radio communication, the life-line of human civilization, has surpassed phenomenal developments during recent past and today it has become indispensable for communication in space research, under-water communication, long distance communication and also in many other areas where cables cannot be laid for communication. For instance, the success of scientific pursuit in the fiercest and hostile environment of Antarctica depends largely on the scope of communication with rest of the world. As of present,, telephone communication is the single reliable option which is very expensive and therefore unsuitable for intensive information exchange. Low cost HF communication may be used for intensive data transfer but it gets interrupted very often by the ionospheric disturbances. In our attempt to find out a reliable alternative, communication in the millimeter wave band was explored during the eleventh Indian Scientific Expedition Do Antarctica. Finally, a detailed specification of millimeter wave communication system has been drawn up.

Communication in the millimeter wave band has the following distinctive advantages over the conventional systems. These are:

a) It is transparent to fog, cloud, smoke and dust,

b) Increased frequency reduces the antenna and component size yielding compact system designs which are truly portable,

c) Large bandwidth permits many channels and each channel is capable of both audio and video communication,

d) Noise immunity is very high and remains unaffected by ionospheric disturbances,

e) Highly directional and narrow beam antenna available at millimeter wave band makes it an excellent choice for ground imaging from satellite.

At frequencies above 10 GHz, electromagnetic radiation starts to interact with different atmospheric gases, in particular oxygen, and water vapour and precipitation, resulting in absorption of energy, thereby attenuating signal levels. The designer of such high frequency communication systems,therefore, requires to predict this attenuation, to determine adequate fading margin in order to ensure a pne-determined level of reliability under a wide range of weather conditions. A detailed knowledge of the physical mechanisms of various atmospheric and meteorological phenomena, and their interactions with electromagnetic radiation must be studied to come out with a final specification of the communication system. In the absence of precipitation, oxygen and water vapour are the principal atmospheric gases responsible for signal attenuation. Since oxygen concentration is almost same around the globe, it is easy to model, *but* water vapour is a highly variable parameter which changes with time and location. In order to study the water vapour variation at Antarctica, a 22.235 GH_Z radiometer was taken to Indian Antarctic Station "Maitri" and operated continuously for three months on round the clock basis.

Choice of radiometer frequency

A welt calibrated radiometer operating at 22.235 GHz may be operated in emission mode to monitor the dynamic variation of water vapour in the upper atmosphere. Westwater (1967) pointed out that operation at 22.235 GHz may lead to serious errors in retrieval mechanisms due to pressure broadening of rotational lines. Therefore, he suggested some offset frequency such as 21.0 or 24 GHz, pressure independent lines, as radiometer operating frequency for use in water vapour measurement. Line width parameters and weighting functions at 22.235, 21.0,24.4 GHz, when calculated for Antarctica, revealed that pressure broadening effect does not contribute much for places with extremely day atmosphere. So,operation of radiometer at resonant frequency i.e. at 22.235 GH_Z does not yield much error at Antarctica (Datta,1993).

Experimental Set-up

A Dicke type 22.235 GHz radiometer, prototypes of what were used in Indian remote sensing satellites Bhaskara I and II, was taken to Indian station "Maitri" at Antarctica. The radiometer was fixed horizontally inside a wooden structure, as shown in Fig 1. The radiometer antenna was made to look at a metallic reflector placed at 45° to the ground outside the hutment, as shown in Fig 2. Arrangement was such that the down-welling emission from atmosphere could be sensed by the radiometer kept inside the temperature controlled hutment. The radiometer specification is as follows :

Operating frequency	22.235 GHz
R.F. Bandwidth	200 MHz
Antenna: corrugated conical	
horn with beam width	22°
Sensitivity	1K
Time constant	1 Sec

Radiometer calibration

The radiometer was calibrated from time to time using a liquid nitrogen load fed to the radiometer through a calibrated variable attenuator. Calibration curves were drawn for different temperatures of the reference load which was monitored by a built-in temperature sensor mounted close to the load.

Calculations

The brightness temperatures observed by the radiometer can be converted into effective zenith attenuation by the radiative transfer equation as:

$$: A = 10\, Log \frac{Tm}{Tm - T\alpha}\ \text{dB}$$

where $T_a$is the measured antenna temperature and T_m is the mean atmospheric temperature which may be assumed to be 275 K. The water vapour content also can be defined by the relation :

$$T_a = 1.47 \times 10^{-4}\ \text{x}\ W + 3.05K$$

Results

Round the clock operation of 22.235 GHz radiometer along zenith were performed during polar summer for 3 months. On analysis of the chart paper records, following results are obtained:-

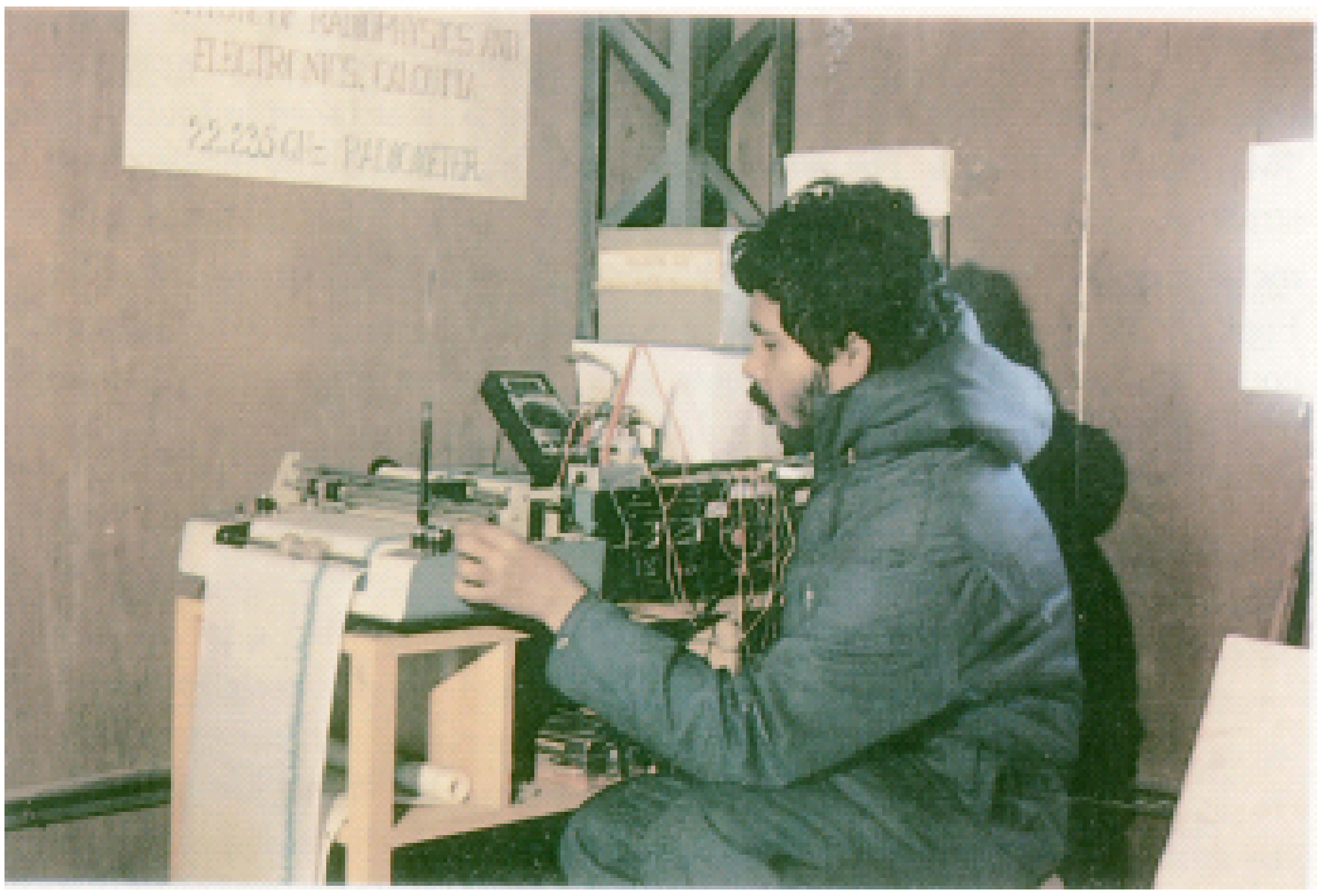

Fig 1: Radiometer position inside "Laser hut", antenna is kept near a hole on the wall.

Fig 2 : Position of metallic reflector kept at 45° to the ground outside the hut, aligned to the radiometer antenna.

a) Radiometric measurement at 22.235 GHz yielded fairly accurate results as confirmed with simultaneous radiosonde data.

b) In general, water vapour content in the Antarctic atmosphere is about one third to that of the tropics. At times, especially during blizzards,the level can reach 5 to 6 times higher than normal value.

c) A number of fast changing water vapour profiles as shown in Fig 3 were recorded which resemble fast passage of water vapour packets across the field of view of antenna and these were mostly associated with frontal weather systems.

d) Diurnal variation in water vapour content in Antarctica was very small in comparison to tropics.

Satellite Communication with Antarctica

The major problem for satellite communication at Antarctica is that a geostationary satellite is not visible from polar regions, leaving only polar

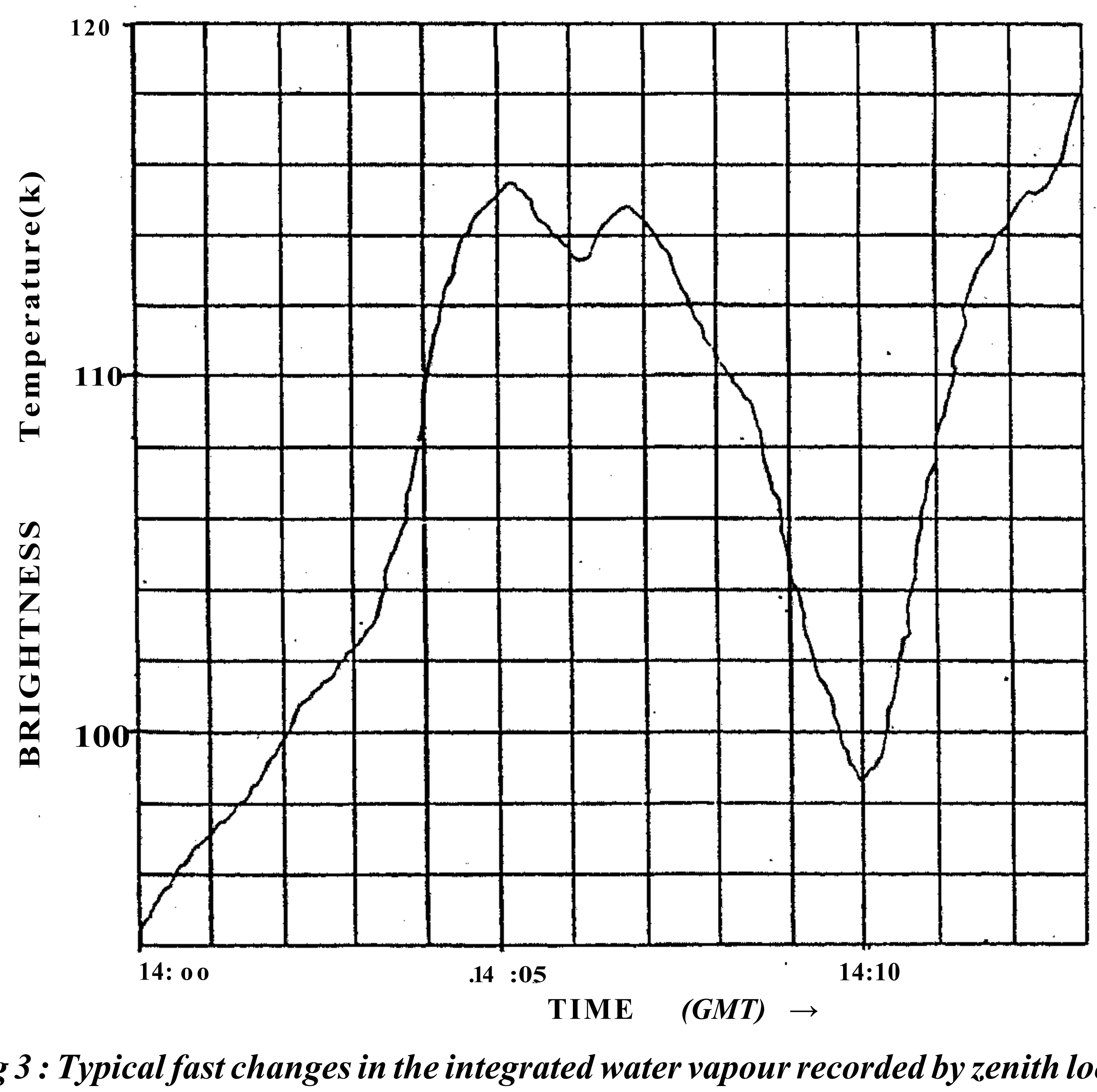

Fig 3 : Typical fast changes in the integrated water vapour recorded by zenith looking 22.235 GHz radiometer at Antarctica.

orbiting satellites to be used for communication. The low altitude of such satellites allows only a limited line of sight coverage of the globe at a time. Recently, the use of a geostationary relay satellite, picking up the signal from the orbiting satellite and relaying back to earth, has. been suggested for achieving a global coverage. The geometry of the problem is illustrated in Fig 4 which slows that a satellite in the geostationary orbit would be below the horizon for the line of sight relay for an earth terminal at Antarctica. An Earth Exploration Satellite (EES) orbiting round the earth in polar orbit at an altitude of about 1,000) kms may be utilized as a mobile relay platform to interconnect the terminals at Antarctica and the GSO. The range of the EES from Antarctica varies from 1000 to 13,756 kms and this must be tracked by the earth terminal for communication. The transponder at EES must have a steerable antenna beam to maintain communication during a satellite pass over Antarctica. At the same time both the EES and the GSO transponders must have a narrow antenna beam of about 0.5° and two beams must remain aligned to each other. The requirement of beam alignment of such narrow beam, in turn, leads to the problem of pre

cision antenna tracking system on the mobile EES platform. The GSO antenna should also be capable of maintaining its beam in the angular field of view of 1.27° within which the EES relay would be useful for the communication between EES and Antarctica. Handling these problems is within the capability of present day technology (Jansky,1983) For antenna tracking problems the monopulse feed system may be used to send pulses periodically.

Suitable frequencies around 19 GHz for down-link and 27 GHz for the up-link have already been allocated for the EES-GSO link (Jansky,1983). The link between GSO and the user at non-polar latitudes could be operated in the

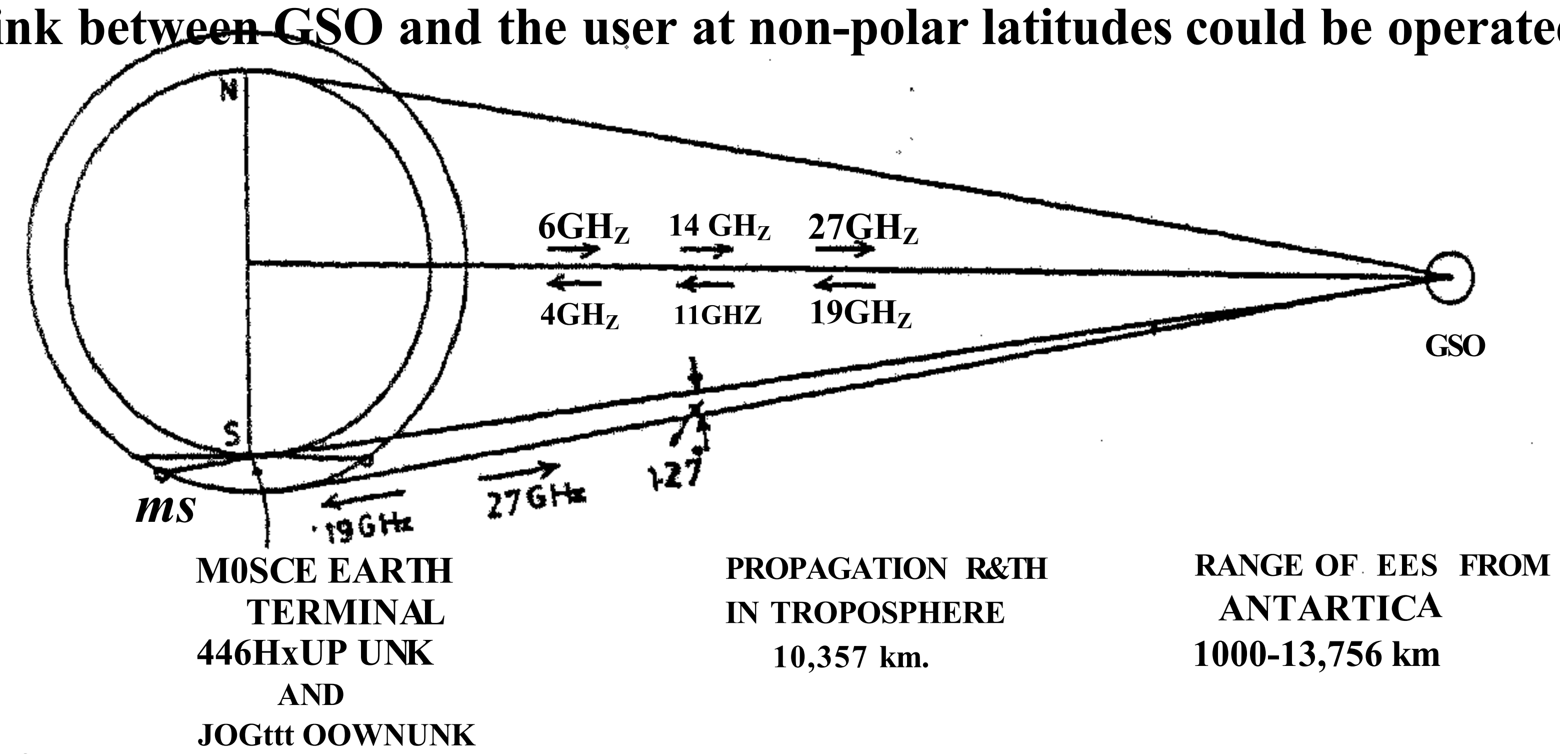

Fig 4 : Geometrical representation illustrating non-visibility of Geostationary Orbital (GSO) satellite from Antarctica and position of orbital Earth Exploration Satellite (EES) above pole.

conventional bands available for global satellite communication network, with a choice amongst 4,11 and 19 GHz for the down-link and 6, 14 and 27 GHz for the up-link.

However, the EES-Antarctica link at a frequency of 44 GHz for the up-link, and 30 GHz for the down-link may be suitable. These frequencies have, in fact, been allocated for futuristic mobile earth terminals.

Configuration of EES-Antarctka Link and Short Range Surface Link

A block diagram of the millimeter wave satellite link at 44/30 GHz between the EES and earth terminal at Antarctica is shown in Fig 5. The use of millimeter wave allows a smaller antenna diameter to facilitate mobile operation, in addition to provision for a wide communication bandwidth available at millimeter waves. A 15 watt CW IMPATT oscillator at 44 GHz is injection locked by a Gunn PLO system having a provision for wideband frequency modulation, based on a 42.5 GHz Gunn PLO followed by an up- converter to obtain 44 GHz with a synthesized local oscillator at 1.5 GHz, capable of wideband modulation. It is important to note that a direct frequency modulation of a 44 GHz Gunn

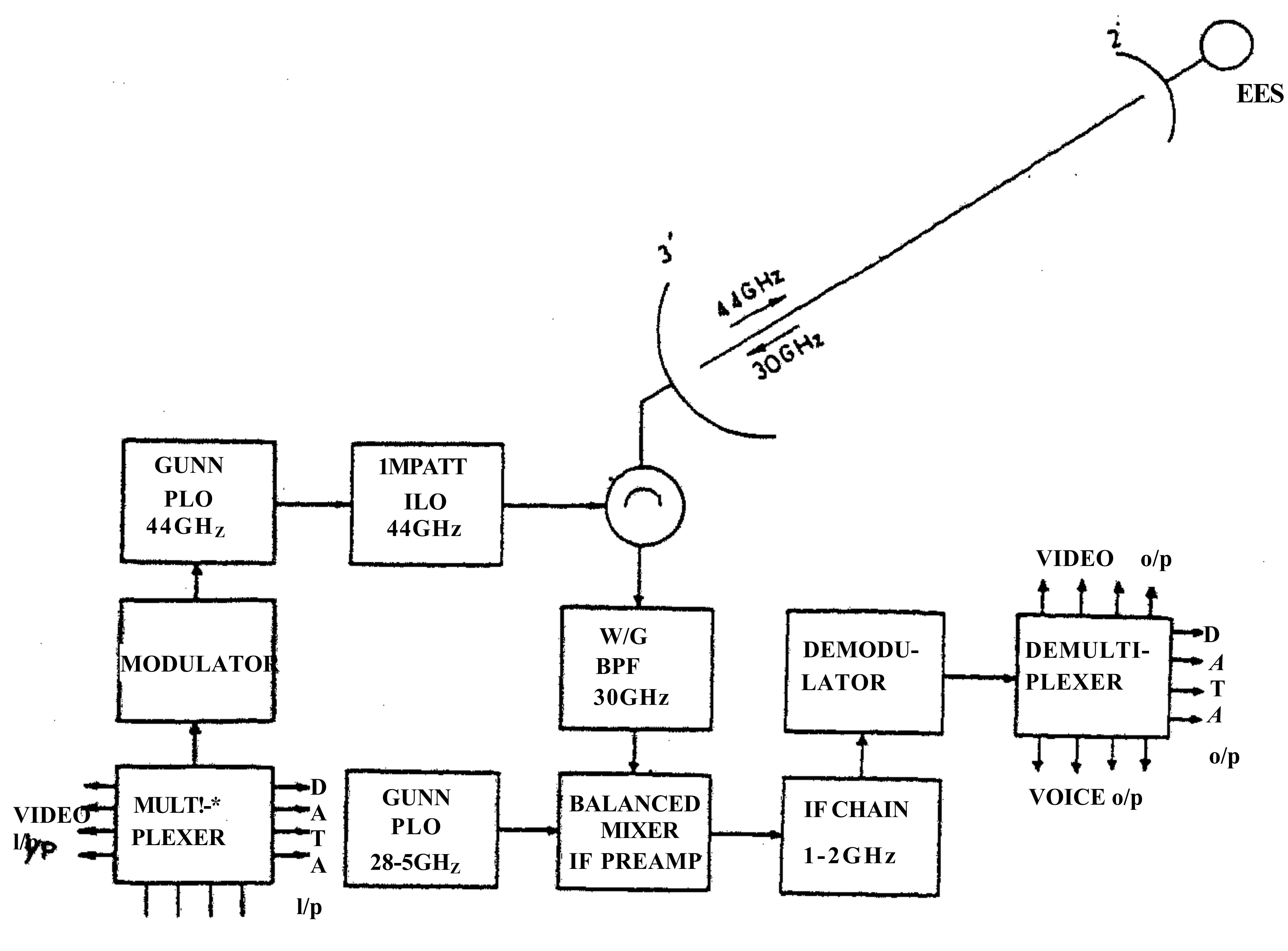

Fig 5 : Block *diagram of millimeter wave satellite link between earth terminal and EES wiih 44 GHz as up-link and 30 GHz as down-link.*

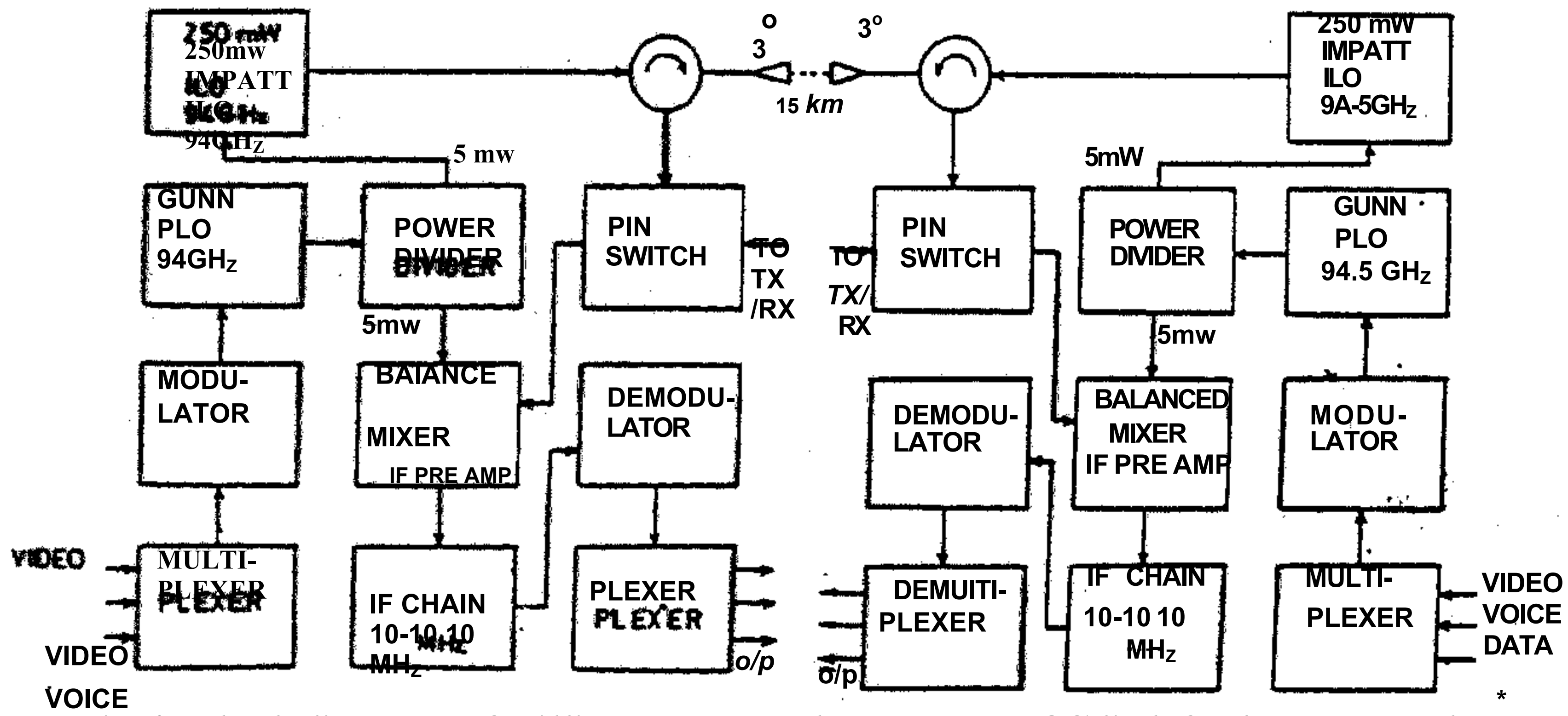

Fig 6: Block diagram of millimeter wave short range LOS link for hutment to hutment and hutment to ship communication.

PLO driver is not feasible as it would be rather sluggish in changing its frequency or amplitude by the signal.

Fig 6 depicts the millimeter wave LOS link over Antarctica for short range LOS link to cover distance between two hutments and also between hutment to ship (15 kms). It may be pointed out that the LOS link operating at the atmospheric window around 94 GHz will acquire very light weight terminal equipment with even 3" to 4" horn lens antenna which would be capable of establishing a link of about 15 km path. The detailed configuration of both systems are given in Table I.

Discussion

Continental Antarctica is surrounded by Southern Ocean which provides an uninterrupted corridor for circum-polar westerly winds to blow around the mid-latitudes. These westerly winds extend through the entire depth of the troposphere and give birth to depressions leading to low pressure centres. These weather systems last for about a week from birth to decay moving generally eastward and poleward across the ocean guided by the waves in the upper part of troposphere. The general pattern of movements is similar at all the times which are reflected several times in radiometer output.

As individual depressions approach the Antarctic coast, they bring warmer and hymid air from over the ocean, particularly in summer when the edge of the sea is close to the coast This results in an increase in cloudiness and easterly wind gets stronger often leading to snow fall. Because of low temperature in Antarctica, the absolute humidity remains very low. By contrast, the relative humidity varies a great deal and may be over 95% when there is drifting snow.

Table: Link parameters for Various mm- wave systems for use in Antarctica

mm-wave link	Antenna dia(inch) with 55% gain (dB)	Freq. (GHz)	T_x power (Watt)	Free path loss (dB)	Receiver characteristics at 300°K			C/N (dB)
					Band width (MHz)	Noise figure (dB)	Sensi-tivity (Watt)	Approx
Hutment to Hutment (6 Km)	4, 37.4 4,37.4	94	0.25	147	40	4.5	$46x10^{-14}$	45
Ship to Hutment (15 Km)	12,46.9 12,46.9	94	0.25	156	40	4.5	$46x10^{-14}$	56
Earth receiving terminal to (13, 756 Km) EES up-link (near horizontal path)	36,49.9 24,46.4	44	15	208	40	4.5	$46x10^{-14}$	24
EES 10(13, 756 Km) Earth receiving terminal down-link (near horizontal oath)	24,43.0 36,46.5	30	15	205	40	4.5	$46X10^{-14}$	20

The Southern Ocean remains very cloudy throughout the year, and the coastal region around Antarctica remains cloudy as well, because of high onshore winds. Generally there is less cloud over the interior. The low, thick stratocumulus cloud over the ocean and along the coast gives way to thinner, multi layered ice crystal clouds over the continent. They do not contain liquid water on their surface. So a single frequency radiometer can record fairly accurate data on measurement of integrated water vapour in the region.

As revealed from this study, Antarctica will be an ideal location for communication of millimeter wavelengths because of very low water vapour presence in the atmosphere. In absence of rain which is the worst offender of millimeter wave propagation, millimeter wave has very low attenuation in the order of about 0.05 dB/km (Curie and Brown ,1987). Snow storms are frequent in the Antarctic continent "where snow is extremely dry like sand due to low temperatures. This contributes negligible attenuation to the signal. Considering all aspects of communication, 94 GHz link would be good enough for local communication and 44/30 GHz satellite link with EES (1000' km orbit) would be a plausible solution for long distance communication.

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