# NOISE OPTIMIZATION OF RADAR AMPLIFIER

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## ABSTRACT

Noise optimization plays a crucial role in design of radar based detection system. In general better noise properties of the system results in better overal range or it can allow to track and trace smaller objects.

This paper focuses on selection of proper technique to minimize noise in two stage amplifier provided with automatic gain control.

## 1 INTRODUCTION

Noise charasteristic of active components play a significant role during processing of signals with low voltage level. This also applies to a radar amplifier, where input voltage levels vary in order of hundreds of microvolts up to ones of milivolts when the measured object moves away from the aperture of the radar.

When selecting the proper amplifier for radar it is important to consider the situation when the measured object moves closer and rebound signal from it gets much stronger. With regards to that it is suitable to choose from variable gain amplifiers and reduce gain of the amplifier to prevent it from over-excitation.

After a careful process of selection, Analog Device's AD603 was chosen as the most suitable variable gain amplifier. It offers gain control in magnitude of 40 dB. Its gain is controlled by a differential amplifier thus it is predetermined for use with automatic gain control (AGC) circuit.

Due to differential gain control amplifier it is possible to implement experimental wiring for paralel and sequential gain control of two AD603's. It is easily possible to change parallel gain control for sequentional one by changing the voltage reference of the differential amplifier. Block schematics of two stage amplifier based on AD603 with AGC is presented in figure 1.

## 2 NOISE CHARACTERISTIC

Electronic systems invoke several types of noise signals, which mutually differ by physical basis of their origin. Consequently we entitle a number of noise sources e.g. thermal noise, shot noise, 1/f noise, and so on.

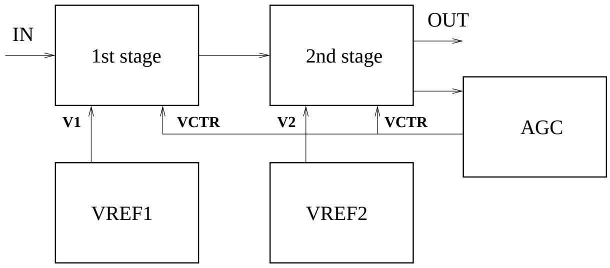


**Figure 1:** Block schematic of two stage radar amplifier based on AD603.

During investigation of two-port networks noise characteristic that process signal small enough to consider them as linear, it is useful to describe them with noise figure F.

Most two-port networks are composed of active and passive components, one of which is source of thermal or other noise. That results in presence of the noise signal at the output of the two-port network even without presence of the signal at the input. If we connect input of two-port network with real signal from signal generator (that adds noise aside from useful signal) we will measure amplified signal at the output together with noise composed of two portions. The first portion constitutes amplified noise signal of the signal source while the second portion represents intrinsic noise of the two-port network. Let's introduce power ratio of the signal and the noise at the input $P_{\mathtt{Si}}/P_{\mathtt{Ni}}$ and at the output $P_{\mathtt{S}o}/P_{\mathtt{N}o}$. Let's set the generator to a normal temperature ($\Theta_0 = 290$) K) so that calculactions are unambiguous. Under such conditions, noise figure is defined by the following formula

$$F = \frac{\frac{P_{\mathtt{Si}}}{P_{\mathtt{Ni}}}}{\frac{P_{\mathtt{So}}}{P_{\mathtt{No}}}} \tag{1}$$

or

$$F_{\mathtt{dB}} = 10 \log F \tag{2}$$

which denotes how many times would the signal to noise ratio worsen by passing through a linear two-port network compared to an original value $P_{\mathtt{Si}}/P_{\mathtt{Ni}}$ when the both sides are matched.

If the two-port network itself did not contain any noise sources, the numerator and denominator would be the same. Because this is not the case, we introduce an intrinsic noise power of two-port network converted to the output $P_{\mathtt{Nvo}}$. Let's designate signal power at the output to the signal power at input as a power ratio $A_P = P_{\mathtt{So}}/P_{\mathtt{Si}}$. Then it is possible to adjust equation 1 as following

$$F = \frac{\frac{P_{\mathtt{Si}}}{P_{\mathtt{Ni}}}}{\frac{P_{\mathtt{So}}}{P_{\mathtt{No}}}} = \frac{P_{\mathtt{No}}}{A_{\mathtt{P}} P_{\mathtt{Ni}}} = \frac{P_{\mathtt{Nvo}} + A_{\mathtt{P}} P_{\mathtt{Ni}}}{A_{\mathtt{P}} P_{\mathtt{Ni}}} = 1 + \frac{P_{\mathtt{Nvo}}}{A_{\mathtt{P}} P_{\mathtt{Ni}}} \tag{3}$$

From 3 we get

$$P_{\mathtt{No}} = F A_{\mathtt{P}} P_{\mathtt{Ni}} \tag{4}$$

and

$$P_{\mathtt{Nvo}} = (F-1) A_{\mathtt{P}} P_{\mathtt{Ni}} \tag{5}$$

Most of the practical applications employ a cascade of several two-port networks with noise figures $F_1, F_2, \ldots, F_N$ and power amplification $A_{P1}, A_{P2}, \ldots, A_{PN}$. Let's look at the case of two two-port networks ($N = 2$). At the output of the first two-port network will be noise power $P_{\mathtt{No1}} = F_1 A_{P1} P_{\mathtt{Ni}}$ with respect to equation 4. At the output of the second two-port network will be noise amplified by the first two-port network and in the same time its intrinsic noise according to equations 4 and 5. Then

$$P_{\mathtt{No2}} = F_1 A_{P1} P_{\mathtt{Ni}} A_{P2} + (F_2 - 1) A_{P2} P_{\mathtt{Ni}} = A_{P2} P_{\mathtt{Ni}} [F_1 A_{P1} + (F_2 - 1)] \tag{6}$$

For overall noise figure of two two-port networks connected in a cascade applies

$$F = \frac{P_{\mathtt{No2}}}{A_P P_{\mathtt{Ni}}} = \frac{A_{P2} P_{\mathtt{Ni}} [F_1 A_{P1} + (F_2 - 1)]}{A_{P1} A_{P2} P_{\mathtt{Ni}}} = F_1 + \frac{F_2 - 1}{A_{P1}} \tag{7}$$

By analogy for $N$ two-port networks in a cascade we get well known Friis's formula

$$F = F_1 + \frac{F_2 - 1}{A_{P1}} + \frac{F_3 - 1}{A_{P1} A_{P2}} + \cdots + \frac{F_N - 1}{\prod_{i=1}^{N-1} A_{\mathtt{Pi}}} \tag{8}$$

If the attainable power transfer $A_{P1}$ would be large enough and the noise figure $F_1$ small enough, then the overall noise factor $F$ will be small as well, even if $F_2 >> 1$. This is a serious fact for construction of $N$ stage amplifiers. Because noise factor $F$ does not solely depend on noise factors of individual two-port networks $F_i$, but also on their attainable power transfers $A_{\mathtt{Pi}}$, noise measure is introduced by the following formula

$$M_i = \frac{F_i - 1}{1 - \frac{1}{A_{\mathtt{Pi}}}} \tag{9}$$

Formula 9 implies that in order to minimize overall noise factor $F$ we need to arrange individual two-port networks in cascade so that the first two-port network in a cascade should have the lowest measure of noise $M$. Other stages are arranged in conjuction with their ascending noise measure.

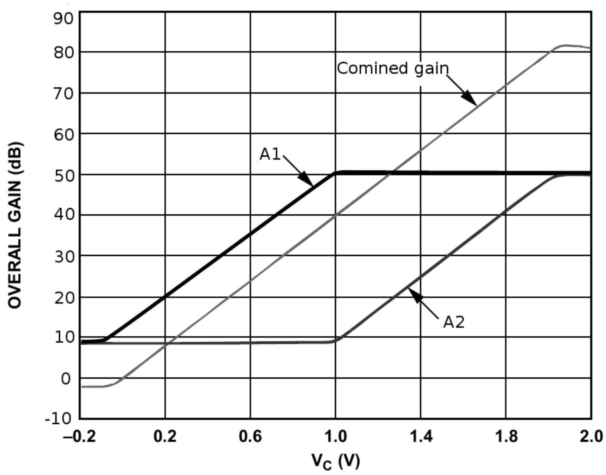


**Figure 2:** Gain control of two AD603's connected in series in sequentional gain control mode

# 3 AMPLIFIER DESIGN

Due to achieve higher gain, two AD603's are connected in series together. AC coupling should be used to prevent the DC offset voltage at the output of each amplifier from overloading the following amplifier at maximum gain. Each amplifier has well-defined 100 Ω input resistance, so the chosen capacity of the coupling capacitor should be of such size to set the desired corner frequency.

## 3.1 SEQUENTIAL GAIN CONTROL

In this mode of operation, the first of two connected amplifiers gradually increases its gain from 10 dB until it reaches maximum of 50 dB, whilst the second one has its gain set to minimum of 10 dB. When the first amplifier reaches maximum gain, the second stage will begin increase gain. It is illustrated in figure 2.

Now we focus on what's going on with noise measure when amplifiers are connected together in the sequential mode. According to Analog Devices's datasheet, the AD603 has noise figure $F = 8.8$ dB and initial gain $A_1 = 10$ dB, maximum gain is then $A_1 = 50$ dB. When we put this into the equation 9 for gain minimum we get

$$M_1 = \frac{F_1 - 1}{1 - \dfrac{1}{A_{\mathrm{P1}}}} = \frac{7.59 - 1}{1 - \dfrac{1}{10}} = 7.32 \tag{10}$$

When the first stage reaches its maximum gain, the noise measure is

$$M_1 = \frac{F_1 - 1}{1 - \dfrac{1}{A_{\mathrm{P1}}}} = \frac{7.59 - 1}{1 - \dfrac{1}{1 \cdot 10^5}} = 6.59 \tag{11}$$

As it can be easily seen from these calculations, the higher gain of the individual stage is, the lower noise measure it has. So when two stages have different gain, it is better from noise perspective to have the stage with higher gain at the beginning of the chain.

### 3.2 PARALLEL GAIN CONTROL

The advantage of this wiring is its simplicity. There is no need to set up different voltage references in individual stages. The gain control voltage is applied to both inputs of the differential gain control amplifier in parallel.

The noise measure $M$ of both stages has the same value which passes over between 6.59 and 7.32. All-round it results in poorer noise properties than the wiring provided with sequentional gain control.

## 4 CONCLUSION

This paper has compared two gain control methods of variable gain amplifier – sequentional and parallel gain control. Sequentional control has shown better results in terms of noise performance, whilst the parallel method is simplier.

A low noise radar amplifier provided with AGC will be constructed on the basis of these results using sequentional gain control. It will then hopefully allow to track and trace objects as small as bullet fired from a gun by multiple Doppler sensor heads.

## ACKNOWLEDGEMENTS

Research described in the paper was financially supported by the Czech Grant Agency under doctoral grant No. 102/ 08/H027 “Advanced Methods, Structures, and Components of Electronic Wireless Communication” and by the research program MSM 0021630513 “Electronic Communication Systems and New Generation Technologies (ELKOM).

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