用于自动化、通讯、生物电子领域的微弱信号放大器

Low level IC amplifier for automation, telecommunication and Bioelectronics

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摘　要: 在微弱信号测量中放大器是关键器件。本文介绍如何选择放大器、使噪声系数最小、以达到良好的性能。给出微弱信号放大器性能表和如何减少外来的干扰等误差源。

关键词: 微弱信号; 放大器; 噪声;

Abstract: This paper introduces how to select amplifier and minimize the noise figure to reach the better system performance. Lists of low level amplifier and ways of elimination extra error source are given.

keywords: Low Level Signal, Amplifier; Noise;

1、引论

设计电子系统经常需要微弱信号处理。噪声和漂移给出了可检测信号的下限。当我们设计时需要知道系统中的各种噪声和漂移、当我们知道各种元器件所引起的噪声和漂移、特别是集成放大器、我们可以选择正确的元器件和仔细地设计印刷电路板以使系统性能最佳。

2、微弱信号放大器

2.1 用于自动化和生物电子领域的微弱信号放大器:

我们可以把微弱信号放大器分为三类 极低电压噪声放大器、极低电流噪声放大器、极低漂移放大器。

1).极低电压噪声放大器 :

这种放大器绝大部份具有双极性晶体管作为输入,具有极低的电压噪声和较低的电流噪声和漂移。如AD797其电压噪声密度为0.9nV/$\sqrt{Hz}$,电流噪声密度为2pA/$\sqrt{Hz}$、失调电压为10μV、失调电压温漂为0.2μV/℃; LT1115其电压噪声密度为0.9nV/$\sqrt{Hz}$,电流噪声密度为1.2pA/$\sqrt{Hz}$,失调电压为50μV. 失调电压温漂为0.5μV/℃。对于电流反馈放大器、其输入端的输入阻抗是不同的,反相端的输入偏流大于同相端的输入偏流。因此其反相端的电流噪声一般大于电压反馈放大器。但电流反馈

1. Introduction

Designing electronic system often needs to deal with low level signal. Noise and drift place a limit on the minimum detectable signal. When we begin to design it is essential to consider the effect of the various noise and drift throughout the system. After determined the noise and drift contributions of the individual components, particular IC amplifier, we can optimize the system by selection the right components and careful PCB design and construction.

2. Low level amplifier:

2.1 Amplifier for automation:

We can divide low level amplifier into three kinds of amplifier. They are ultra low noise voltage amplifier, ultra low noise current amplifier, and ultra low drift amplifier.

1). Ultra low noise voltage amplifier

Most of them are bipolar operational amplifier. This kind of amplifier offers very low noise voltage and low noise current, low drift as well. Such as AD 797 with e_n=0.9 nV/rhHz ; in= 2 pA/rhHz; VOS 10μV and VOS/ΔT, 0.2 μV/℃ ; LT1115 e_n 0.9 nV/rtHz, in 1.2 pA/rtHz ,V_{OS}=50 μV and V_{OS}= 0.5 μV/℃. For the current feedback amplifier due to the asymetrical input impedance the bias current on the inverting input is higher than on the non-inverting input. Therefore the inverting current noise usually is higher than the voltage-feedback amplifier.

However current feedback amplifier has an advantage of its higher loop gain at higher frequency compared with voltage feedback amplifier, so in broadband application current feedback amplifier may be adopted.

2) Ultra low current noise amplifier.

Most of them are FET input amplifier. They offer ultra low current noise and low voltage noise, low drift as well such as OPA111 with input current noise 1.6 fA/rtHz , input voltage noise 7 nV/rtHz , offset voltage 250μV and VOS drift 1 μV/℃.

3). Ultra low drift ampifier

In process control drift is often concerned. In this kind of application low drift amplifier is suitable. Most of them are either error-correction amplifier(MAX 425), or chopper-stable amplifier (TC 7652). The specification of MAX 425 is Vos 0.5μV, Vos drift 0.005 μV/℃ for TC7652 Vos 2 μV, Vos drift 0.01 μV/℃ , in = 10fA/rtHz, en=(0.1-10Hz) 0.7 μVp-p

2.2 Noise Figure:

Noise factor, F is a figure-of-merit for a device or a circuit with respect to noise.

放大器在高增益情况下其带宽大于电压反馈放大器，因此在宽带情况下有时需要采用电流反馈放大器。

2).极低电流噪声放大器:

这种放大器绝大部份采用场效应管作为输入，具有极低的电流噪声和较低的电压噪声和漂移。如OPA111，其电流噪声密度为1.6fA/√Hz，电压噪声为7nV/√Hz，失调电压为250μV，失调电压温漂为1μV/℃。

3).极低漂移放大器:

在过程控制中漂移需要重点关注。在这种应用中宜采用低漂移放大器。它们或者是自动稳零放大器或者是斩波器放大器。自动稳零放大器如MAX426其技术指标为失调电压0.5μV，失调电压温漂0.005 μV/℃，电压噪声密度为8nv/√Hz。斩波器放大器如TC7652其失调电压为2μV，失调电压温漂为0.01μV/℃。电压噪声（0.1-10Hz）为0.7μVP-P电流噪声密度为10fA/√Hz，输入偏流为30pA。

2.2 噪声系数

噪声因数、F是用来评估一器件或者一电路的噪声性能。F=输出端总的噪声功率/在输出端由信号源阻抗引起的热噪声功能率 et 这里 e_t（为信号源阻抗的热噪声）。

$$e_K=\sqrt{4KT\,Rs\,\triangle f}$$

K为波尔兹曼常数 $K=1.38\times10^{-23}$

T为温度开氏温标，R_S 为源阻抗，△f为频带宽度。

总的输出端噪声电压为 $e_t^2+e_n^2+in^2R_S^2$

e_n 为放大器的噪声电压，i_n 是放大器的噪声电流

$$F=1+e_n^2/e_t^2+i_n^2R_S^2/e_t^2$$

噪声因数的对数表达式NF即为噪声系数

NF=10logF

$$=10\log(1+e_n^2/e_t^2+i_n^2R_S^2/e_t^2)\cdots\cdots①$$

2.3 用于自动化和生物电子学的微弱信号放大器选择准则:

在放大器输入端的噪声电压是噪声电压和噪声电流的函数。同时也和信号源的阻抗有关。当信号源阻抗低时可根据放大器的噪声电压来选择。如源阻抗高时、噪声电流影响很大、故应根据噪声电流选择。可采用极低电流噪声放大器。

F= total available output noise power/ portion of output noise power caused by e of source resistance

Here et is source resistance thermal noise.

$$e_K=\sqrt{4KT\,Rs\,\triangle f}$$

K= Boltzman's = 1.38×10^{-23}

T= temperature of the conductor in degree Kelvin, R is the resistance of source. Δ f is bandwidth.

Total available output noise power= $e_t^2+e_n^2+i_n^2R_S^2$, e_n is the amplifier noise voltage, in is the amplifier noise current.

$$F=1+e_n^2/e_t^2+i_n^2R_S^2/e_t^2$$

The logarithmic expression for noise figure:

NF=10 log F

$$=10\log(1+e_n^2/e_t^2+i_n^2R_S^2/e_t^2)\text{-----}(1)$$

2.3 How to choose low level amplifier for automation and bioelectronics:

Total noise voltage at the input of an amplifier is a function of noise voltage as well as noise current. It also dependent on the resistance of signal source. When source resistance is low we can select amplifier according to the noise voltage performance of the amplifier. When the source resistance is high, the noise current is crucial, amplifier with ultra low current noise should be adopted.

For example, when the source resistance is 1 k ohm at the frequency 1kHz, bandwidth 1Hz.

For AD 797

$$e_{nl}=\sqrt{(0.9)\times10^{-9})^2+(2\times10^{-12}\times10^3)^2}=2.2\text{nV}$$

For OPA 111 e_{n} = 7 nV

In this circumstance, AD797 performs better noise merit than OPA111.

For AD797

$$e_{n}=\sqrt{(0.9)\times10^{-9})^2+(2\times10^{-12}\times10^3)^2}=2.2\text{nV}$$

So when source resistance is high, OPA111 has better noise performance

We also can select low noise amplifier by minimum the noise figure.

To illustrate this point, it is worth to compare the performance of two mentioned amplifiers above OPA111 and AD797.

From formula (1) the noise figure of OPA111 and AD797 can be compared at RS= 1K ohm and Rs = 1M ohm respectively

For R_S= 1Kohm AD797, NF=1 14

OPA111, NF= 6

For R_S = 1 M ohm AD 797, NF= 24

OPA111, NF= 0.014

From the calculation it is clear that when R_S = 1K ohm AD797's NF is lower than OPA 111's NF so it is better to use AD797, on the contrary when R_S = 1 M ohm OPA111's NF is close to zero OPA111 is a suitable amplifier.

Noise figure can be calculated by a basic program.[1] The noise figure plot has a characteristic shape : it has a minimum at a certain source resistance and increases for lower and higher resistance. At lower resistance the main noise contribution comes from the amplifier's noise voltage. For higher resistance the noise current takes over and accounts for the increase in the noise figure. For a given source impedance using noise figure to select a right amplifier is essential for design a low noise system

The following are lists of some parameters of low level amplifier, all parameters are typical value if without indicate:

2.4 Low noise amplifier for telecommunication:

The low noise amplifier for telecommunication achieves broadband bandwidth. This kind of amplifier must perform in the either 50 ohm or 75 ohm terminal for which the noise figure is developed. A gain block can be completed characterized by its noise figure. Most of this kind of amplifier is made by Si-Ge, GaAs and is widely used in CDMA,GSM,GPS,optical communication, etc

3. The Consideration of Application Low Level Amplifier:

To realize a low level signal processing, not only select a right amplifier is important but also must take some measure to prevent source of error. We can identify each error contributor and minimize their detrimental effects in the system.

3.1 Interference:

The following steps can minimize this kind of error:

Limiting circuit bandwidth helps to avoid noise amplification- using just enough bandwidth

Separating the power/ground connections used for the small signal sections from

例如当源阻抗为1千欧时对于AD797，放大器的噪声

$$e_{nt}=\sqrt{(0.9)\times 10^{-9})^2+(2\times 10^{-12}\times 10^{6})^2}=2.2nV$$

对于OPA111，e_{nt}=7Nv

在这种情况下AD797的噪声性能较OPA111好。

当源阻抗为1兆欧时，对于AD797

$$e_{nt}=\sqrt{(0.9)\times 10^{-9})^2+(2\times 10^{-12}\times 10^{3})^2}=2.2nV$$

对于OPA111，根据计算，e_{nt}为7.2nV

所以当源阻抗高时OPA111的性能较AD797好。也可以根据噪声系数选择，噪声系数小的放大器为佳。为了说明这一点我们可再选用AD797和OPA111在不同源阻抗计算其噪声系数进行比较。我们可根据①式计算阻抗为1千欧时AD797和OPA111的噪声系数。当源阻抗为1千欧时，AD797的NF=1.14，OPA111的NF=6，

当R_s为1兆欧时AD797的NF=24，OPA111的NF=0.014

通过器件的NF可以清楚地看到，在源阻抗为1千欧时，AD797的NF为1.14比OPA111的NF6为小，故我们应该用AD797；而在源阻抗为1兆欧时OPA111的NF为0.014接近零而AD797的NF为24故应选择OPA111。

噪声系数NF可用一个BASIC程序来计算①。噪声系数的图形如有以下特征，在一定的源阻抗时达到最小而当源阻抗高或者低均为增高。当源阻抗噪声低时噪声主要由于放大器的噪声电压引起，当源阻抗高时噪声主要由放大器的电流噪声引起。利用噪声系数来选择放大器在设计微弱信号放大器是很有用的。

2.4 用于通讯的微弱讯号放大器

用于通讯的放大器具有宽的频带。这种放大器的负载为50欧，噪声系数也是在50欧的条件下给出的。其特性可由噪声系数所描述。这种放大器绝大部份由锗—硅，砷化镓所构成的，广泛用于CDMA、GSM、GPS和光通信中。

3.使用微弱信号放大器要考虑的问题

实现一个微弱信号测量系统，不仅要选择正确的放大器并且必须采取措施以避免其他误差。我们可以考虑各种影响因素并设法减少它们。

3.1 干扰：

可采取如下措施以减少误差：

● 限止电路的带宽以避免噪声和干扰—带宽只要足够即可

● 把小讯号的电源和地与大讯号的电源及地分开以避免由共用电源和地而起的误差

表1　超低电压噪声放大器

Figure.1 A List of Some Ultra Low Noise Voltage Amplifier.

	AD797	EL2125C	LT1115	OP27	AD8001
电压噪声 e_n 密度 1KHz	0.9nV/$\sqrt{HZ}$	0.83 nV/$\sqrt{HZ}$	0.9nV/$\sqrt{HZ}$	3nV/ $\sqrt{HZ}$	2nV/$\sqrt{HZ}$
电压噪声 en 0.1-10HZ	40nVp-p			80 nV_{p-p}	
电流噪声 in 密度 1KHz	2pA/ $\sqrt{Hz}$	2.4 pA/ $\sqrt{Hz}$	1.2 pA/$\sqrt{Hz}$	1.7 pA/$\sqrt{Hz}$	+2pA/ $\sqrt{Hz}$ -182pA/$\sqrt{Hz}$
失调电压 V_{os}	10 μV	200 μV	50 μV	100 μV	2mV
失调电压 V_{os}/△T 温漂	0.2 μV/℃		0.5 μV/℃	0.4 μV/℃	10 μV/℃
输入偏流 I_b	250 μA	21 μA	50 μA	10 μA	-5 μA+3 μA
压摆率 SR	20V/ μS	225 V/ μS	10 V/ μS	1.9 V/ μS	1000 V/ μS
带宽 BW	80MHZ	175MHZ	40MHZ	8MHZ	880MHZ

AD8001为电流反馈型放大器，其他均为电压反馈型放大器

（除注明者外其他均为典型值）

表2　极低电流噪声放大器

Figure.2 A List of Some Ultra Low Noise Current Amplifier.

	AD8610	OPA111	OPA627	LT1793	LMC6001
电压噪声 e_n	6nV/$\sqrt{HZ}$	6nV/$\sqrt{HZ}$	3.2 nV/$\sqrt{HZ}$	6nV/$\sqrt{HZ}$	22nV/$\sqrt{HZ}$
密度 1KHz					
电压噪声 e_n 0.1-10 HZ	1.8 μV_{p-p}	2.4 μV_{p-p}			
电流噪声 i_n 密度 1KHZ	5fA/ $\sqrt{HZ}$	1.6fA/$\sqrt{HZ}$		1fA/$\sqrt{HZ}$	0.13fA/$\sqrt{HZ}$
失调电压 V_{os}	45 μV	250 μV	100 μV	250 μV	350 μV
失调电压 V_{os}/△T 温漂	0.5 μV/℃	1 μV/℃	0.4 μV/℃	8 μV/℃	2.5 μV/℃
输入偏流 I_b	2pA	1pA	1pA	3pA	25fA
压摆率 SR	50V/ μS	2V/ μS	55V/ μS	3.4V/ μS	1.5V/ μS
带宽 BW	25MHZ	2MHZ	16MHZ	4.2MHZ	1.3MHZ

表3 极低漂移放大器

Figure 3 A List of Some Ultra Low Drift Amplifier

	MAX426	AD8551	TC7652	LTC2050	TLC2654
电压噪声 e_n 密度 1KHZ	8nV/ $\sqrt{HZ}$	42nV/ $\sqrt{HZ}$			13nV/ $\sqrt{HZ}$
电压噪声 e_n 0.1-10 HZ	250 μ V_{p-p}	1000 μ V_{p-p}	7000 μ V_{p-p}	1.5 μ V (0.01-10HZ)	1.5 μ V
电流噪声 i_n 密度 1KHz		2fA/ $\sqrt{HZ}$	10fA/ $\sqrt{HZ}$		
失调电压 V_{os}	0.5 μ V	1 μ V	2 μ V	0.5 μ V	10 μ V
失调电压 V_{os}/△T 温漂	0.005 μ V/℃	0 005 μ V/C	0.01 μ V/℃	0.03 μ V/℃ (最大值)	0.01 μ V/℃
输入偏流 I_b	0.12PA	10PA	15PA	20PA	
压摆率 SR	12V/ μ S	0.4V/ μ S	1V/ μ S	2V/ μ S	3.7V/ μ S
带宽 BW	15MHZ	1.5MHZ		3MHZ	1.9MHZ

表4 用于通讯的微弱信号放大器

A List of Some Low Noise Amplifier for Telecommunication:

SGL-01	SG-02	TQ3131	TQ3631	IBM3604011S010	
增益 Gain	15db	14db	13db	13db	17.5db
噪声系数 NF	1.1	1.3	1.4	1.5	2.3
频带 BW	800-1000MHz	1900-2400 MHz	832-894 MHz	1810-1990 MHz	1930-1990 MHz
用途	CDMA/GSM	CDMA/GSM	CDMA	CDMA	GSM

● 屏蔽：把讯号彼此隔离和屏蔽避免干扰通过分布电容耦合到讯号中去

3.2 EMF

不同的金属连接在一起会产生结电压、在低漂移放大电路中，热电势是主要误差源，减少结的数目并在放大器输入端回路中平衡。另一个方法是选择低电势焊料如 60% 镉/40% 锡的焊料其热电势为 0.16 μ V/Co 而 64% 镉/36% 锡势电势为 1.5 μ V/℃。对于差分式电路如运算放大器，保持其输入平衡是重要的，因为其热幅度相同位相同可以彼此抵消；一个细微的气流可以使运放的温度不平衡而产生漂移和噪声；一个小的塑料盒子覆盖在放大器上可使漂移和噪声由 0.2 μ V_{p-p} 减少到 0.05 μ V_{p-p}。

3.3 漏电流

屏蔽环是防止漏电流的一种有效方法。在印刷电路板上用一个环围在放大器的输入端、该环的电位跟随输入端的电位这样由于等电位可以防止输入端的漏电流。另一个方法是将输入直接，在聚四氟乙烯的支架上。

4. 小结

微弱信号放大器广泛地用于自动化、通讯和生物电子领域中。当信号源阻抗低时双极型放大器可以提供极低噪声而 FET 输入的放大器适用于高源阻抗。利用噪声系数可以评估一个放大器的噪声在整个系统噪声所占的比重。当需要低漂移时需采用自动稳零或者斩波器放大器。除了选择正确的放大器、仔细考虑外来的干扰和防止它们也是很重要的。

参考文献:

[1]John Christensen. Using Noise Figure to select a Low-noise Op-amp. Electronic Engineering, 1997,(4) 41-43

[2]Jim William. Chopper-stablilized monolithic op amp suit diverse uses. EDN, 1985,(2): 305-312

those used for the large signal will avoid the Shield. Signal separation and shielding helps to avoid noise coupling through parastic capacitance.

3.2 EMF

Any connection of dissimilar metals produce a potential that varies with the junctions In low drift amplifier circuits, thermal EMF is usually the primary error source. Limiting the number of junction and balancing junctions in amplifiers input are good practice. Choice better solder is an another way, the solder with 60% Cd/40% Sn contributes thermally induced voltage of 0.16 μV/℃ on the contrast the solder with 64% Sn/36% Pb contributes 1.5 μV/℃. For a differential circuit such as operational amplifier, keep the thermal-EMF- induced shift are equal in phase and amplitude and cancellation result. A slight air currents may cause drift and noise due to it unbalances the temperature of the operational amplifier's input transistor pairs. A small plastic covered the amplifier can reduce drift and noise from 0.2μVP-P to 0.05 μVP-P(2).

3.3 Leakage:

Guarding is an effective way to solve this problem. The guard is a PC-board trace that encircles the amplifier's input and drives the trace at a potential equal to the input, thereby preventing leakage to the amplifier input terminal Another choice is to connect the amplifier's input directly to the signal source via a Telfon standoff.

4. Conclusion:

Low noise and low drift are widely used in automation, telecommunication and bioelectronics. For low signal source impedance situation, bipolar amplifier can provide very low noise characteristic and FET amplifier with high resistance signal source can result in an excellent system performance.

Reference:

[1] John Christensen " Using Noise Figure to select a low noise op-amp" Electronic Engineering, 1997 April 41-43

[2] Jim William " Chopper-stablilized monolithic op amp suit diverse uses" EDN 1985 Feb. 21 305-312