# MICROWAVE ICE THICKNESS SENSOR

by

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This paper describes a method of measuring ice thickness with a microwave spectrometer operating in the 800 MHz - 4 GHz region of the electromagnetic spectrum.

The basic theoretical model used to determine and measure ice thickness assumes flat, parallel surfaces and is shown in Figure 1. The major radiative contribution to the measured radiometric antenna temperature comes from the underlying water, and not the ice layer. This is illustrated in Figure 2, which shows the loss tangent of ice and water over the frequency range of 100 MHz to 10 GHz. Note that over the 800 MHz - 4 GHz band, the loss tangent of water is at least two orders of magnitude greater than the loss tangent of fresh water ice. The thermal emissions from the water will be partially reflected at the water/ice and ice/air interfaces before they reach the radiometer antenna. It is, therefore, possible to establish an "effective" reflection coefficient which will take into account the multiple reflections at these interfaces and allow the determination of ice thickness from radiometric antenna temperature measurements.

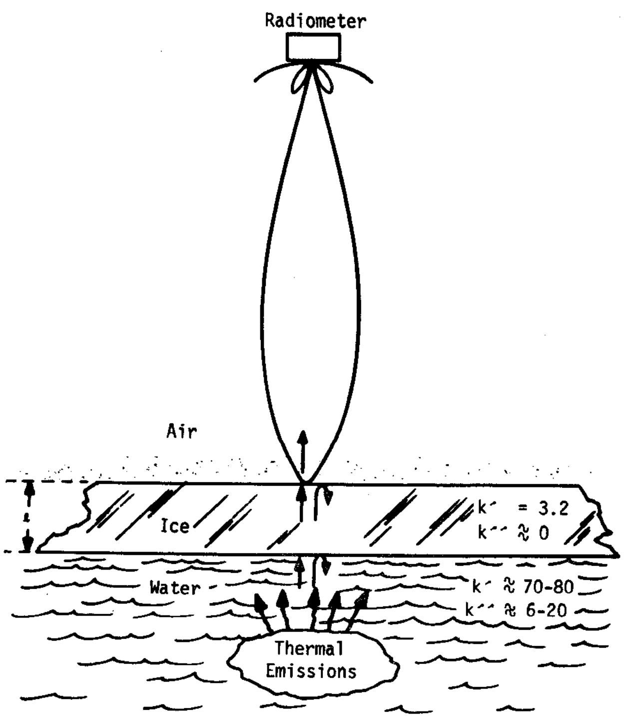


Fig. 1 Fresh Water Ice Model

The radiometric antenna temperature is given by:

$$T_a = \varepsilon_W T_W + \rho_e T_S = \left(1 - \rho_e\right) T_W + \rho_e T_S.$$

Since both $\varepsilon_W$ and $\rho_e$ are functions of frequency, the recorded antenna temperatures will be periodic functions of ice thickness. To resolve the resulting ambiguities, it is essential to perform simultaneous measurements of the antenna temperature at multiple frequencies and to employ a radiometer antenna that will maintain a constant beamwidth over the above band. It is also important to minimize the $\rho_e T_S$ term or introduce an appropriate correction in the final result.

Figure 3 shows the radiometer response as a function of frequency for three different thicknesses of the ice layer. Note that certain frequencies must be avoided to obtain an unambiguous measurement of ice thickness with a microwave spectrometer. These "forbidden regions" occur

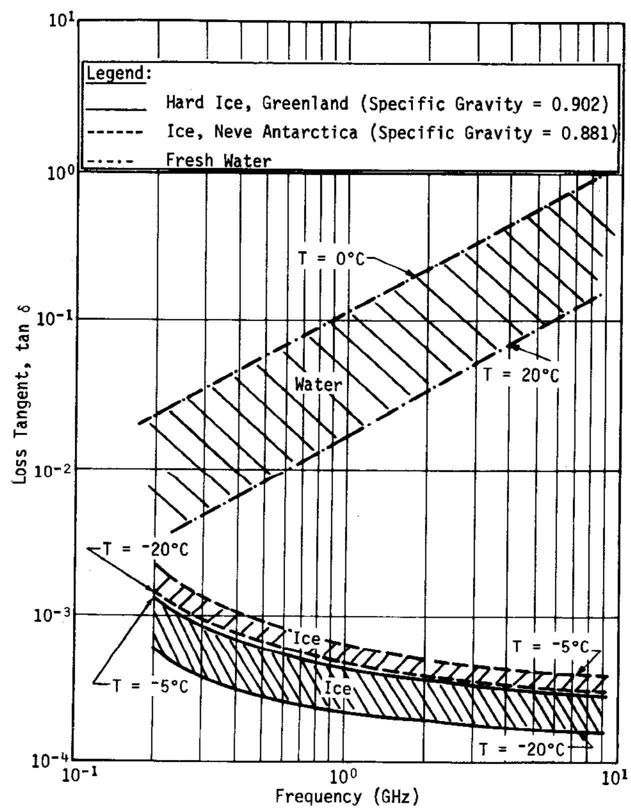


Fig. 2 Microwave Losses of Ice and Water

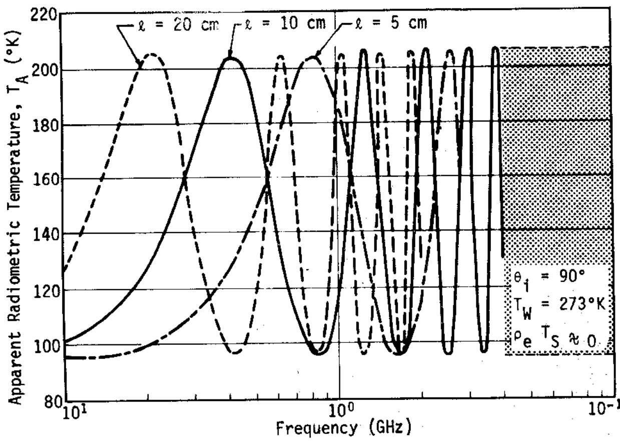


Fig. 3 Microwave Spectrometer - Apparent Radiometric Antenna Temperatures

where the antenna temperature curves for different ice thicknesses cross each other, and must be avoided when designing an ice thickness sensor. These forbidden regions can be easily established for any practical configuration.

A block diagram of a broadband microwave spectrometer operating at a number of frequencies over this band is shown in Figure 4. The spectrometer employs a parabolic reflector antenna fed by a ridge-loaded horn. Since the beamwidth of the feed horn decreases as the frequency increases, a correspondingly smaller portion of the reflector surface will be illuminated at higher frequencies. This results in a constant antenna beamwidth over extremely wide bandwidths. The spectrometer receiver consists of a conventional, multichannel Dicke radiometer and uses a multiplexer to conduct the received signals picked up by the broadband antenna to the appropriate receivers. Noise received by the antenna is compared to the noise generated by a 50-ohm load at the temperature of liquid nitrogen (77.3°K) through a synchronous switching procedure. In space applications, the liquid nitrogen source is replaced by an antenna pointing at deep space. The system can also be calibrated by substituting a hot load (373.2°K) for the antenna. A broadband, low-noise amplifier follows the fast switch, giving a system noise of about 8 db. Standard IF amplifier techniques are used following the mixer, except that balanced mixers are used for automatic gain control. The noise is detected with an envelope detector, is low-pass-filtered, and is then passed through a synchronous detector. The outputs of the synchronous detector consist of the reference noise, plus the noise generated by the observed ice layer and received by the antenna. After integrating, the reference noise is used for AGC in the system and the antenna noise is measured to obtain the source temperature.

The remote ice thickness sensor described in this paper can be mounted on a helicopter or aircraft to perform surveys over regions containing fresh water ice. The same spectrometer, with a smaller antenna, can be employed directly above the ice surface (H = 10 to 20 ft) to obtain localized measurements of ice thickness during a field research program.

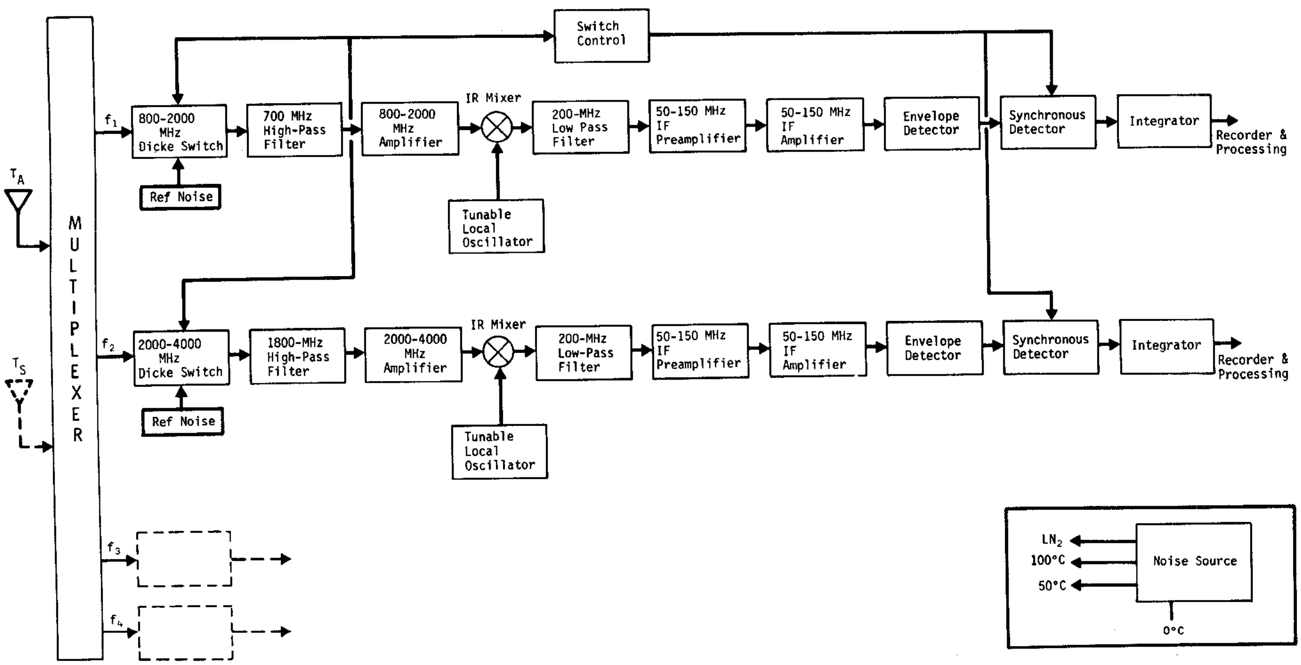


Fig. 4 Broadband Microwave Spectrometer Receiver

# Notes