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Airborne microwave refractometer to exploit the effects of atmospheric refraction to tactical advantage

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Microwave communications has reached a turning point in its long career as both flexible and efficient transmission medium. For many years, microwave frequencies served as the workhorse of communication engineers seeking a longhaul transmission medium that avoided the hassle of laying extensive cable systems over unsuitable terrain. Perhaps the biggest threat to microwave communications is the weather, particularly in tropics as microwaves are susceptible to path distortion due to varying radiowave propagation conditions. Effects of atmospheric refraction on ship-borne radars were noticed as early as World war II. Since then, extensive investigations led to a quantitative understanding. Indian Navy has realised the increasing importance of refractive phenomena in its fleet operations. Urgent need is envisaged to influence the future direction of refractivity measurements and assessment. However, work on the development of new refractivity sensors, refractivity forecasting techniques (especially on realtime basis) and the assessment system is still going on throughout the world. As water vapour plays a dominant role in tropospheric refractivity, especially in tropics, its distribution assumes a great significance due to its role in modifying turbulence related refractivity fluctuations leading to anomalous propagation conditions. Thus, information on fine structure of radio refractivity is useful in estimating the magnitude of the propagation anomalies on systems like earth-space, line-of-sight, radar, satellite navigation etc. Unfortunately, most of the sharp gradients in refractivity (leading to ducting conditions) are smoothed out in the profiles obtained by the conventional meteorological systems, (due to their poor height resolution). In addition, the large response time of these sensors gives highly erroneous results and hence can not be applied in designing high reliability radio and radar systems for tactical applications. Airborne microwave refractometer (AMR) is the only instrument of its kind which can provide information on the fine structure of radio refractivity at a rate of even as high as few hundreds of cycles to meet the operational requirements of all operational commanders. Thus, these refractometers are ideally suited for deriving sub and super refraction and duct occurrence statistics and for measuring tropospheric turbulence parameters that can be directly used (for realtime assessment) in radio and radar operations.

Modern electronic warfare is highly dependent on the use of the electromagnetic spectrum for command and control communications, radar detection, ESM (Electronic Surveillance Measure) and ECM (Electronic Counter Measure). All these operations are deleteriously affected by the atmospheric conditions. A knowledge of these conditions, in real-time, is mandatory for successful offensive and defensive operations. Thus, airborne microwave refractometer has the capability in detecting and measuring the anomalous propagation of electromagnetic waves in the atmosphere enabling the carrier strike group commander to employ his forces in a manner to optimise the probability of success in the assigned missions. The desired capabilities of the surveillance and reconnaissance aircraft will be improved with the installation of a microwave refractometer. Thus, there is a need to determine the anomalous conditions using AMR on a surveillance aircraft.

The basic principle of operation of a microwave refractometer is to measure the change in the resonant frequency of a cylindrical cavity with ends open to sample the ambient atmosphere and compare it with the standard atmosphere (vaccum). With the incorporation of sophisticated design, the weight and volume of these refractometers have reduced considerably while increasing the reliability and accuracy to less than 0.01 N unit of refractivity. The height resolution of the radio refractivity gradients obtainable using airborne microwave refractometer is far superior to any other derived techniques that are presently used.

The radio refractivity (N) is defined as

$$N=(n-1)\times 10^{6} \tag{1}$$

and N is a function of pressure, P (in mb), temperature, T (in degrees absolute) water vapour pressure, e (in mb) and n the radio refractive index of the atmosphere.

Thus radio refractivity information may be obtained by radiosonde, rawinsonde meterological sensors for measuring P,T and e or by microwave refractometer and the degree of accuracy depends on the type of instrument used to collect the information. A change in the resonance frequency of a microwave cavity, Δf, produced by a change in the refractivity, ΔN of the enclosed atmosphere is given by

$$\Delta N=-10^{6}\Delta f/f \tag{2}$$

This ΔN measurement can be carried out by microwave refractometer very precisely. The error involved in the measurement of radio refractivity is ± 0.6 N unit in the present case using the airborne microwave refractometer. In case of radiosonde data the error involved is about ±3 N units.

For data collection, the microwave refractometer should be mounted in an aircraft with its sensing element (sounding cavity through which the atmosphere under investigation can pass through freely) located in such a position (along the fuselage) that the air sample was undisturbed by the aircraft's slip-stream. This cavity sensor should be periodically checked for plate erosion due to salt spray and the impact of ice and hence rinsing is necessary with distilled water before and after each flight. Refractivity measurements are affected by moderate to heavy rain and under these conditions the data needs a careful examination for spikes and other inhomogeneities before analysis. The refractometer measurements can reveal the order of magnitude of variability of the refractivity in vertical and horizontal directions along its path. Airborne microwave refractometer has an excellent manoeuvrability.

Typical radio refractivity finestructure measurement is shown in Figure 1. Standard practice of refractivity gradient classification (Almond and Clarke 1983)

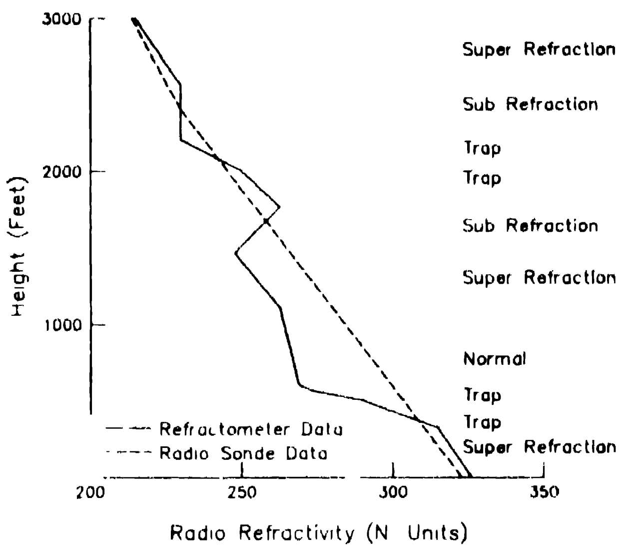

Figure 1. Radio refractivity over the ocean under anomalous propagation condition.

was used in this figure. It is widely accepted that for a normal atmosphere, the refractivity gradient lies in the range of −76 to 0 N units/km while in case of sub-refraction, the gradient becomes positive i.e. greater than zero. In case of super-refraction, the gradient lies in the range of −156 to −77 N units/km and if it reaches −157 N units/km or less, a ducting/trapping condition sets in. This figure obviously demonstrates the sharp gradients of the radio refractive index and the variability of the troposphere in time and space indicating the orientation of the layers and ducts. Further, the figure shows that the shipborne radiosonde data and airborne microwave refractometer data agree well in the gross structure showing the super refractive condition (– 110 N km). However, the shipborne radiosonde could not resolve the fine structure information to indicate the existence of various layers of sub, super and duct (trap) conditions at various heights which is a vital information for modern warfare. Therefore, data base is to be created due to the following reasons for Indian subcontinent giving the information on the statistics of tropospheric ducts and super-refracting layers and their probability distributions and variations. Firstly, the local weather changes much more frequently and hence the quantitative links between the propagation of radiowaves and the atmospheric conditions, which have been obtained for one climatic zone are not applicable for another climatic zone due to the fact that the structure in different climate zones differs and influences the radio waves in different ways. This does not allow the results obtained in other countries to be used, particularly under other climatic conditions, and requires accumulation of fundamental statistical data. Secondly, the meteorological data base contains data averaged over several minutes, whereas in the design of tactical communication circuits it is necessary to operate with second-averaged values on real time basis. This leads to the problem of determining the quantitative relationships between statistical data with different averaging intervals. Finally, the theory of microwave radio propagation in the atmosphere depends on the assumed knowledge of the atmospheric conditions, in real-time, along the entire propagation path. This information enables to predict the refractivity conditions at any specific area and can also give an opportunity to examine the question of the extent of horizontal uniformity in super-refracting atmosphere which is of major importance of tactical operations.

The following are some of the advantages of integrating microwave refractometer in the surveillance and reconnaissance aircrafts.

Strike warfare at sea :

The effectiveness of the air strike against surface ships is extremely dependent upon the survivability of the strike vehicle. This survivability can be enhanced by denying the enemy electromagnetic detection capability through the proper choice of the path of the vehicle based on the existing refractive layers as detected by the airborne microwave refractometer. The refractive layers can be used either to increase or decrease the jamming effectiveness by proper jammer altitude selection which is dependent on the layer composition.

Anti-submarine warfare (ASW) :

A surface based duct which refracts emissions normally result in erroneous estimates of the altitude of radar detected aircraft. Elevated ducts influence the propagation in much the same fashion as surface ducts for emitters within the duct. However in the case of an elevated duct depending on the position of the emitter false ranges are derived from radar detections of surface targets, and detections are lost by shadow zones at very achievable ranges for aircraft targets.

ASW aircraft flying at altitudes without knowledge of refraction anomalies can produce situations which cause loss of sonobuoy RF data during operations, loss of communication links with friendly surface vessels or task force and more subtly, a false security from distant enemy detection and attack. If refraction conditions are known, using AMR, proper altitude selection can optimise the successful completion of the mission and return of deployed aircraft, even for maximum effectiveness of a missile strike (from ship or submarine).

Anti aircraft warfare (AAW) :

Force detection platforms should be positioned based on existing atmospheric conditions which could be known in real time, only by AMR. The operational commander normally uses the "fade chart" designed for each radar antenna system to preclude "holes" in coverage by varying ship station. However, these charts are accurate only on a standard day and do not apply under anomalous propagation conditions. He must have the data available to station his forces during amomalous propagation conditions which could be determined only by AMR.

Altitude of Combat Air Patrol (CAP) stations, air borne ESM platforms and airborne early warning (AEW) stations are particularly dependent upon atmospheric conditions. Stationing on the wrongside of a refractive layer can essentially negate the sophisticated radar and passive detection system of these aircraft. Operation stations should always be chosen below a strong refracting layer, to optimise low flyer detection, as the detection ranges are always beyond the normally expected ranges under the above condition which could be known only by AMR. It is always preferable to utilize data on existing layers and ducts, which could be detected only by AMR, to plan their mission profiles.

Command and control communications :

Control of CAP via UHF link from a surface platform, particularly at the mid and low altitudes can be seriously degenerated when the CAP nears a refractive layer. Normally the pilot of the interceptor climbs to regain communications, an accurate knowledge of atmospheric conditions might indicate that descending below the layer would be the proper action.

AMR is the only instrument of its kind which can meet the operational requirements for data on atmospheric anomalies to all operational commanders. The success of offensive and defensive task force mission demands the capability to measure and utilize atmospheric conditions. It acts as an aid in determining the optimum flight profiles for attack aircraft to avoid detection by hostile radar. It also helps in investigating the incidence and uniformity of superrefracting atmospheres.

Reference

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