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INTERFEROMETER CALIBRATION VS. QUANTIZATION

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ABSTRACT - The calibration of interferometers is shown to be qualitatively different for three cases of quantization: Q=inf, 2<Q<inf, and Q=2. Here Q is the number of levels to which each signal is quantized before cross multiplication. In the first case, called the unquantized case, the cross-power of the signals at the separated antenna terminals may be estimated from the correlator output merely by dividing by the product of the gains between the respective antennas and the correlator; no knowledge of the total power received by each antenna is needed. In the second case, the correlator output is in general a non-linear function of the cross-power and the two (self) powers of its inputs; thus knowledge of the total powers, in addition to the gains, is needed. In this case, the total powers can be determined from the quantized signals by self-correlators. The last case (Q=2) is similar, except that all information about the total powers is destroyed by the quantizations; this information must therefore be obtained from a pre-quantization measurement.

Consider the simplified interferometer block diagrams of Figure 1. We desire to measure the cross-power of the signals received by two separated antennas. Each signal is first amplified and then quantized, and then the two are multiplied together and the result is averaged for a fixed time. The result can be used to estimate the desired cross-power if certain calibration information is available. The calibration information needed will be seen to depend on the kind of quantization used.

In Fig. 1(a), there is no quantization, or equivalently the quantizers have infinitely many levels of resolution. The expected multiplier output (estimated by its average) is then equal to the cross power of its inputs, and is also equal to the desired cross power times the product of the amplifier gains. Knowledge of this product of the gains constitutes calibration. Here and in the following cases, we assume that the multiplier is accurate and noise-free, and that the amplifiers are linear and add independent noise. Notice that no knowledge of the total powers at the antenna terminals nor of the noise powers of the amplifiers is needed.

In Fig. 1(b), each signal is quantized to a finite number of levels Q before multiplication. As Q-->inf, this case approaches the first one, but for gaussian noise signals fairly small values of Q are of interest and these have been extensively analyzed in the literature. However, the arguments given here apply generally to any finite value of Q>2. It is found that, for gaussian noise signals, if the powers of the two inputs to the quantizers are held fixed, then the correlator output is a calculable, monotonic function of their cross-powers. Furthermore, if the output of each quantizer is squared, then the expected value of this quantity is a calculable, monotonic function of the corresponding input power. Although these functions are all non-linear, they can be known a priori. Therefore, if all three quantities are measured as indicated in Fig. 1(b), then the cross-power of the quantizer inputs can be deduced; this can then be converted to the desired quantity at the antenna terminals by dividing by the amplifier gains, as before. Thus the calibration required (knowledge of the gain product) is the same as before, but the correlator is somewhat more complicated. In practice, if Q is small (say, 3 to 8), then it is necessary to keep the two signal powers within a limited range in order to avoid significant loss of accuracy in inverting the non-linear functions. This, together with the uncorrelated noise in the system (such as from the amplifiers), constrains the allowable values of gain.

In Fig. 1(c), we have Q=2 or "infinite clipping" quantization. Here, only the sign of the unquantized signals is retained. It would be useless to square each quantizer output, since the result would always be the same. Nevertheless, the correlator output provides a measure of the cross-power of the quantizer inputs; it is a known, non-linear function of the ratio of the cross-power to the geometric mean of the signal powers. Thus, to determine the desired cross-power of the signals at the antennas, one needs to know the signal powers. The latter can no longer be determined from the quantized signals, so they must be measured by some other means before quantization. Now, in principal one can avoid having to know the gains if one can determine the signal powers at the antennas, since an ideal clipper could have been placed at the antenna terminals and the result would be (in principal) the same. More generally, the signal powers can be measured at any points in the system; then it is only necessary to know the gain ahead of those points, provided that the noise introduced by later stages is negligible. But in practice the signal powers at the antenna terminals are very weak, and cannot be directly measured. The measurements must be done after most, if not all, of the system gain. Thus, in this case only, calibration requires knowledge of both the gains and the signal powers. It might be further argued that only the ratio of each signal power to its corresponding gain is needed. However, in practice this ratio can only be determined from two separate measurements, with separate errors.

Remark: It is sometimes argued that the Q=2 case is the easiest to calibrate and the least sensitive to calibration errors, because the inherent normalization of the infinite clippers makes the correlator output invariant to changes in the gains. This note has shown that the situation is in fact the opposite: the 2-level case requires the most calibration information about the pre-quantization system.

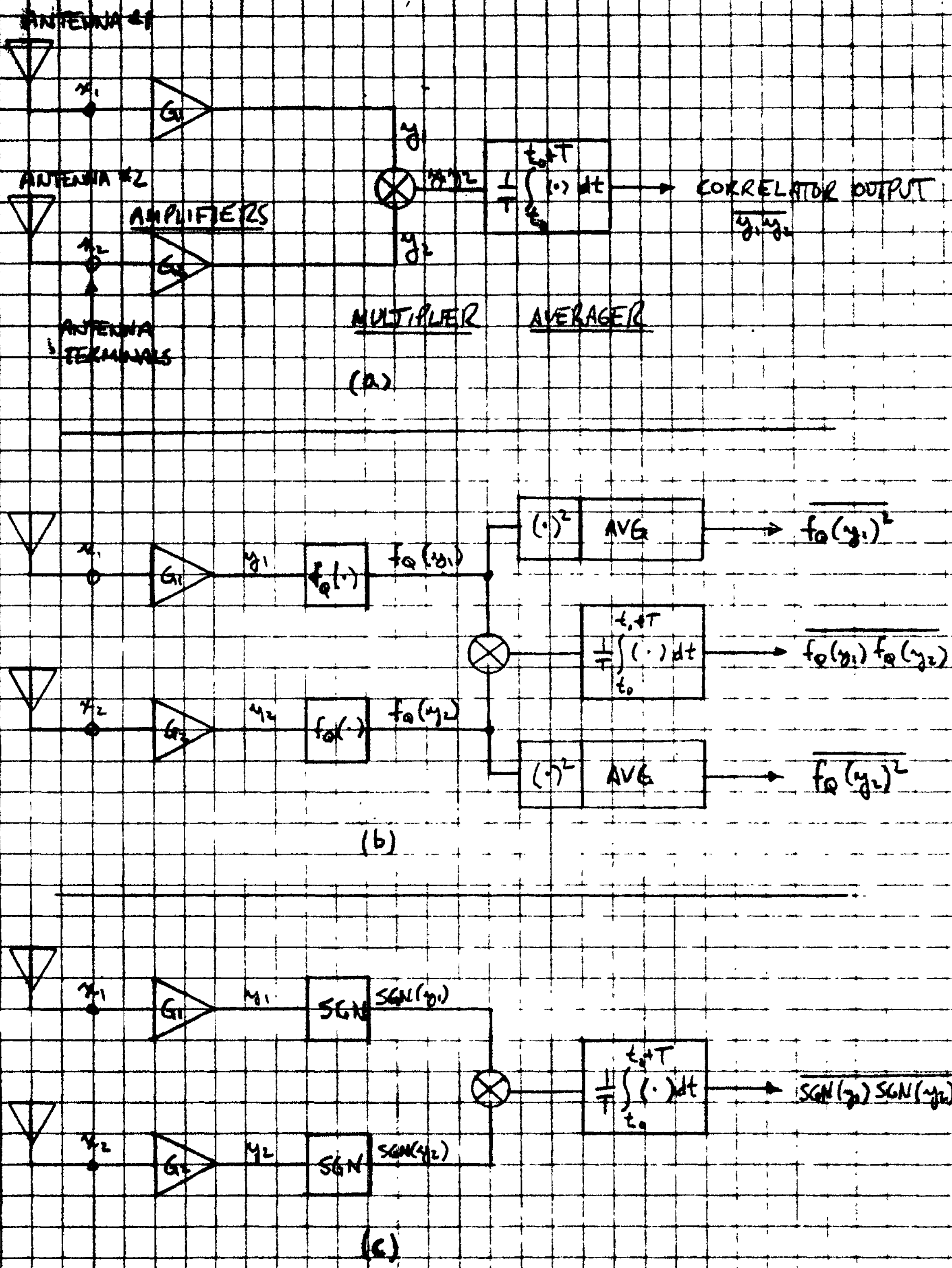

FIGURE 1: Interferometer block diagrams for the three qualitatively different kinds of quantization.