Analogue kurtosis detector for radio-frequency interference in microwave radiometers

P.N. Mohammed, J.J. Knuble and J.R. Piepmeier

An analogue system has been developed for radio frequency interference (RFI) detection in microwave radiometers. The detector measures the higher order moments of the signal and the kurtosis measurement is used to determine the presence of RFI. The hardware comprises a square-law detector and a high-speed analogue multiplier. Because the circuit uses only analogue components at radio and/or intermediate frequencies, it can easily augment conventional radiometer architectures used in both airborne and spaceborne instruments.

Introduction: There have been several instances to date where radio frequency interference (RFI) has compromised microwave radiometer measurements; see e.g. [1] and [2]. Difficulty in detecting low-level RFI has prompted the development of more robust detection methods. The analogue RFI detector is based on the concept of using the kurtosis statistic to determine if the incoming signal is non-Gaussian RFI [3]. The kurtosis is the ratio of the fourth central moment to the square of the second central moment. For Gaussian signals, such as naturally emitted thermal radiation, the kurtosis is equal to three. A deviation from this expected constant indicates RFI such as communication or radar signals. RFI detection and mitigation using kurtosis detectors and algorithms have been previously addressed by [3] and [4]. The double detector described in [4] is an analogue scheme that was devised for use on future spaceborne radiometers with little modification to their designs. The system presented in this Letter is an alternative analogue approach to the double detector.

Kurtosis detector: Much of the development of the analogue kurtosis detector parallels that of the double detector. A block diagram of the kurtosis detector is shown in Fig. 1. This system includes a microwave detector to measure the second central moment of the incoming signal. The multiplier acts as the higher-order statistical fourth-moment detector. The voltages v_1 and v_2 indicated on the block diagram can therefore be used to calculate the kurtosis estimator. A kurtosis measurement using this system is defined as

$$\alpha \equiv \frac{\langle y^2 \rangle}{\langle y \rangle^2} \tag{1}$$

where $y(t)$ is the baseband video signal (lowpass filtered $x^2(t)$ or $LPF(x^2(t))$) of the detected RF, $x(t)$, and the operator $\langle \cdot \rangle$ denotes the expected value.

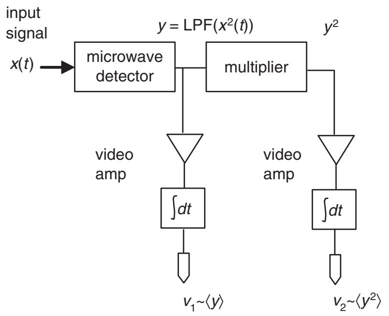

Fig. 1 *Block diagram of analogue kurtosis detector*

As with the true kurtosis, α is constant as the power of $x(t)$ varies, a characteristic key for detecting low-level RFI. When $x(t)$ is Gaussian, α reduces to two instead of three, a result due to the lowpass filtered output of the microwave detector. The standard deviation of α, which determines the RFI detection threshold, is shown to be [5]:

$$\mathrm{NE}\Delta\alpha = \sqrt{\frac{2}{B\tau_v}} \tag{2}$$

where B is the bandwidth of the input and τ_v is the integration time of the video amplifiers. This equation has been verified using Monte Carlo simulations.

Linearisation: Nonlinearities from the detectors must be characterised and removed before α can be used for RFI detection. A deflection ratio method [6] is used to find the constant in the linearising formula

$$v_{lin} = v_1 + C_2 v_1^2 + \cdots \tag{3}$$

where v_1 is indicated in Fig. 1.

Forward models are then used to derive a nonlinear α, represented as

$$\alpha_{nonlin} = \frac{d_1\langle y^2 \rangle + d_2\langle y \rangle + d_3\langle y^3 \rangle + d_4\langle y^4 \rangle}{\langle y \rangle^2} \tag{4}$$

where the numerator is the nonlinear model for the multiplier output. This reduces to a function of v_{lin} and C_2, given by

$$\alpha_{nonlin} = \frac{v_2}{v_1^2} = d_1(2 + f_1(v_{lin}, C_2)) + d_2 f_2(v_{lin}, C_2) + d_3 f_3(v_{lin}, C_2) + d_4 f_4(v_{lin}, C_2)$$

The unknowns, d_i ($i = 1,2,3,4$) including system gain, d_1, are obtained similarly to [4]. The linearised α is therefore

$$\alpha_{lin} = \frac{(v_2/v_1^2) - d_2 f_2 - d_3 f_3 - d_4 f_4}{d_1} - f_1 \tag{5}$$

which reduces to a value of two for RFI free data.

Laboratory experiment: A laboratory experiment similar to that described in [4] was designed to test the system's theoretical response to CW RFI. If the incoming signal, $x(t)$, consists of Gaussian noise plus a continuous wave (CW), using (1) the kurtosis becomes

$$\alpha(CW) = 2 - \frac{INR^2}{(1 + INR)^2} \tag{6}$$

where INR is the interferer (CW signal) to Gaussian noise ratio (see [4] for derivation).

A noise source with 20 MHz bandwidth centred at 200 MHz was varied from −25 to −20 dBm in 1 dB steps, while a sinusoid at the band centre was varied from −40 to −25 dBm for each noise increment, producing INRs from approximately −30 to 0 dB. The measured responses are linearised as described above and the results are shown in Fig. 2.

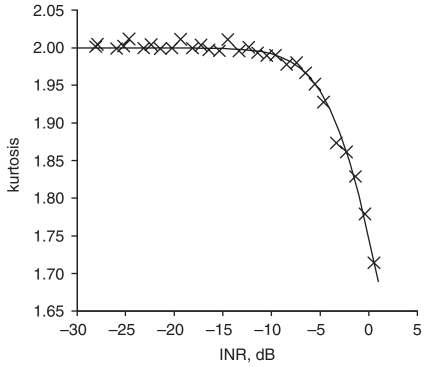

Fig. 2 *Plot of laboratory data showing α against INR (×) with theoretical response curve (solid line)*

Conclusions: An analogue kurtosis detector for non-Gaussian RFI detection in microwave radiometers and a method for its linearisation are presented. The behaviour of the kurtosis to CW RFI was tested in a laboratory experiment and the results show close agreement with theory for a wide range of INRs. The root-mean-square error between the theoretical and estimated kurtosis values is 0.0069 with the absolute mean of the error equal to 0.00036. The standard deviation of the error is 0.0070, which is approximately twice the theoretical NEΔα

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