A Parallel Amplifier Structure for Increasing Dynamic Range of EW Receivers

YUAN Shun-yi, TANG Bin
School of Electronic Engineering, University of Electronic Science and Technology of China Chengdu 610054 China

Abstract In Electronic Warfare (EW) receivers, the desired Dynamic Range (DR) often far exceeds the dynamic range attainable with available Analog-to-Digital Converter (ADC) technology. ADC is the key bottleneck in achieving the needed dynamic range. In this paper, an approach for improving the effective DR by utilizing multiple amplifiers is presented. The amplifiers, arranged in parallel channels with different gains, can increase the dynamic range greatly.

Key words analog-to-digital converter; dynamic range; amplifier; electronic warfare receivers

The need for increasing dynamic range of the input of Electronic Warfare (EW) receivers has increased steadily over the last decade. A modern EW receiver should provide maximum possible sensitivity and large dynamic range for the detection of targets\(^1\)\(^-\)\(^2\). The signals detected by the EW receiver, such as communication signals and radar signals, may have a wide power discrepancy between the two kinds of signals in the same frequency range. The dynamic range of signals, noise, and clutter at the input can be as high as 80 dB to 100 dB above thermal noise. Therefore, the dynamic range required is beyond the capabilities of currently available dynamic range 10-bit to 14-bit ADC by 20 dB to 40 dB.

To overcome these dynamic range limitations, several techniques have been used, including Sensitivity Time Control (STC), Automatic Gain Control (AGC), and band-pass Intermediate Frequency (IF) limiting. However, these techniques, constraining the dynamic range of the input signals to the dynamic range available from an ADC, have serious drawbacks which may cause the sensitivity reduction and incorrect parameters estimation etc. STC reduces the sensitivity of the radar receiver in close ranges\(^3\). On the other hand, AGC introduces switching transients during gain adjustments which cause false alarms\(^4\). Finally, band-pass IF limiters brings substantial nonlinearities in the presence of large returns\(^5\).

This paper presents a technique, referred to as parallel amplifier, which overcomes some shortcomings associated with the techniques mentioned previously. The parallel amplifier structure uses multiple amplifiers with different gain factors, and each amplifier connects to the same IF. After signals estimation and selection, signals are sent to ADC, then, a composite dynamic range is got which is much larger than the dynamic range of an individual ADC.

To demonstrate the feasibility and performance of this concept, a simulation system based on the parallel amplifier approach is designed and testified. Detailed descriptions of the demonstration the parallel amplifier concept and of the results obtained during the test are presented in this paper.
1 Parallel Amplifier

To avoid many drawbacks associated with the techniques discussed above, the basic concept of the parallel amplifier structure depicted in Fig.1 is proposed.

Prior to the ADC, the IF signal is split into $N$ parallel channels with equal power. The channels have incremental gain in steps of $\Delta$ dB. The signal outputs passing through channels are sent to estimation system which corrects the channel-to-channel gain and selects the outputs which are in the ADC dynamic range. The multiple channels are combined into a signal stream with a total dynamic range $(N-1)\Delta$ (in dB), which is greater than that of a single stream. After that, the outputs are connected to ADC. A certain required dynamic range can be realized by adjusting the number of channels.

In every channel, there is an important structure, shown in Fig.2. It increases the dynamic range by using the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$, the output is not different from the input, and the amplifier distortion. When the signal power is too strong to the amplifier, it works, and the distortion produced by the amplifier $G_i$ is in the DR of without distortion. Obviously $s_d=0$.

The IF signal is split into two paths. In one path, the signal $s$ passes through the amplifier $G^{i}$, and its output signal is expressed as

$$s_o = G^{i}s + s_d$$  
(1)

where $G^{i}=(N-1)\Delta$ is the gain factor of the amplifier $G^{i}$ and $s_d$ is the distortion produced by $G^{i}$ when the input signal goes out the range of the amplifier $G^{i}$. Then, the amplified signal $s_o$ is split into two flows, one of which is multiplied with $1/G^{i}$, the output can be written as

$$s_o = s_o / G^{i} = s + s_d / G^{i}$$  
(2)

In the other path, by subtracting the input $s$ from the signal $s_o$, we can obtain the signal

$$s_p = s_o - s = s_d / G^{i}$$  
(3)

which must be in the range of the amplifier $G^{i}$, so that undistorted signal is produced by the amplifier $G^{i}$.

Finally, the signal $s_o$ from the other flow of the amplifier $G^{i}$ and the signal $s_p$ from the second path are added together and the no error amplified output signal $s_o$ of input signal $s$ can be obtained. It is expressed as follows

$$s_o = s_o - s_p = G^{i} s$$  
(4)

After that, let the signal $s_p$ pass through the amplifier $G^{j}$. The output of the amplifier $G^{j}$ is then

$$s_{o_j} = G^{j}s_p = G^{j}s / G^{i}$$  
(5)

where $G^{j} = \Delta$ is the gain factor of the amplifier $G^{j}$. Then the amplified signal $s_{o_j}$ is multiplied with $G^{i} / G^{j}$ again and the signal $s_{o_j}$ is gotten

$$s_{o_j} = s_{o_j} G^{i} / G^{j} = s_d$$  
(6)

Finally, the signal $s_o$ is the distortion produced by the amplifier $G^{i}$ and the signal $s_{o_j}$ from the second path are added together and the no error amplified output signal $s_o$ of input signal $s$ can be obtained. It is expressed as follows

$$s_o = s_o - s_{o_j} = G^{i} s + G^{j} s / G^{i}$$  
(7)

After this process, the DR of input signals is changed. Assuming that the peak value of input signals is $V^i$, and the saturation voltage of the amplifier $G^{i}$ is $V_L$, then we get the results of different cases. The discussions are given as follows.

When $G^{i}V^i < V_L$, the input signal after amplified is in the DR of $G^{i}$ without distortion. Obviously $s_d = 0$, $s_o = s$, and $s_{o_j} = 0$, the output is not different from conventional amplifier, namely, the Distortion Compensation Approach (DCA) does not have impact on the signals in dynamic range.

When $G^{i}V^i \geq V_L$, the input signal goes beyond the DR of $G^{i}$, and $G^{j}$ will produce distortion. In this case, the peak value of signal $s^o$ is

$$V_o = V_L / G^{i}$$  
(8)

and the peak value of $s_p$ is

$$V_p = V_o - V_L / G^{i}$$  
(9)

The condition of the amplifier $G^{j}$ working in the linear range is

$$G^{j}(V_o - V_L / G^{i}) \leq V_L$$  
(10)

or

$$G^{j}(V^i - V_L / G^{i}) \leq V_L$$  
(11)

Thus

$$G^{j}V^i \leq (G^{i} + G^{j})V_L / G^{j}$$  
(12)

where $G^{i} = (N-1)G^{j}$. So the input signal DR is

$$G = 20\log(G^{i} + G^{j}) / G^{j} = 20\log N$$  
(13)

Clearly, the DR changes when the input signals
pass through the amplifier \( G_i \) and \( G_i \) is saturated. The increase of the DR is corresponding to the number of channels. For example, when \( N = 1 \), the DR can increase 0 dB, there is no change; when \( N = 2, 3, 4 \), the increase of DR is 6.02, 9.54 and 12.04 dB, respectively.

The system DR change is obvious, which is equal to the DR change by the distortion compensation structure adding to the DR change from channel to channel. When the DCA has no impact on the dynamic range, the minimum change is the DR change from channel to channel equal to \( (N-1)\Delta \) dB. Tab.1 shows the relation of the DR and channel numbers. If channel gain change is \( \Delta = 6 \) dB, and there are \( N = 4 \) channels, then the DR increased by channel inner structure is 12 dB and the DR change by channel to channel is 18 dB, so the whole DR will increase 30 dB, which is a considerable DR change in the EW receiver.

<table>
<thead>
<tr>
<th>Channel number ( N )</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR change by channel to channel/dB</td>
<td>0</td>
<td>6.00</td>
<td>12.00</td>
<td>18.00</td>
</tr>
<tr>
<td>DR change by the distortion compensation/dB</td>
<td>0</td>
<td>6.02</td>
<td>9.54</td>
<td>12.04</td>
</tr>
<tr>
<td>Total DR change/dB</td>
<td>0</td>
<td>12.02</td>
<td>21.54</td>
<td>30.04</td>
</tr>
</tbody>
</table>

2 Simulation results

A simulated system is built with the objective of providing 90 dB of dynamic range. Using 12-bit ADC, a dynamic range extension of approximately 30 dB is required to achieve a total dynamic range of approximately 90 dB. To realize this 30 dB extension, four channels with 6 dB gain differentials are used. These channels are referred to in this paper as the 1x, 2x, 3x and 4x channels.

The BPSK signal is used in the test, whose power is \(-80\) dBmW. The ADC maximum input voltage is \( \pm 5 \) V\(^6\). Therefore the system dynamic range is 90 dB from +10 dBmW to \(-80\) dBmW. The Matlab is used to simulate the feasibility and performance of the parallel amplifier approach.

To demonstrate the performance of the distortion compensation, we consider the outputs by simulation in three cases: the ideal condition, the DCA and the saturation condition, as shown in Fig.3. Fig.3(a) is the output in the ideal condition in which the input signal only passes through an amplifier with gain \( (N-1)\Delta \) and the saturation level large enough but without saturation. Fig.3(b) is the DCA output generated by the amplifier shown in Fig.2. In this condition the amplifier \( G_i \) is distorted. Fig.3(c) shows the saturated output generated by a single amplifier with gain \( (N-1)\Delta \). Obviously, the DCA preserves the signal amplitude parameter although the amplifier is saturation.

---

\( V \)
We use the simulation approach to illuminate the dynamic range extension of the parallel amplifier structure compared with an amplifier with fixed gain (12dB). The parallel amplifier is composed of 4 channels with different gain value (0, 6, 12, 18dB). The results are shown in Fig.4 and Fig.5. When the signal amplitude is under the ADC minimum quantified voltage, the output will be set to zero. From Fig.4, we can see that only the 4x channel (Fig.4 (a)) sends the correct output to ADC, but the other channels, 1x, 2x and 3x, as in Fig.4 (b), (c) and (d), respectively, are all zeros, i.e. they have no contribution to the following signal processing. In Fig.5, the output of the fixed gain amplifier is distorted because the signal amplitude is under the ADC minimum quantified voltage.

![Parallel Amplifier](image1)

![Single ADC](image2)

Fig.6 Output spectrum estimation of the parallel amplifier approach and the single ADC

Fig.6 shows the output spectrum estimation captured with FFT from the parallel amplifier approach and from the single ADC. It is clear that the output signal generated by the parallel amplifier structure is reconstructed, but the output of the single ADC is distorted.

3 Conclusions

The simulation results described in this paper have demonstrated the parallel amplifier approach can effectively increase the dynamic range in EW receivers. This approach, without the drawbacks of the traditional mitigation techniques, is a promising way to meet the dynamic range requirements of EW receivers designed with existing ADCs available in market. In our demonstration system, the parallel amplifier gives output with approximately 100 dB of dynamic range, extending the dynamic range of the ADC by approximately 30 dB.

References


Brief Introduction to Author(s)

YUAN Shun-yi (袁舜轶) was born in Sichuan Province, China, in 1980. She received B.S. degree from University of Electronic Science and Technology of China (UESTC) in 2003. She is currently pursuing the M.S degree with School of Electronic Engineering, UESTC. Her research interests include signal receivers. E-mail: shunyiyuan@yahoo.com.cn.

TANG Bin (唐斌) was born in Sichuan Province, China, in 1964. He is currently a professor with School of Electronic Engineering, UESTC. His research interests include electronic scout and countermeasure, digital signal processing and wireless communications. E-mail: bint@uestc.edu.cn.