STATISTICAL CHARACTERISTICS OF RADIOFREQUENCY SPACE-INTEGRATING ACOUSTO-OPTIC CORRELATORS

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Abstract

Performance analysis for the quadrature radiofrequency space-integrating acousto-optic correlator (RFSIAOC) with external noise and allowance for shot noise of photodetector is presented. Signal-to-noise ratio (SNR) and dynamic range (DR) are obtained in the general form, the results in the graphical form are also presented.

Keywords: space-integrating acousto-optic correlator, signal-to-noise ratio, dynamic range.

1. INTRODUCTION

Wideband signal processing is an actual problem of modern radio engineering. The use of acousto-optic devices, through their relative simplicity and possibility of multichannel operation, makes possible real-time processing of wideband radio signals. Processing of wideband pulsed radio signals can be implemented by quadrature radiofrequency space-integrating acousto-optic correlator (QRFSIAOC) Ref. 1 and space-integrating acousto-optic correlator based on optical interference (SIAOC-OI) Ref. 2. From the practical standpoint, it is interesting to consider the operation of this QRFSIAOC influenced by external noise with allowance for shot noise of photodetectors. The results of such analysis and calculations are presented below. The graphical representation of performance calculations will be presented also.

2. SIGNAL-TO-NOISE RATIO OF QRFSIAOC OPERATING WITH BINARY PHASE-SHIFT KEYED SIGNALS

General analysis of QRFSIAOC has been obtained previously Ref. 1. Output signal-to-noise ratio of the QRFSIAOC has been derived for the case of input signal in the form of additive mixture of attenuated binary phase-shift keyed signal with known shape ($S_1(t) = \beta S_2(t)$, where $S_2(t)$ is the reference signal, and β is an attenuation factor) and stationary zero-mean Gaussian noise $n(t)$ with uniform power spectrum density N_0 over acousto-optic cell (AOC) operating band.

Photodetector shot noise level is determined by the properties of the photodetector itself and of the post-detector amplifier. Photodetector noise and external noise are considered independent.

Signal-to-noise ratio, defined as the ratio between mean value increase and the square root of variance, is obtained as follows:

$$SNR = \sqrt{\frac{W_{in} W_0}{G_1 \Delta f_{ph} + W_0 W_n / B}} \qquad (1)$$

where G_1 is a real coefficient determined by the properties of photodetectors, QRFSIAOC geometry and used components, Δf_{ph} is the photodetector bandwidth, W_{in} is the input signal energy, W_n is the noise energy, B is the signal time-bandwidth product, W_0 is the reference signal energy. Eq.(1) is valid under the following assumption:

$$W_{in} + W_n << W_0 .$$

3. DYNAMIC RANGE OF QRFSIAOC OPERATING WITH BINARY PHASE-SHIFT KEYED SIGNALS

Another important characteristic of signal processing device is its dynamic range. Generally accepted definition of DR for SIAOC does not exist. Under dynamic range we mean the ratio between maximum energy of input signal and its minimum energy, or, what amounts to the same thing, the ratio between squared maximum and minimum phase modulation indices in the AOC:

$$DR = W_{\max} / W_{\min} .$$

Minimal energy of the input signal can be determined from Eq.(1): $W_{in\min} = q^2 \left[G_1 \Delta f_{ph} + W_n / B \right]$

Dynamic range can be evaluated from the next formula:

$$DR = \frac{W_{in\max}}{q^2 (G_1 \Delta f_{ph} + W_n / B)} . \qquad (2)$$

This is valid under the following assumption:

$$W_{in\max} + W_n = W_s << W_0 , \qquad (3)$$

that is, total energy of input mixture of signal and noise (W_s) should be much less than the reference signal energy, according to the definition of input signal level upper limit.

The minimum input signal-to-noise ratio can be determined as follows (for more details, see Ref. 3):

$$SNR_{in\min} = \sqrt{\frac{q^2(G_1\Delta f_{ph} + W_n / B)}{W_n}} \qquad (4)$$

From Eqs.(1), (2), (4) it is obvious that the dynamic range and the signal-to-noise ratio depends on several parameters.

Coefficient G_1 is determined by the parameters of photodetectors, AOCs and QRFSIAOC geometry. B is determined by the AOC's parameters. Parameters $W_{in\max}$, W_n can be relatively easily changed by varying signal levels in AOCs. These levels can be conveniently measured not in absolute values, but as dimensionless coefficients, i. e. relations between level and maximum allowable energy $W_{\max}$:

$$a = \frac{W_0}{W_{\max}},\ b = \frac{W_n}{W_{\max}}. \qquad (5)$$

In view of Eq.(5), Eq(3) can be written as

$$\frac{W_{in\max}}{W_{\max}} + \frac{W_n}{W_{\max}} << \frac{W_0}{W_{\max}}.$$

Let $W_{in\max} + W_n = lW_0$, where $l << 1$, then Eq.(2) can be presented in the following form:

$$DR = \frac{la - b}{q^2[G_2 + b/B]}$$

where $G_2 = G_1\Delta f_{ph} / W_{\max}$.

Similarly Eqs. (4), (1):

$$SNR_{in\min} = q\sqrt{\frac{G_2}{b} + \frac{1}{b}},$$

$$SNR = \sqrt{\frac{ca}{G_2\left[\frac{a}{b} + \frac{a}{B}\right]}},$$

where $c = \sqrt{\frac{W_{in}}{W_0}}$ - input signal-to-noise ratio (see Ref. 3).

4. CALCULATIONS

Before performance calculations, we need to estimate the values of G_1 coefficient and the maximum allowable energy or (that is the same) maximum allowable phase modulation indices. Value of coefficient G_2 is calculated under the following conditions: light wave length 630 nm; height of AOC 150 μm; laser light power 1 mW; multiplication factor of photomultiplier 10^3; anode spectral sensitivity 10^4 A/W; diffraction efficiency of AOC 0.05; $B = 500$; $l = 0.1$; $\Delta f_{ph} = 100$ MHz. Numerical value of this coefficient is $2 \cdot 10^{-5}$ ($G_2 \approx 2 \cdot 10^{-5}$).

Notice that SNR and DR are parametric dependencies and the same value can be reached with various combinations of the reference and input signal levels.

Figs. 1, 2, 3 show SNR as a function of normalised levels of reference and input signals. Figures present the curves in coordinates (a, b).

Figs. 4, 6 illustrate behaviour of DR and $SNR_{in\min}$ in the same coordinates. Figures 5 and 7 present the curves of constant value for corresponding parameters.

As a result of calculations, we can make the following conclusions:

- Increasing sensitivity and increasing DR are conflicting demands.
- Increasing one is possible at the price of decreasing another.
- For each value of sensitivity there are optimal reference and input signal levels, providing maximum DR.

CONCLUSION

The results obtained show the general properties of basic statistical dependencies for QRFSIAOC and allow us to choose the optimal operating mode for any specific task. Comparing these results with corresponding results from Refs. 4, 5 shows that QRFSIAOC lose dynamic range in comparison to SIAOC-OI. But this QRFSIAOC can process signals with arbitrary modulation law. The results obtained allow us to choose the optimal type of correlator and its operating mode for a specific task.

References

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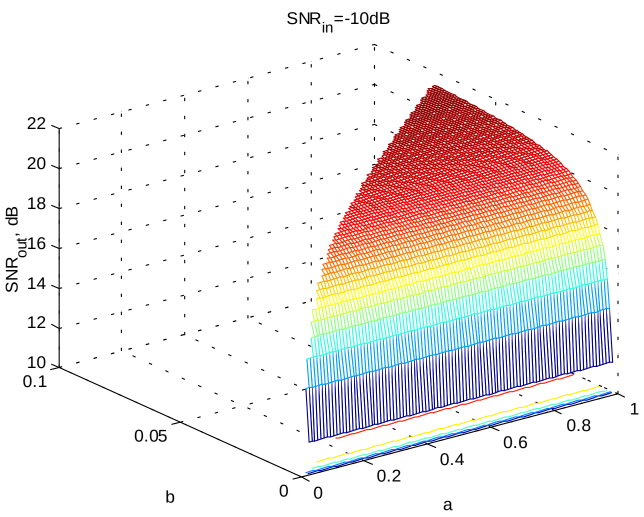

Figure 1. Output signal-to-noise ratio. (SNR_{in}=-10dB).

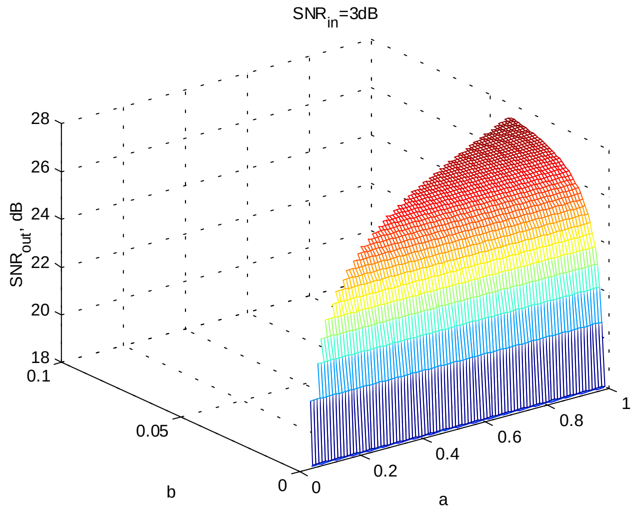

Figure 3. Output signal-to-noise ratio.(SNR_{in}=3dB)

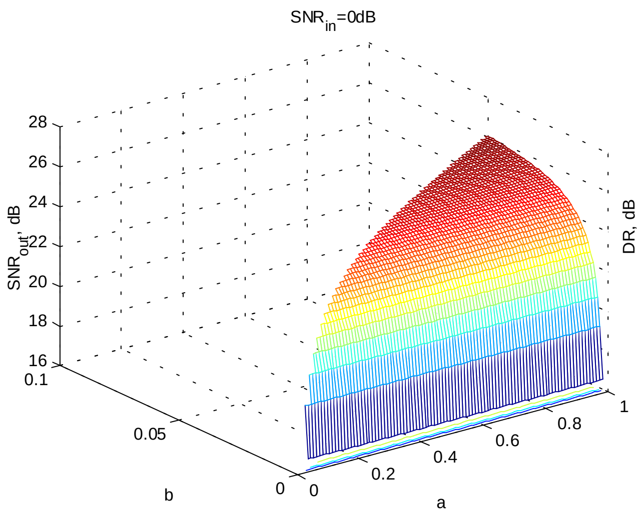

Figure 2. Output signal-to-noise ratio. (SNR_{in}=0dB).

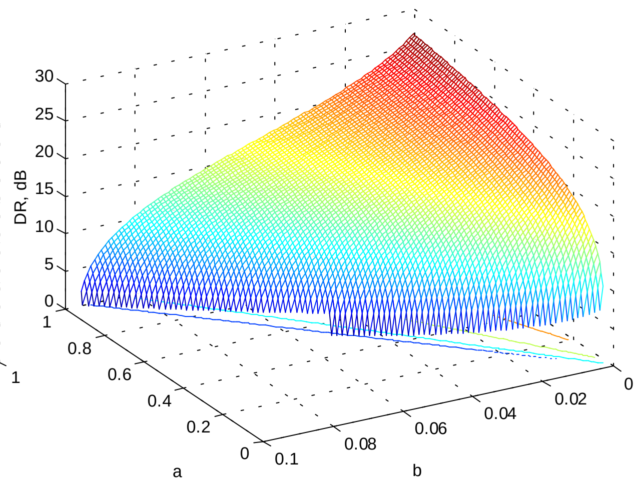

Figure 4. Dynamic range.

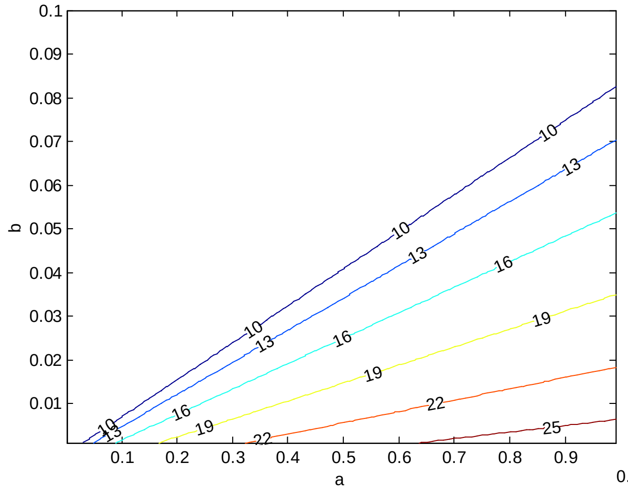

Figure 5. Dynamic range. Constant levels.

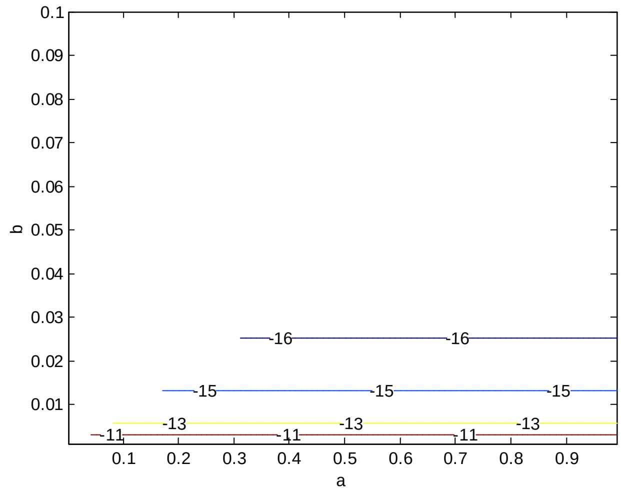

Figure 7. Mimimum input signal-to-noise ratio. Constant levels.

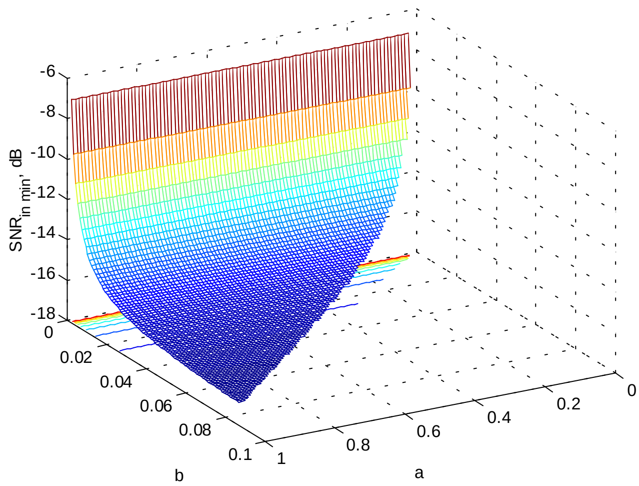

Figure 6. Mimimum input signal-to-noise ratio.