Design and Implementation of a New Gain Control RF Amplifier

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ABSTRACT: The system is made by the connection of broadband amplifier OPA847, current-feedback operational amplifier OPA695, attenuation network, filter circuit and MCU gain control module. In the first stage, the system can achieve 2 times fixed-gain by OPA847. Then, in the intermediate stage, it is made by the connection of two OPA847 to achieve 5 times gain. In the latter part, the system achieves 21~100V/V gain variation by OPA695 and T attenuation network. In the last stage, the system achieves the gain reduction by the high-pass filter network, AT89C52 is used to control the gain adjustment of this system, as well as the real-time display of the present output voltage gain. The range of the gain is 12dB~40dB, changed by 4dB step-by-step. After testing, the whole system has stable performance and good control.

KEYWORDS: RF broadband amplifier; Gain control; Filter network; OPA847; OPA695

1 MAIN TECHNICAL INDICATORS OF RF AMPLIFIERS

1.1 Basic Requirements

(1) Amplifier voltage gain AV≥40dB, input voltage effective value Vi≤20mV, the input impedance and output impedance is 50Ω, load resistance 50Ω, and output voltage effective value Vo≥2V and waveform hasn’t significant distortion.

(2) Within the frequency range 75MHz ~ 108MHz, the gain fluctuation is not more than 2dB.

(3) Passband of -3dB is beyond 60MHz ~ 130MHz, and fl≤60MHz and fh≥130MHz.

(4) Achieve AV gain step control, with the gain control range of 12dB ~ 40dB and step length 4dB. The gain absolute error is less than 2dB, and can display the set gain value.

1.2 Extended demand

(1) Amplifier voltage gain AV≥52Db, gain control extends to 52dB, and gain control step length doesn’t change. The input voltage effective value Vi≤5mV, the input impedance and output impedance is 50Ω, load resistance 50Ω, and output voltage effective value Vo≥2V. The waveform hasn’t significant distortion.

(2) Gain fluctuation in the frequency range of 160MHz ~ 50MHz is not more than 2dB.

(3) Passband of -3dB is beyond 40MHz ~ 200MHz, and fl≤40MHz and fh≥200MHz.

(4) Voltage gain AV≥52dB. When the frequency of the input signal f ≤20MHz or f≤20MHz, the measured voltage gain AV is not greater than 20dB.

2 SYSTEMATIC SCHEME DESIGN AND DEMONSTRATION

2.1 Scheme demonstration

2.1.1 Gain design ≥ 40dB

In the first design, a simple amplifying circuit can be formed by a triode lap of amplification circuit, because in order to meet the requirements of gain ≥40dB, a multistage amplifier circuit can be applied. The output circuit with the diode detector regulating former circuit can adjust the automatic gain feedback voltage. Due to the large number of discrete components, such as the transistor, the circuit is more complex, the operating point is difficult to adjust, and especially the quantitative gain regulation is very difficult. In addition, due to the use of multi-stage amplifier, the circuit stability is poor, which is prone to self-excitation.

In the second design, broadband amplifier is fulfilled. The high bandwidth, high slew rate broadband amplifier is used to achieve more than 40dB amplification. Due to the operational amplifier with high open loop gain, high input impedance and low output impedance, the amplifier circuit consisting of operational amplifier has the better linear, with high circuit integration, the simple structure, high accuracy, and external wiring simplification.

To sum up, the second design is chosen, because the three integrated amplifier OPA847 and a piece of four cascaded amplification circuit OPA695 can reach gain ≥40dB.
2.1.2 Adjustable amplifier Gain Design
The first design applies a voltage controlled amplifier. Intermediate level through the voltage controlled amplifier VCA824 achieve gain variation 0.05~5V/V, and the gain can be controlled by an external voltage. The microcontroller for calculates and controls a chip output control voltage D/A to achieve an adjustable gain step within certain range.

The second design is fixed gain and resistance network attenuation. In the end of the final amplifier circuit is added well-designed attenuation network, such as T type resistance attenuation network. Control the output voltage gain and realize gain within 12~40dB with MCU, stepping to 4dB.

The first design applies VCA to realize adjustable gain, but because of limited bandwidth and gain amplifier, the regulating range is small. The second design uses resistor network attenuation with simple circuit structure to implement. Thus, considered comprehensively, the second design is adopted, where former adopts fixed gain change, and later part realizes programmed control attenuation network, to reach adjustable amplification gain.

2.1.3 Filter circuit design
In the first design, active filter circuit or integrated chip would bring high cost, and the filter of the cutoff frequency can rarely reach 20MHz.

In the second design, the high pass filter after four stage operational amplifier, have larger attenuation to frequency of input signal of f≤20MHz or f≥270MHz.

To sum up, the second one is easily to realize, also can achieve ideal attenuation. Although passive attenuation network will attenuate the input signal to the frequency of 20MHz~270MHz, the little attenuation can be compensated by the front three op amp. Thus, the second design is better.

2.1.4 DC voltage stabilizing circuit design
The 12V voltage is connected to the three terminal voltage regulator chip 7812, 7912, 7805, and 7905, and the DC power ±5V and ±12V can be respectively obtained. This can reduce the power consumption in a certain extent, but the great number of chips and integrated circuit complexity run counter to low cost.

In the second design, about the stable voltage, we adopt the power module WRA1205MD-6W, which is better than the 7805V7905 series in stability. This module is applied to the design of the stable output voltage and the low output ripple noise. It is clear and easy to control with a high degree of circuit integration.

In summary, the second design with simple circuit is easy to use, and can provide a stable +5V operating voltage, so it is applied in this system.

2.1.5 Single chip microcomputer control and display circuit design
About the scheme selection, this system only plays the role of control gain and display, so the software design is relatively simple and we choose AT89C52 MCU control with low power consumption and rich display content. After starting the system, we enter the gain control interface, and can adjust the gain by buttons, with step 4dB.

2.2 System design
The preceding stage of this system is amplified to twice through OPA847, the middle achieves 5 times the gain amplification through the two OPA847 cascade, and the post stage circuit achieves 10 times the fixed gain through the OPA695. System gain control function is controlled by the single chip microcomputer, the ultimate stage switches to 12dB ~ 40dB and step 4 dB attenuation through relays, and gain attenuation is through cascade with low-pass filter. The system block diagram is shown in figure 1.

3 THEORETICAL ANALYSIS AND CALCULATION

3.1 RF amplifier design
Through the demonstration program, RF amplifier integrated operational amplifier is implemented. The extended demand requires that when getting the input signal effective value and the output voltage RMS, the peak to peak value is, with frequency 200MHz, 3dB down, and final amplifier pressure slew rate is:

(1) At the same time, the subject requires voltage gain and 130MHz input signal frequency. Then if the adoption of single stage amplifies, the amplifier gain bandwidth product is:
(2) The current operational amplifier cannot achieve single amplifier 40dB, and this system adopts multistage amplifier to get adjustable gain 40dB. The proceeding stage adopts fixed gain, to get twice gain by a broadband high slew rate amplifier OPA847. Middle stage reaches 5times gain through the OPA847, whose bandwidth is 3.9GHz, so that it can fully meet the requirements of the subject. The
post stage is composed of OPA695 and relay, and it is adjustable within the final range 12dB~40dB.

3.2 Gain fluctuation control within band

The proceeding stage of the system has amplified fixed gain, and according to the OPA847 Datasheet, when the gain is G=12, the bandwidth can be up to 600MHz and achieve the requirements of fluctuation in the frequency range of 160MHz ~ 50MHz in the extended demand of subject. The middle stage uses voltage feedback operational amplifier OPA847, getting low distortion of high slew rate and bandwidth of 3.9GHz that is much greater than 70MHz.

Post stage circuits using current feedback op amp OPA695 through gentle frequency band, and the bandwidth of 1.7GHz is far greater than the 70MHz, meeting the output voltage effective value Vo≥2V and waveform without significant distortion.

3.3 Stability analysis of RF amplifier

The system input signal frequency is 60M~130MHz, the signal effective value is less than 20mV, the amplifier is easy to introduce noise in the work process, and the system is not stable and easy to cause the self-excitation. Therefore, the proceeding stage in this design applies the fixed gain amplifier circuit, and the first stage uses low gain with 2 times amplification, to reduce the impact of noise on the post stage and improve the stability of the system.

3.4 Gain adjustment

Adjustment of the system gain is fulfilled mainly through relay regulating T type attenuation network. An attenuator composed of a resistor and a relay is added to the polar amplification circuit. And the single chip microcomputer AT89C52 controls the attenuation of amplitude of the signal, in order to achieve voltage gain control. Through the key input, the voltage gain is adjust within the range of 12dB ~ 40dB with 4dB step. Attenuator uses standard T type network, when meeting the required voltage attenuation, to ensure that the output impedance of the amplifier is 50Ω.

3.5 Amplifier bandwidth design

According to the requirements of the subject, the bandwidth limits lower frequency and the upper frequency. The bandwidth of amplifier chip in the design is far greater than 70MHz. Amplifier frequency band also achieves the index of the upper limited frequency of through the RC frequency compensation.

3.6 Stability of Amplifier

To make the amplifier stable, we must eliminate the self-oscillation, which means the phase shift at magnification 0dB is less than 180°. Identify that the phase shift is j and the phase margin \( \phi_m = 180°-j \).

When \( \phi_m > 45 \), the circuit has sufficient phase margin to meet the reliability of the amplifier. The result of the simulation shows there is not self-excited oscillation after the circuit outputs, but the actual circuit interference between devices will easily cause self-excited oscillation. Therefore, we should pay attention to the ground connection of the welding, so that you can better eliminate the self-excitation.

4 CIRCUIT AND PROGRAM DESIGN

4.1 Fixed gain circuit in front stage

Through the scheme demonstration and theoretical analysis, the system uses a broadband amplifier OPA847 to achieve 2 times gain amplification. OPA847 in front stage circuit. OPA847 is a wide bandwidth amplifier with a bandwidth of 3.9GHz, slew rate, and stable system gain. The effective value of the front stage input signal, and the peak value of the output voltage amplified 2 times:

(3) The required slew rate of operational amplifier:

(4) OPA847 fully meets the requirements of the index. The specific circuit is shown in Figure 2.

4.2 Circuit design of post stage

Circuit of post stage through the OPA695 achieves 10 times gain amplification, and attenuates through the relay switching resistance network, to achieve adjustable gain within 12~40dB in the entire system. OPA695 is a current feedback operational amplifier with high slew rate and bandwidth, and it can realize the effective value of 2V, bandwidth of 70MHz signal output. The specific circuit is shown in figure 3.

4.3 Voltage gain control

An attenuator composed of a resistor and a relay is added to the polar amplification circuit. And the single chip microcomputer AT89C52 controls the attenuation of amplitude of the signal, in order to
achieve voltage gain control. Through the key input, the voltage gain is adjust within the range of 12dB ~ 40dB with 4dB step. Attenuator uses standard T type network, when meeting the required voltage attenuation, to ensure that the output impedance of the amplifier is 50Ω. The specific circuit is shown in Figure 4.

4.4 Filter design
According to the extended demand of the project, bandwidth requires the 3dB pass band of 40 MHz MHZ~200. And when the input signal frequency f≤20MHz or f≥270MHz, voltage gain AV is less than 20 dB. This design uses the seven order Butterworth, can largely attenuates the input signal with the frequency of f≤20MHz or f≥270MHz. At the same time it reduces the gain in the pass band and gain fluctuation is less than 2dB in the 75MHz~108MHz frequency range. The specific circuit is shown in Figure 5.

4.5 Power circuit design
Because the + 5V is operating voltage of broadband amplifier OPA847, so the use of WRA1205MD-6W power supply module will make the +12V single

5 TEST PLAN AND RESULTS
5.1 Test instrument
(1) Digital oscilloscope DS6104
(2) DDS function signal generator TFG3605
(3) Digital multi meter U3402A
(4)Self-made power module WRA1205MD-6W
5.2 Test condition
Ambient temperature is 25 degrees, +12V single power supply (added to the homemade linear regulated power supply).
5.3 Test plan
5.3.1 Amplifier voltage gain test
Set the signal source to generate the effective value of Ui as 0.2mv, the frequency as the sinusoidal signal sends into the system, and the system output parallels to the ground as a load resistance. Use an oscilloscope to observe the input signal and output signal of the system. Whether the output signal of the observation system meets the effective value, the gain control of the attenuation network is controlled by the single chip microcomputer, and the system gain is satisfied with the adjustable range 12dB~40dB.
5.3.2 Amplifier bandwidth test
The signal generator is provided with an effective value sine signal \( U_i = 0.2 \text{mv} \), the system gain is 40dB, and the input signal frequency is continuously changed in the range of 1MHz~200MHz. Find the maximum and minimum amplitude of the output signal in the frequency band of the input signal, and calculate whether the corresponding upper and lower limited frequency of the band meets the 75MHz~108MHz bandwidth. Continue to expand the frequency range of the input signal, find the corresponding upper and lower frequencies when the output signal amplitude decreases by 3dB, and calculate whether it is satisfied.

5.4 Test results and analysis
5.4.1 Amplifier voltage gain test
According to the test plan, amplifier voltage gain test results through the oscilloscope observation are as shown in table 1.

<table>
<thead>
<tr>
<th>Gain Setting/dB (( U_i = 0.2 \text{mv} ), Gain 40dB)</th>
<th>40</th>
<th>32</th>
<th>20</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test result /mV</td>
<td>21</td>
<td>8</td>
<td>1.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Waveform quality (distortion)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

According to the test results in table 1, we can see that the system can achieve the input signal and the effective value of output signal in the basic requirements, and the system can achieve adjustable gain within 12dB~40dB.

5.4.2 Amplifier bandwidth test
According to the test plan, the amplifier test results are shown in table 2.

<table>
<thead>
<tr>
<th>Frequency Setting /MHz (( U_i = 0.2 \text{mv} ), gain 40dB)</th>
<th>60</th>
<th>75</th>
<th>80</th>
<th>90</th>
<th>108</th>
<th>120</th>
<th>130</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band gain /dB</td>
<td>41.6</td>
<td>41.4</td>
<td>41.3</td>
<td>41.7</td>
<td>40.7</td>
<td>40.3</td>
<td>41.2</td>
</tr>
<tr>
<td>Gain fluctuation /dB</td>
<td>1.6</td>
<td>1.4</td>
<td>1.3</td>
<td>1.7</td>
<td>0.7</td>
<td>0.3</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Note: gain fluctuation =

From the test results it can be seen that in the 60M~130MHz, the maximum output signal amplitude corresponds to gain 41.7dB, the minimum output signal amplitude corresponds to gain 40.3dB. According to the topic request, gain fluctuation in the frequency is:

(6) Through the calculation, in the 75M~108MHz band, the system gain fluctuation can meet the requirements of the subject. At the same time, based on the test table, when the system gain decreases by 3dB, the corresponding lower limited frequency and the upper limited frequency achieve the bandwidth requirements of the subject.

6 CONCLUSION
The test results of the above mentioned parts show that this design has successfully completed the requirements of the topic, better expanded the gain and bandwidth range, and reduced the system noise and interference, leading to good waveform. A comprehensive application of various noise reduction measures ensures the stability of the amplifier and reduces the noise. When the circuit is made into the PCB board, reasonable layout and the large area of copper and other measures can make the noise voltage drop to a lower level. If the output gain is further measured and corrected or equipped with better device, the index can also be further improved.

REFERENCES