Polarimetric Radiometry – Coherent vs. Incoherent Detection

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Abstract -- There are two popular approaches to the design of a polarimetric radiometer: using either coherent or incoherent detection. Coherent detection implies that a direct cross-correlation is performed of the vertical and horizontal components of the incident electrical field. Incoherent detection derives the third and fourth Stokes parameters indirectly, by differencing the brightness temperatures detected at +/- 45 degree linear and left and right hand circular polarizations. In this paper, we consider the calibration accuracy of both types of radiometers. A relationship is developed between the true Stokes parameters and the measurements, as functions of non-ideal antenna characteristics. The sensitivity of calibration equations, which correct for these characteristics, to errors in knowledge of the polarization impurity is examined. It is found that, in most cases, the incoherent approach is considerably more tolerant of polarization impurity than is the coherent approach.

INTRODUCTION

A polarimetric microwave radiometer measures V- and H-pol brightness temperatures in the conventional manner. If Ev and Eh are the vertical and horizontal components of the electric field incident on the radiometer's antenna, then Tv and Th are given by

$$T_v = c\langle|E_v|^2\rangle \tag{1}$$
$$T_h = c\langle|E_h|^2\rangle \tag{2}$$

where c = l /khB, l is the RF center frequency, k is Boltzmann's constant, h is the intrinsic impedance of free space, and B is the RF bandwidth. Coherent detection of the third and fourth Stokes parameters implies that a direct cross-correlation is made of the vertical and horizontal components of the incident electric field [1]

$$T_3 + jT_4 = 2c\langle|E_vE_h^*|\rangle \tag{3}$$

Incoherent detection relies on the following relationships between the Stokes parameters and other polarized brightness temperatures

$$T_p = (T_v + T_h)/2 + c\,\mathrm{Re}\{\langle|E_vE_h^*|\rangle\} \tag{4}$$
$$T_m = (T_v + T_h)/2 - c\,\mathrm{Re}\{\langle|E_vE_h^*|\rangle\} \tag{5}$$
$$T_l = (T_v + T_h)/2 + c\,\mathrm{Im}\{\langle|E_vE_h^*|\rangle\} \tag{6}$$
$$T_r = (T_v + T_h)/2 - c\,\mathrm{Im}\{\langle|E_vE_h^*|\rangle\} \tag{7}$$

where Tp(Tm) is +(-) 45 deg linear polarization and Tl(Tr) is left(right) hand circular polarization (L(R)HCP). The incoherent estimates of T3 and T4 follow as [2]

$$T_{3inc} = T_p - T_m \tag{8}$$
$$T_{4inc} = T_l - T_r \tag{9}$$

MODEL FOR CONTAMINATED MEASUREMENT OF STOKES PARAMETERS

There are numerous characteristics of an antenna subsystem which result in contaminated measurements of the Stokes parameters. Examples include: 1) Offset reflector induced cross polarization; 2) Orthomode transducer leakage; and 3) Amplitude imbalances and phase errors in the hybrids used to form +/- 45 deg linear pol and LHCP/RHCP. All of these characteristics can be combined into a single set of equations which relate the true values of the Stokes parameters to the contaminated measurements [3]. The measurements will be functions of: 1) the isolation at the vertical(horizontal) port from leakage of the horizontal(vertical) signal; 2) the phase of the horizontal(vertical) signal with respect to the vertical(horizontal) signal leaving the vertical(horizontal) port; 3) the isolation at the +45 deg(-45 deg) port from leakage of the -45 deg(+45 deg) signal; 4) the phase of the -45 deg(+45 deg) signal with respect to the +45 deg(-45 deg) signal leaving the +45 deg(-45 deg) port; 5) the eccentricity of the LHCP(RHCP) channel, defined as the ratio of sensitivity to horizontal vs. vertical polarized signals; and 5) the phase deviation from -90 deg(+90 deg) of the quadrature hybrid.

CORRECTION FOR THE CONTAMINATION - COHERENT CASE

The contamination can be corrected exactly provided there is no error in knowledge of the various isolation and eccentricity magnitudes and phases. Consider the accuracy of the correction when errors in knowledge of the contamination are modeled by zero mean normally distributed random variables. The error analysis is performed as follows: Nominal values are assumed for the Stokes parameters over open ocean (TB at 19 GHz for 10-12 m/s winds at 45 deg azimuth angle). Nominal values for the contamination are also assumed. Measurements of Tcoh are then computed. The effects of error in knowledge of the contamination are determined by a numerical simulation. Five thousand realizations of the correction are simulated in which, prior to correction, the level of the contamination is randomly perturbed by adding gaussian noise to each of the hardware specifications. The noise represents error in knowledge. The standard deviation of the corrected Stokes parameters represents the error in the correction.

Consider first the effects on T3 calibration of errors in knowledge of the level of isolation. In Fig. 1, the level of isolation between channels is varied from 10 to 50 dB. Knowledge of the level of isolation is assumed to be accurate to either -40 dB or -50 dB (for example, isolation of 30 dB with -40 dB knowledge implies that the leakage is 30 dB below the primary signal and that its level is known to one part in 10). Three cases of relative phase between the leakage signals are also considered. In the figure, the error in the calibration is lowest when the relative knowledge of the level of leakage is best. This occurs either when the leakage is large or the absolute knowledge is small. Note that when the level of isolation becomes comparable to the knowledge, the error tends to level out. This can be explained by noting, for example, that if the isolation is known to -40 dB, then it makes little difference whether the isolation itself is 40 dB or 50 dB.

The effects on T3 calibration of errors in knowledge of the phase of the leakage are considered next. In Fig. 2, the phase is assumed known to within ñ5 deg RMS. The level of leakage is assumed known exactly. The RMS error in T3 is seen to drop monotonically with increasing isolation. This is in contrast to the behavior described in Fig. 1, in which the error increases with increasing isolation. In practice, both the level and relative phase of the leakage can never be known exactly. The RMS errors in T3 due to the two causes must be combined. The resulting behavior of the error in calibration will feature a minimum at some level of leakage where the two competing sources of error are balanced. Note that, because of the dependence of the error on the relative phase of the leakage, the location of its minimum will depend on that phase.

Now consider variations in the level of the isolation, assuming that the errors in knowledge are -40 dB for the level and 5 deg for the phase. The resulting calibration errors are shown in Figure 3. As expected, for each relative phase, there is an isolation level at which the error is a minimum.

CORRECTION FOR THE CONTAMINATION - INCOHERENT CASE

Calibration inaccuracies in T3inc are caused by the leakage characteristics of the +/- 45 deg channels. In a manner similar to Fig. 1, the effect on T3 calibration of error in knowledge of the level of leakage tends to increase as the leakage decreases. In a manner similar to Fig. 2, error in knowledge of the phase of the leakage becomes more important as the leakage increases. In both cases, however, the level of the error is significantly lower using incoherent detection. In Fig. 4 is shown the error in calibration of T3inc due to both errors in knowledge of the level and phase of the leakage. Note that there is again a minimum error present at a particular level of leakage, and that the minimum varies depending on the phase of the leakage.

COMPARISON BETWEEN COHERENT AND INCOHERENT DETECTION

The relative insensitivity to errors in knowledge of the contamination on the part of T3inc, relative to T3coh, is largely the result of an important difference between the functional dependence of their contaminated measurements on the level of isolation. In the coherent case, T3 depends directly on both Tv and Th via factors which scale with the level of leakage. The magnitudes of Tv and Th greatly exceed those of either T3 or T4, and so errors in the correction for this leakage will tend to dominate the correction algorithm. In the incoherent case, on the other hand, the Tv and Th scale factors consist of differences between similar functions of the P- and M-pol isolation. Therefore, mutual increases in P- and M-pol leakage levels will tend to cancel one another out. This fortuitous cancellation effect is a result of the differencing scheme used in incoherent detection. Even for the case of unequal isolation, there is still significant partial cancellation.

DISCUSSION

For radiometers using coherent detection, there are two competing components of calibration error which affect the required isolation. Errors due to inexact knowledge of the level of leakage tend to increase as isolation improves. Errors due to knowledge of the phase of the leakage will decrease with improving isolation. The optimum level of isolation, at which the calibration error is a minimum, will vary according to the nominal phase of the leakage and according to the errors in knowledge. For incoherent detection of T3, the same competing components of error exist. The result is an optimum level of isolation between the P- and M-pol channels which varies with the relative phase of the leakage and with the errors in knowledge of both the leakage phase and level. In the incoherent case, however, the magnitude of the resulting calibration error is generally much lower.

References
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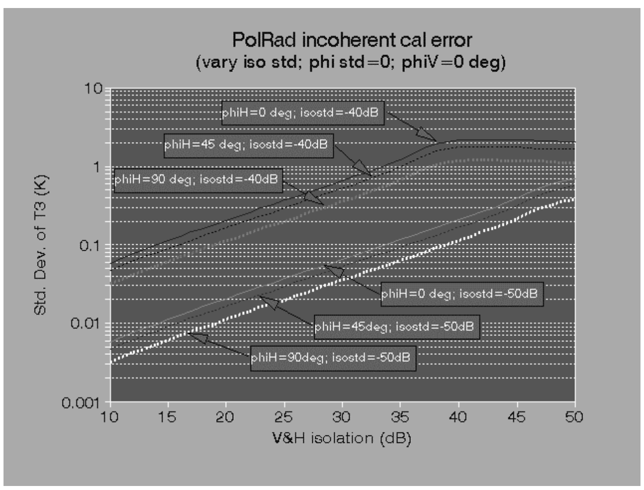

Figure 1. Error in the correction for T3coh contamination due to uncertainties in the level of isolation.

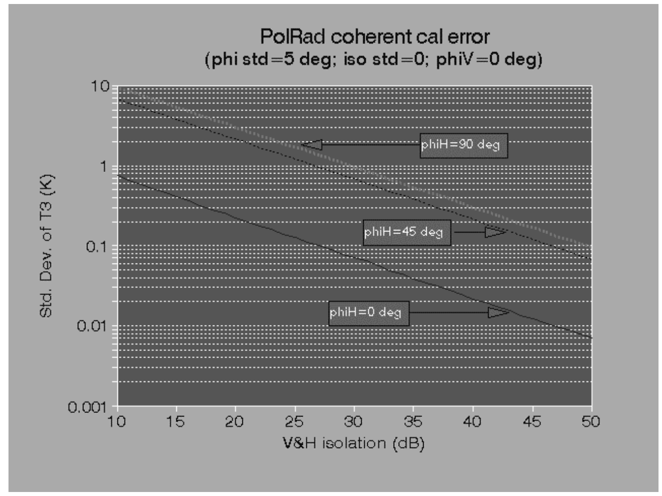

Figure 2. Error in T3coh due to uncertainties in the phase of the leakage.

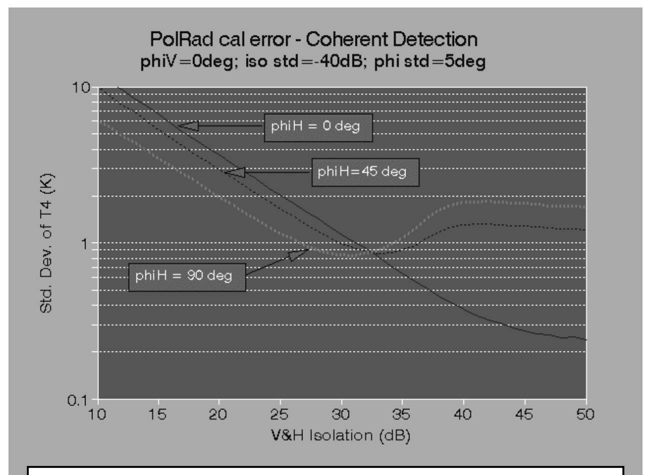

Figure 3. Error in T3coh due to uncertainties in both the level and phase of the leakage.

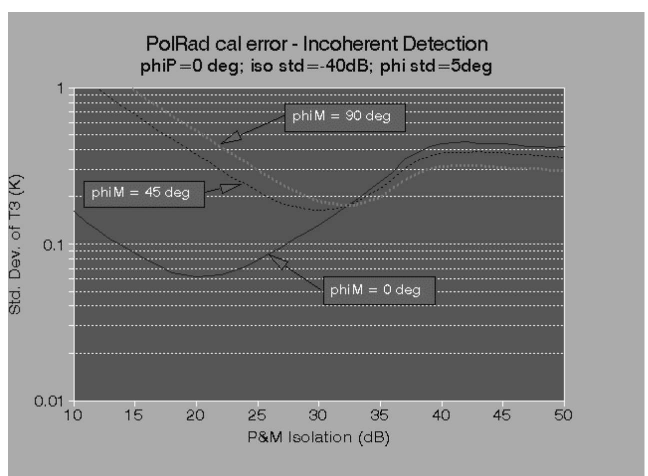

Figure 4. Error in T3inc due to uncertainties in the both the level and phase of the leakage.