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DISCUSSION AND CONCLUDING REMARKS

For many years, mm-wave systems could not gain popularity due to its prohibitive cost even though their potential were not unknown. Congestion of conventional communication bands, interference and other limitations have accelerated research in the field of mm-wave propagation and some remarkable break-throughs are achieved in the development and production technique in recent times. This has reduced the mm-wave system cost considerably and new application areas are being opened up. Communication and remote sensing are two broad areas where mm-wave systems are increasingly used because of having several distinct advantages over other frequencies. This includes wide frequency band, compact and light equipment and ease of interference-free system configuration.

Attenuation by atmospheric gases arises principally through interactions with water vapour and oxygen molecules. The combined effect of gaseous attenuation can be calculated with high degree of precision using recent models (*Liebe*, 1985, 1989). High levels of signal attenuation might appear as a severe restriction for communication but the same feature can be used for some advantageous applications, such as frequency re-use over quite small distances, thus conserving spectrum utilisation.

While gaseous effects can be readily estimated, attenuation by precipitation, caused by scattering from raindrops, is highly variable, both in time and space and is thus predictable to a much lesser degree of certainty. Rainfall attenuation, statistically the dominant problem at mm-wavelengths, depends on the rainfall rate. Numerous models for rainfall attenuation have been developed, the more important and widely used of which are summarised by the International Radio Consultative Committee (CCIR, 721-2, 1986). The resultant attenuation is generally assessed statistically, in the form of fade margins which are exceeded for percentages of time specified by the degree of reliability required by for a particular communication system, under a wide range of climatic conditions. Such changes of systems performance are further supplemented by an assessment of extremes. In general, there are two distinct methods available to system designers to assess fade margins for inclusion in link budgets;

- From direct measurement of propagation conditions over extended period
- Prediction from a knowledge of the prevailing meteorology

The first method is costly and time consuming while the second method can be implemented with a reliable prediction procedure through available meteorological data taken regularly by various weather monitoring agencies. Implicit in any prediction procedure, however, is a detailed understanding of the physical mechanisms of the various atmospheric and meteorological phenomena and their interactions with radio waves over wide range of frequencies. Below 30 GHz, there are enough data available for direct use. Above 30 GHz, reliability of various prediction procedures are less certain. Therefore, either new prediction method should be developed or measured data should be utilised for direct application.

In the present thesis, a comprehensive attempt has been taken to focus on the significant aspects of millimetre wave communication, measurement of parameters affecting mm-wave propagation, earth imaging by radars, radiometers. Various atmospheric and meteorological phenomena and their interactions with electromagnetic radiation have been thoroughly studied for proper understanding of the subject.

In chapter 1, a comprehensive review on communication, wave propagation studies and use of radiometers and radars at microwave and millimetre wavelengths, in imaging of earth's surface as reported by previous workers has been presented.

Chapter 2 deals with hardware and calibration technique of Dicke type radiometer that has been used in the study. This is basically a super-heterodyne receiver with excellent gain stability and is achieved by a Dicke switch which constantly switches between the receiver input and a reference load kept at a particular temperature (constant noise source). The switching rate is chosen so that it is higher than the highest significant spectral component in the gain fluctuation spectrum. Linear response of the radio-meter makes it ideal for accurate remote sensing of atmospheric gases and imaging of earth's surface as well. The radiometer was calibrated time to time to ensure measurement accuracy.

In chapter 3, choice of radiometer operating frequency in atmospheric water vapour sensing is examined in the light of existing theories. The purpose of this chapter is to re-examine actual need of this frequency deviation irrespective of the location. For investigation, two completely different climatic regions were chosen, viz., Antarctica (dry) and Calcutta (wet). Line shape functions at different heights of the atmosphere were calculated with radiosonde data for both Calcutta and Antarctica. For Antarctica, the line shape functions were found to be almost same for different heights. But for Calcutta, they were found to be different at different heights. Pressure broadening effect is the cause of this difference which is guided by collisions between H_2O and N_2 molecules and further increased by temperature of the medium. At Antarctica, surface water vapour concentration and temperature remains low, pressure broadening do not affect much and, therefore, line shape function at different heights of the atmosphere remains almost same. So, 22.235 GHz line remains pressure independent there. Hence, a 22.235 GHz radiometer can provide consistently accurate measurement of water vapour in the continent.

Water vapour weighting functions have been calculated at 21.0 and 22.235 GHz using radiosonde data for Calcutta and Antarctica. It is seen that the water vapour weighting function remains invariant up to 3 Km height. As 75-80% of the attenuation is caused by the lower 3 Km of atmosphere. Beyond that the weighting function tends to vary slightly.

Therefore, it may be concluded that a 22.235 GHz radiometer can provide reasonably accurate information on integrated water vapour at Antarctica. But as a profiler, it is unsuitable. The other water vapour peak at 183 GHz is suitable for profiling of the atmosphere.

In chapter 4, measurement of integrated water vapour at Calcutta, Antarctica with 22.235 GHz radiometer are discussed. As it has been confirmed in Chapter III that a 22.235 GHz radiometer is most suitable for measurement of water vapour at Antarctica or similar dry regions. A 22.235 GHz radiometer was taken to Antarctica during polar summer and collected continuous radiometric records for 3 months. The time of measurement is crucial considering water vapour concentration remains at its maximum value during that time. The same radiometer was used for water vapour sensing at Calcutta. Comparison of both measurements with corresponding radiosonde values revealed that 22.235 GHz radiometer is far superior in the prediction of water vapour at Antarctica than in Calcutta.

In chapter 5, a study was made to understand water vapour distribution and transport in the icy continent. Water vapour distribution in the atmosphere is the key factor of global heat budget and climatological change. Non uniform mixing ratio along the altitude makes it difficult to profile. At Antarctica, it is more complicated due to high wind speed and low temperature. To understand how water vapour distribution and transport takes place, a microwave radiometer was taken to Antarctica and was put into continuous operation during polar summer under XI Indian Antarctic Expedition Programme. Some interesting variations in water vapour were found. Several cold-front passages were recorded out of which few cold-front passages are singled out for detailed study. A number of events with very fast changes in integrated water vapour were also recorded.

In chapter 6, significant shift of millimetre wave window frequencies are discussed. 22.235 GHz radiometric water vapour measurement values can be effectively utilised to calculate attenuation at other frequencies in the millimetre wave band. In the present study it has been found that window frequencies are different from place to place and is critically dependent on radiometeorological parameters of the location. Moreover, operating frequencies for ground to ground and ground to space communication should be different. Choice of operating frequency becomes extremely important to ensure better signal to noise ratio of the system.

In the present study it has been seen that the window frequency is guided by the amount of water vapour present in the atmosphere and also on the temperature. A comprehensive study has been made for all major locations in India to establish the fact. The observations are given below.

- All window frequencies are found to be shifted from their standard value and 94 GHz window is the most seriously affected one.
- Window frequency for surface to surface and surface to space communication are different.
- At window frequencies theoretical estimate of attenuation is found to be varying with the experimental values.
- A good relationship has been found between the window frequency and surface water vapour density especially around 94 GHz.

In chapter 7, a comparison between theoretical and experimental results in the prediction of millimeterwave attenuation is carried out. Theoretical values were calculated following different models viz. (1) Water's model (2) Liebe's model (3) Gibbin's model (4) CCIR model and were compared with experimental values in order study the goodness of the models in the prediction of attenuation. Two frequencies were used, one at 22.235 GHz and another at 31.4. For each model, accuracy in the prediction of attenuation both at peak and in the window region is studied as they were compared with corresponding experimental values. Radiosonde values were used to calculate the theoretical values. The findings are,

- All models are good in the prediction of attenuation at the peak but poor/weak at window frequency. The error increases for regions with higher relative humidity and temperature.
- Water's model is fairly good between 1-100 GHz and Liebe model is good for both higher and lower frequency ranges i.e. 1-1000 GHz.
- In surface absorption coefficient estimation, Gibbin's value is slightly higher than the others. But experimental values are consistently lower than the theoretical value.
- For clear weather, absorption is directly proportional to the length of the propagation path.
- Surface absorption coefficient and zenith attenuation are found to be well correlated at Calcutta.
- Surface absolute humidity and zenith attenuation are compared.

Since absorption is a function of temperature, pressure and humidity, these meteorological parameters are to be known along the propagation path. Again, for small path the attenuation at window is small so a long path should be chosen. The main difficulty faced to perform the experiment was to measure meteorological parameters at different points and also multipath fading and earth's curvature limits the prospect of experiment. Joss et al. [1974] compared between theoretical and experimental attenuation data and got good agreement.

In chapter 8, a proposal of millimeter wave communication over Antarctica is furnished. Radiometric measurement of water vapour at Antarctica prompted me to suggest mm-wave system for communication. Since rain and thunder are sparse in the icy continent, and rain being the worst offender of mm-wave communication, Antarctica would be the ideal place for mm-wave communication. Water vapour concentration, which play dominant role in attenuation of signal, was found to be at lower value during polar summer when it is at maximum. Therefore, low power transmitters will be required for both ground to ground and ground to space communication. In mm-wavelength antenna beam is sharp and highly directive which implies that the total signal power will be channelled through a narrow beam causing less attenuation to the signal.

A major problem in satellite communication is that no geostationary satellite is visible from poles and Polar orbiting satellite remains the only alternative which requires a very efficient tracking system. Incidentally, mm-wave attenuation at the poles are very low and tracking error would be small. Development of a communication system for Antarctica at mm-wavelength would have the following advantages;

- Shorter wavelength makes the antenna small and system compact.
- Wider bandwidth to accommodate more channels for audio, video, data.
- In absence of rain and lower relative humidity, relatively low.
- power transmitter and receiver will be required.
- Signals at mm-band are more immune to interference and jamming.

Polar satellites remain at lower altitudes as compared to geostationary satellites and therefore it can cover less earth area for line-of-sight communication. Signal picked up from Antarctica by polar orbiting satellite may be relayed to the geostationary satellite for global communication. Low altitude of polar satellites restricts the line of sight coverage of the earth's surface. The requirement of beam alignment of such narrow beam demands precision antenna tracking system on the mobile EES platform, which is within the state of the art technology.

For inland communication over Antarctica the millimeter wave region would be very useful. Measurement of water vapour provided information to decide the fade margin of the system. Very low power communication systems are required. Only snow fall is experienced which offer attenuation to the order of 0.05 dB/km. So, considering all aspects mm-wave communication is ideal for Antarctica.

This Chapter covers discussion on the use of mm-wave communication and remote sensing. As observed, communication in mm-wave band is attractive due to its wider band width and reliability. Design of a mm-wave system is site dependent as it is largely affected by atmospheric water vapour in the region. Yearly variation in water vapour should be studied before coming out with a final specification of a mm-wave system. It is found that a 22.235 GHz radiometer is good enough to measure integrated water vapour in the dry regions like Antarctica and some offset frequency such as 18.0 or 24.0 GHz is good for tropical region. Measurement with a 22.235 GHz radiometer has revealed that Antarctica is the right place for use of mm-wave communication because rain is sparse in the continent. Window frequencies are found to vary for place to place and the 94 GHz window is most affected one. Attenuation at different mm-wave frequencies could be theoretically estimated from meteorological parameters with different models. A comparison among different models with experimental values have shown that Liebe model is good, which allows prediction of attenuation in the frequency range 1-1000 GHz with reasonable accuracy.

Rain, still posing a serious problem to mm-wave communication, as the transmitted signal is heavily attenuated by it. With the availability of high power sources, performance may be improved to some extent by increasing transmitter power at proper selected window frequency.

Earth imaging from a space platform or aircraft in mm-wave band can provide many critical information on earth's surface where both mm-wave radars and radiometers are used. A combined system would be ideal to collect comprehensive knowledge on the surface under observation. The potential of mm-wave communication and remote sensing were not unknown in the past but high component cost restricted the application and research for long time. with newer break-throughs in the production technology and introduction of GA-AS technology, the component cost is reducing sharply and thereby uses of mm-wave systems are increasing steadily.

Widespread utilisation of millmetric wavelengths for communications systems will only become a reality given readily available and inexpensive components and devices. Currently, millimetric technology is still relatively expensive and somewhat primitive, compared with lower frequencies. Circuit integration, at the substrate level, is relatively uncommon, particularly in commercially available components and systems; it is also rendered more difficult since both silicon and GaAs devices tend to be employed. Considerable effort is being devoted, however, at a number of laboratories to increase the degree of circuit integration. At present, though, most systems are built from discrete components, using waveguides rather than microstrip circuitry, especially at the shorter wavelengths. Such waveguides are, of course, rather small, and so components thus tend to be relatively expensive, since the engineering precision required is very high, in order to reduce impedance mismatches.

The millimetre-wavelength part of the electromagnetic spectrum is at present largely unused, and thus offers considerable scope for many and exciting new possibilities for future communications and other applications. Although there are still unresolved difficulties in implementations of such applications, there are some very active programmes of research into the propagation problems to provide some of the basic data required for systems planning and design, while advances in millimetric technology should facilitate considerable exploitation of frequencies above 30 GHz in near future. In Japan, high speed wireless Local Area Network at 60 Ghz for indoor communication has already been set up and much work being done to operate at a transmission rate up to 160 Mbps [Ihara, 1993]. A lot of research work is still needed to achieve a reliable mm-wave communication network which efficiently covers large area and effectively minimise multipath propagation impairment.