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Antenna G/T Degradation with Inefficient Receive Antennas at HF (2-30 MHz)

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Abstract - This paper presents the antenna G/T degradation incurred when communications systems use very inefficient receive antennas. This work is relevant when considering propagation predictions at HF (2-30 MHz), where it is commonly assumed that antennas are efficient/lossless and external noise dominates over internally generated noise at the receiver. Knowledge of the antenna G/T degradation enables correction of potentially optimistic HF predictions. Simple rules-of-thumb are provided to identify scenarios when receive signal-to-noise ratios might be degraded.

Keywords—antenna temperature, ASAPS, electrically small antenna, G/T, HF, ITURHFPROP, noise, propagation, prediction, receive, VOACAP.

I. INTRODUCTION

At HF (2-30 MHz), it is commonly assumed that external noise dominates over internally generated noise at the receiver. This assumption requires receive antennas to be moderately efficient and receiver noise figures not to be excessive, which is valid in most practical cases. HF propagation prediction software (e.g. ASAPS, ITURHFPROP and VOACAP) function on this premise [1][2][3].

Electrically small active antennas can be designed to offer comparable receive performance as full-size antennas [4]. In general, receive antenna efficiencies “need only be sufficiently high to ensure that the system is externally noise limited” [5].

However, use of very inefficient receive antennas can degrade receive signal-to-noise ratios (SNR) and, consequently, predictions of SNR at HF can be overly optimistic. Recent work considers the influence of efficiency and impedance match on the receive performance of electrically small antennas at HF [6][7].

This paper presents the antenna G/T degradation incurred when communications systems use very inefficient receive antennas. A generic approach using antenna directivity has been adopted for relevance with all antenna types at all frequencies, although the emphasis of this work is at HF when using propagation prediction software. Knowledge of the antenna G/T degradation enables correction of potentially optimistic HF predictions. Simple rules-of-thumb are provided to identify scenarios where receive SNR might be degraded and corrective action is required.

II. ANTENNA G/T

The antenna G/T, also termed the receiver sensitivity, is a figure of merit for receive antennas commonly used in link analysis for satellite systems. System designers can trade-off receive antenna performance (e.g. gain and radiation pattern) against system noise temperature in order to maximize G/T [8].

III. NOISE TEMPERATURES

A. Antenna Noise Temperature

An antenna receives radio noise from a variety of sources. At HF, the noise sources are typically atmospheric, galactic and man-made. ITU-R Recommendation P.372 provides models to determine the antenna noise temperature T_A for a short, lossless vertical monopole [9].
At HF, antenna noise temperatures can be in the range ~10^5-10^{12} K.

If the antenna is not 100% efficient, the effective antenna noise temperature is the weighted average of the antenna noise temperature and the noise contribution related to the antenna physical temperature (e.g. [10]):

$$T_{A\_eff} = \eta T_A + (1-\eta) T_{AP} \qquad (1)$$

where η is the antenna efficiency ($0 < \eta < 1$) and T_{AP} is the antenna physical temperature. In the limit when the efficiency tends to zero, the effective antenna noise temperature tends to the antenna physical temperature.

B. System Noise Temperature

The system noise temperature T_{sys} – the T in antenna G/T – is the sum of the effective antenna temperature and the receiver noise temperature T_R for a receiver located at the antenna.

$$T_{sys} = T_{A\_eff} + T_R = \eta T_A + (1-\eta)T_{AP} + T_R \quad (2)$$

IV. DEGRADATION OF ANTENNA G/T

A. Consideration of Antenna Efficiency

The antenna gain *G* is related to its directivity *D* through the efficiency (i.e. $G = \eta D$ [11]). Therefore, the antenna G/T is:

$$G/T = D / [T_A + (1-\eta)T_{AP}/\eta + T_R/\eta] \quad (3)$$

B. G/T Degradation

The antenna G/T remains effectively constant for a large given antenna temperature as the antenna efficiency is reduced. However, as the effective antenna noise temperature approaches the antenna physical temperature (see equation (1)), the G/T begins to degrade as efficiency is decreased further. The degradation in G/T relative to the G/T for a lossless antenna – equivalent to the degradation in SNR – is given by the ratio of equation (3) with $\eta \neq 1$ and equation (3) with $\eta = 1$.

$$\Delta_{G/T} = \eta(T_A + T_R) / [\eta T_A + (1-\eta)T_{AP} + T_R] \quad (4)$$

The directivity term D is absent in equation (4), which makes this approach generic for all antenna types.

C. Rules of Thumb

For 'modest' receiver noise figures (e.g. a few dB at least, which is typical of HF receivers), two simple rules of thumb are obtained.

The degradation in G/T is small (i.e. the receive system is limited by external noise) when the product of the antenna efficiency and the antenna noise temperature is greater than the receiver noise temperature.

$$\Delta_{G/T} > 0.5, \quad \text{if } \eta T_A > T_R \quad (5)$$

Otherwise, the degradation in G/T starts to become sizeable and HF SNR predictions should be corrected by the amount determined using equation (4). In the limit when the antenna noise temperature is less than the receiver noise temperature, the degradation in G/T tends to the antenna efficiency.

$$\Delta_{G/T} \rightarrow \sim\eta, \quad \text{if } T_A < T_R \quad (6)$$

D. Worked Example

Fig. 1 shows the G/T degradation assuming a receiver noise temperature of 2610 K (i.e. 10 dB noise figure) and an antenna physical temperature of 290 K for a variety of antenna efficiencies ranging from unity down to 10^{-6} (i.e. 0 dB down to −60 dB respectively). The horizontal dotted line represents a G/T degradation of −3 dB (i.e. $\Delta_{G/T} = 0.5$), with the degradation above this line consistent with (5). The vertical dashed line indicates $T_A = T_R$. To the left of this line, the degradation tends to the antenna efficiency, as given by (6).

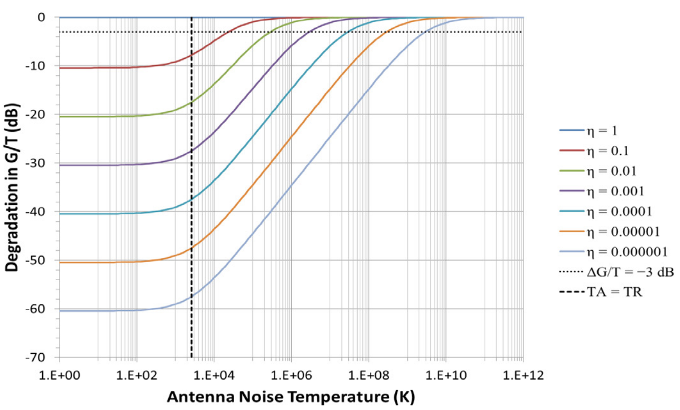

Fig. 1. G/T degradation versus antenna noise temperature for T_R = 2610 K (i.e. 10 dB noise figure) and T_{AP} = 290 K.

E. Frequency and Temporal Considerations
It is necessary to calculate the degradation over the frequency band of interest because the antenna noise temperature – possibly the receiver noise temperature too – and the antenna efficiency will vary with frequency. Temporal variations in noise are also likely and should be considered accordingly.

V. SUMMARY

Communications systems that use inefficient receive antennas can incur a degradation in antenna G/T compared to the case with a lossless antenna. At HF, this point is important because HF propagation predictions assume the use of efficient/lossless receive antennas, such that external noise determines the receive SNR. Predictions, in this case, can be overly optimistic with very inefficient receive antennas.

An expression for the degradation in G/T has been derived that allows HF SNR predictions to be corrected where appropriate. Simple rules of thumb have been provided to identify scenarios when corrective action is needed.

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