Chapter 43 Low Noise Amplifier

Amplifier users are always annoyed by noise. We may have a low noise amplifier by selecting appropriate components, such as power supply and transistors. Indeed, proper semiconductor manufacture process may help reduce noise level. But in this lecture notes, we try to avoid the semiconductor manufacturing aspects. Therefore, in the following sections, we are focusing on noise canceling techniques.

Section 43.1 Noise Cancelation for Low Frequency Amplifier

Fig 43.1-1 shows an amplifier with a noise source added. The circuit of the amplifier without the added noise is shown in Fig. 43.1-2.

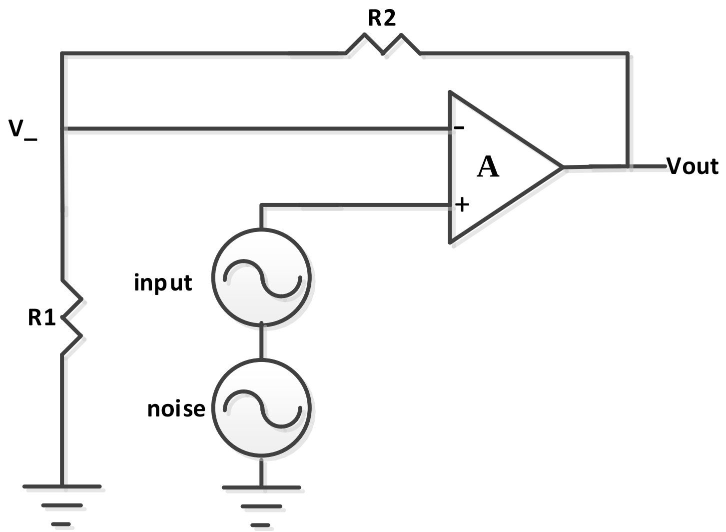

Fig. 43.1-1 An amplifier with noise added.

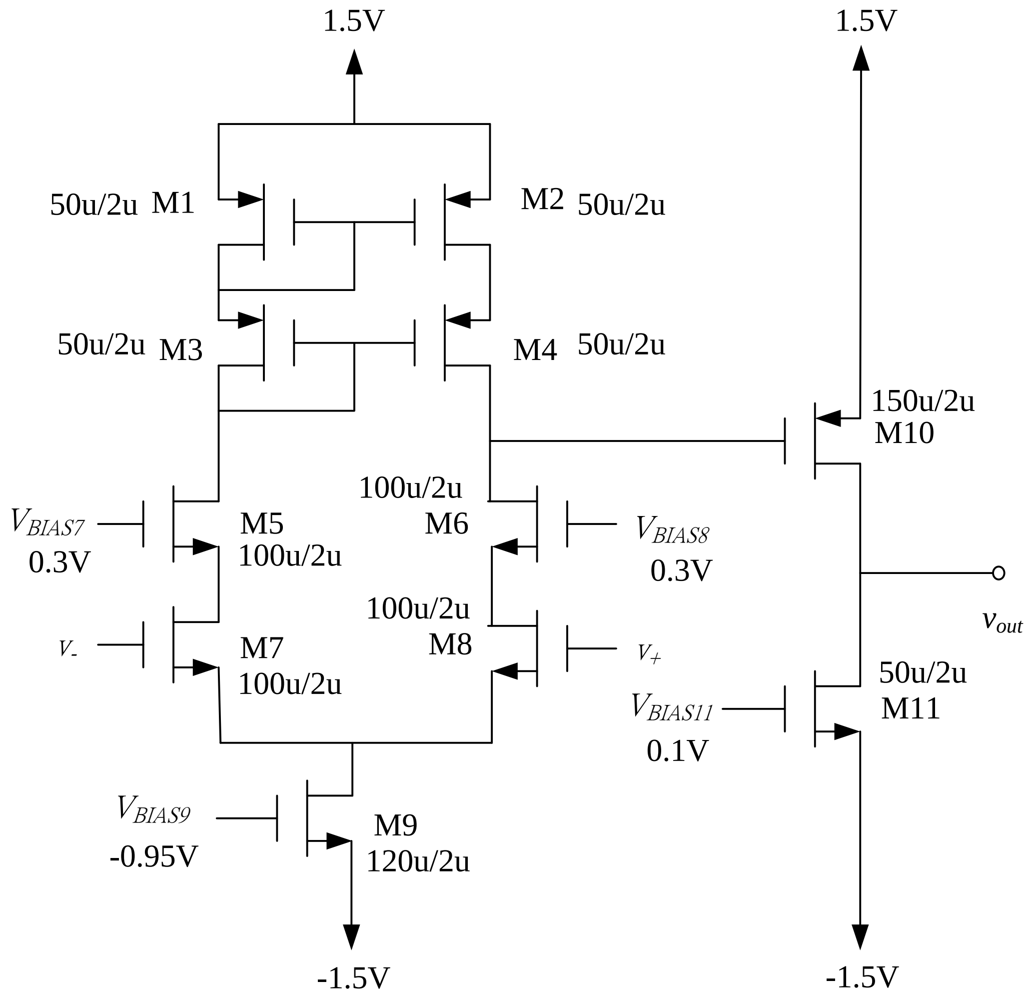

Fig. 43.1-2 The circuit of the amplifier in Fig, 43.1-1

Experiment 43.1-1 Testing of the Amplifier with Noise

In this experiment, we test the amplifier with noise which is shown in Fig. 43.1-1 and Fig. 43.1-2. The program is in Table 43.1-1 and the results are in Fig. 43.1-3. The frequency of the input signal is 1kHz and that of the noise is 1MHz. We can see that the output is contaminated by the noise.

Table 43.1-1 The program of Experiment 43.1-1

```
NOIN_AM
.protect
.option post
```

```
.lib “C:\model\tsmc\MIXED035\mm0355v.l” TT
.unprotect
.op

VDD      VDD!    0      1.5V
VSS      VSS!    0     -1.5V

M1    1    1      VDD!    VDD!    PCH     W=50U    L=2U
M2    2    1      VDD!    VDD!    PCH     W=50U    L=2U
M3    3    3         1    VDD!    PCH     W=50U    L=2U
M4    4    3         2    VDD!    PCH     W=50U    L=2U
M5    3    VB7       5    VSS!    NCH     W=100U   L=2U
M6    4    VB8       6    VSS!    NCH     W=100U   L=2U
M7    5    Vi-       7    VSS!    NCH     W=100U   L=2U
M8    6    Vi+       7    VSS!    NCH     W=100U   L=2U
M9    7    VB9    VSS!    VSS!    NCH     W=100U   L=2U
M10   Vo   4      VDD!    VDD!    PCH     W=150U   L=2U
M11   Vo   VB11 VSS!     VSS!    NCH     W=50U    L=2U

VIN+      Vi+       8     sin(0v 0.0001 1k)
Vnoise    8     0 sin(0v 0.000005 1Meg)

VBIAS7   VB7 0     0.3V
VBIAS8   VB8 0     0.3V
VBIAS9   VB9 0     -0.95V
VBIAS1 VB11 0     0.1V

R2         Vi-   Vo    10000k
R1   Vi-   0     1000k

.tf    V(vo)      VIN+
.tran1us  10ms
.end
```

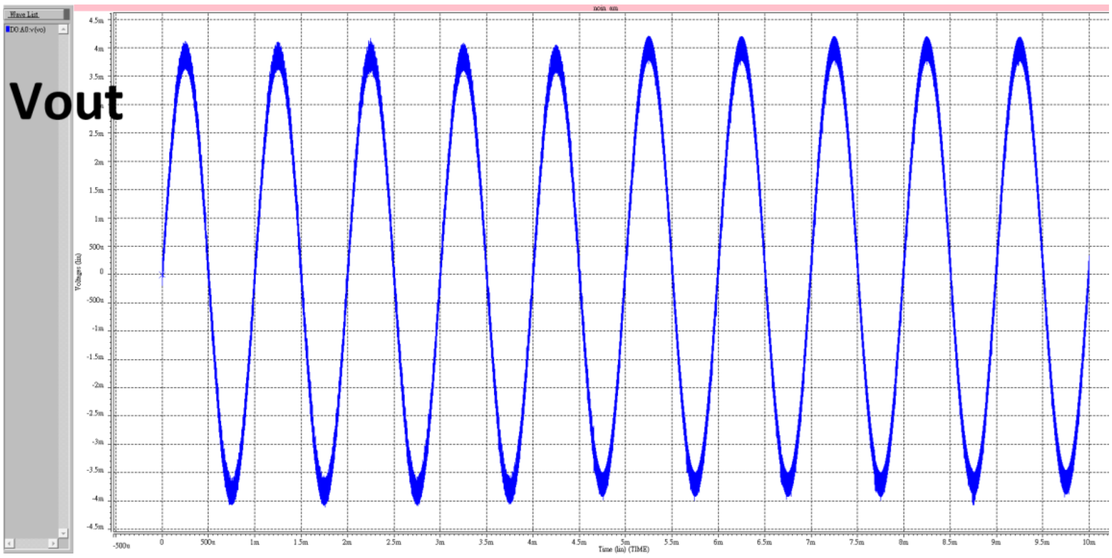

Fig. 43.1-3 The results of Experiment 43.1-1

We need a filter to eliminate the high frequency noise. Consider Fig. 43-4.

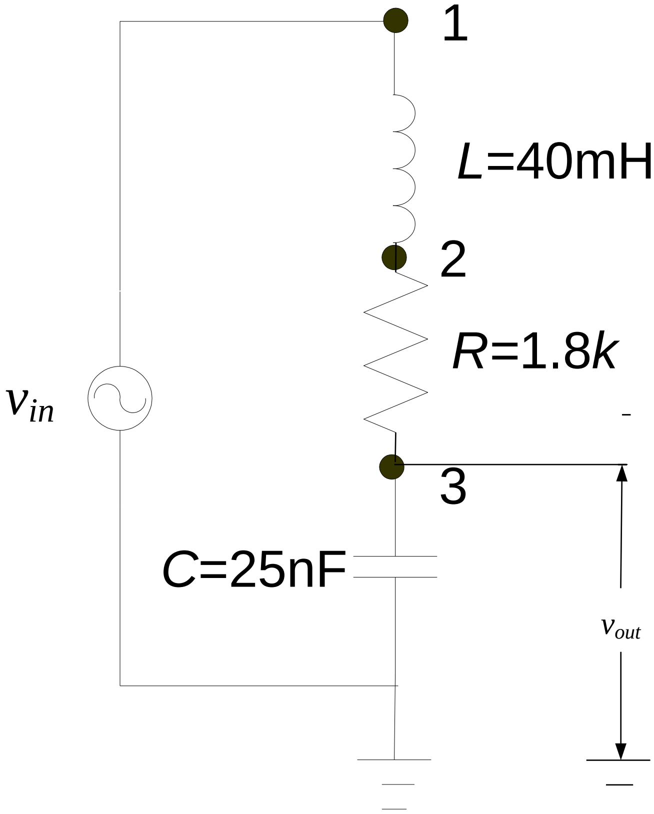

Fig. 43.1-4 A low pass filer

The filter in Fig. 43.1.-4 is an RLC low pass filter which was discussed in detail in Chapter 11. The transfer function of filter is shown in Fig. 43.1-5.

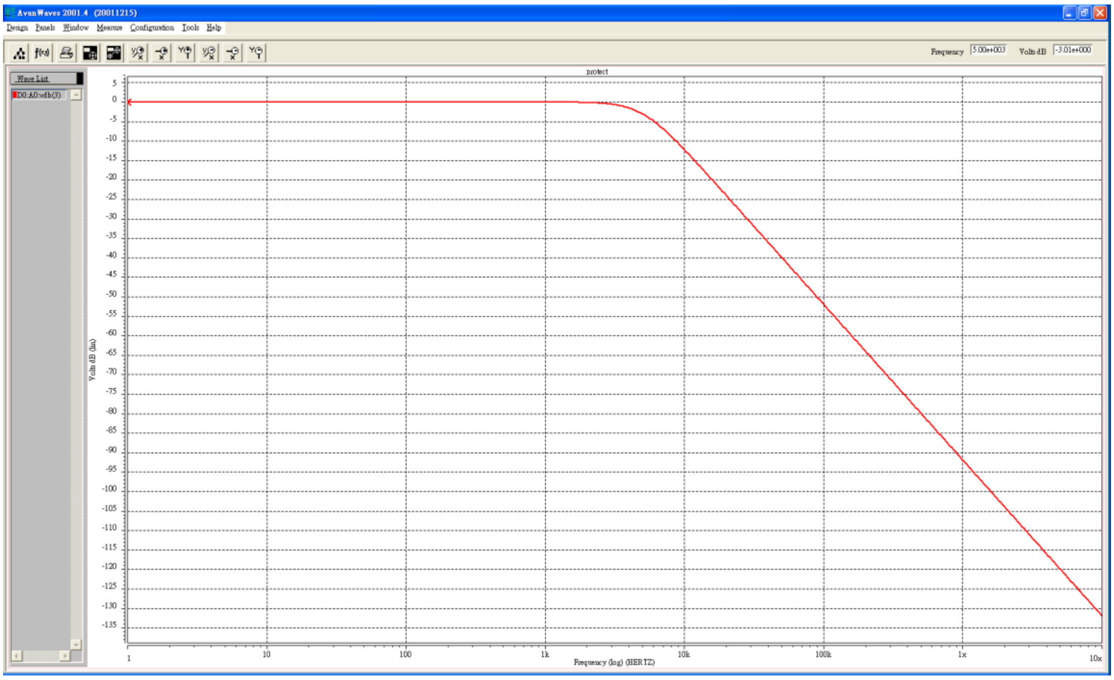

Fig. 43.1-5 The *LCR* low-pass filter transfer function in log scale

The amplifier with the low pass filter is now shoen in Fig. 43.1-6.

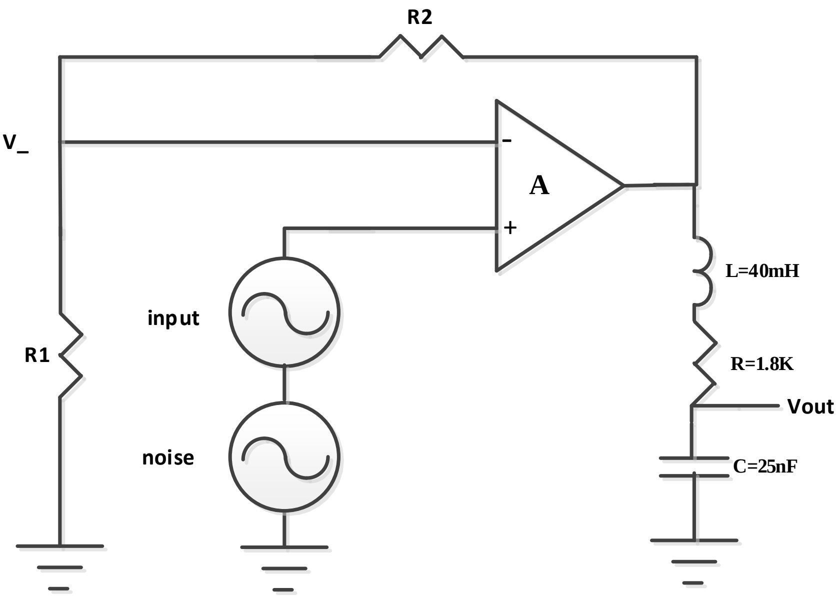

Fig. 43.1-6 The a,plifier with a low pass filter

Experiment 43.1-2 Testing of the Amplifier with a Low Pass Filter

In this experiment, we test the circuit in Fig. 43.1-6 to see whether the noise can be eliminated by the low pass filter. The program is in Table 43.1-2 and the results are in Fig. 43.1-7. The reader can see that the high frequency noise is eliminated.

Table 43.1-2 The program of Experiment 43.1-2

```
NOIN_AM
.protect
.option post
.lib "C:\model\tsmc\MIXED035\mm0355v.l" TT
.unprotect
.op

VDD     VDD!    0     1.5V
VSS     VSS!    0     -1.5V

M1    1    1      VDD!   VDD!   PCH    W=50U    L=2U
M2    2    1      VDD!   VDD!   PCH    W=50U    L=2U
M3    3    3      1      VDD!   PCH    W=50U    L=2U
M4    4    3      2      VDD!   PCH    W=50U    L=2U
M5    3    VB7    5      VSS!   NCH    W=100U   L=2U
M6    4    VB8    6      VSS!   NCH    W=100U   L=2U
M7    5    Vi-    7      VSS!   NCH    W=100U   L=2U
M8    6    Vi+    7      VSS!   NCH    W=100U   L=2U
M9    7    VB9    VSS!   VSS!   NCH    W=100U   L=2U
M10   Vo   4      VDD!   VDD!   PCH    W=150U   L=2U
M11   Vo   VB11   VSS!   VSS!   NCH    W=50U    L=2U

VIN+     Vi+     8    sin(0v 0.0001 1k)
Vnoise   8    0 sin(0v 0.000005 1Meg)

VBIAS7   VB7 0    0.3V
VBIAS8   VB8 0    0.3V
```

```
VBIAS9   VB9 0      -0.95V
VBIAS1 VB11 0      0.1V

C1    10 0 25n
R3    9 10 1.8K
L1 Vo 9 40m

R2           Vi-   Vo    10000k
R1    Vi-    0      1000k

.tf    V(vo)       VIN+
.tran1us  10ms
.end
```

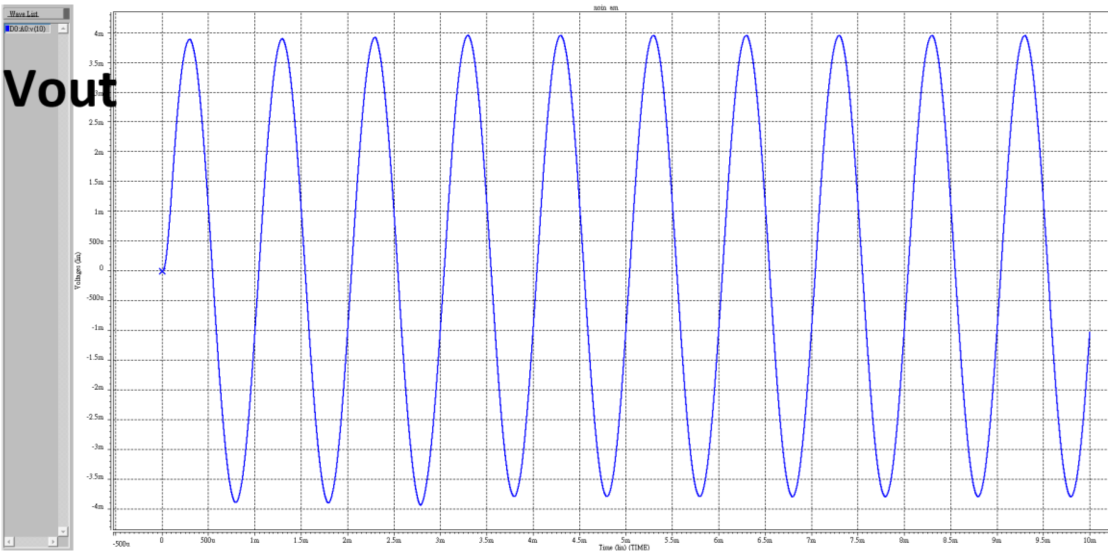

Fig. 43.1-7 The results of Experiment 43.1-2

Section 43.2 Noise Cancellation for High Frequency Amplifiers

If the input signal is a high frequency signal, we need a band pass filter which centers at this input signal frequency. Fig. 43.2-1 shows such a filter,

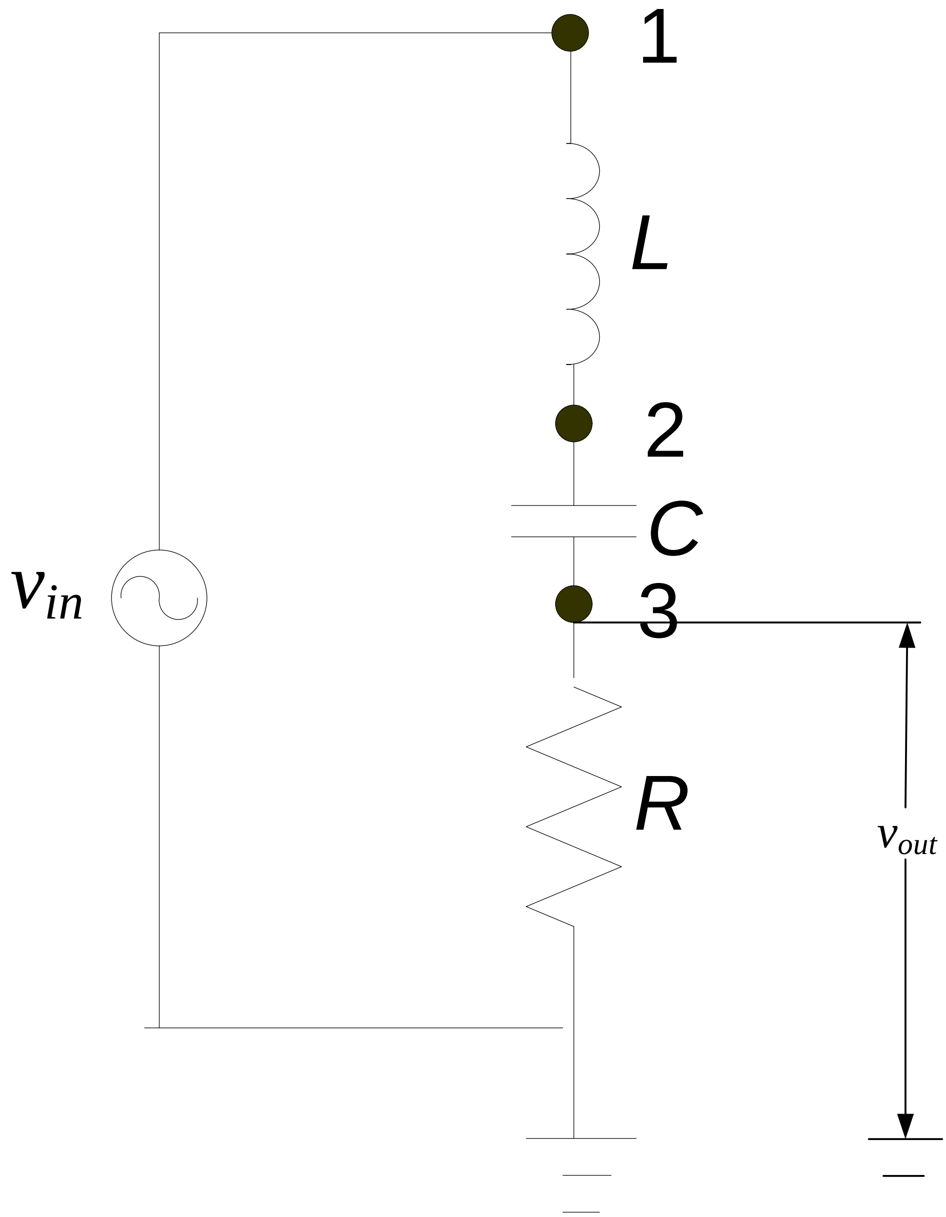

Fig. 43.2-1 An LCR band pass filter

Experiment 43.2-1 A Testing of the Band Pass Filter in Fig. 43.2-1

In this experiment, we test the band pass filter in Fig, 43.2-1. L=0.16 mH, C=0.16 nF and R=1K. The program is in Table 43.2-1 and the transfer function of the filter is in Fig. 43.2-1. We can see that the center frequency of this band pass filter is at 1MHz.

Table 43.2-1 The program of Experiment 43.2-1

```
LCR
.PROTECT
.OPTION POST
.LIB 'c:\mm0355v.l' TT
.UNPROTECT
.op

L      1      2      0.16mH
C      2      3      0.16nF
R      3      0      1k
Vin    1      0      AC          1
.AC    DEC    100    1           1000000k
.PLOT AC VDB(3)
.END
```

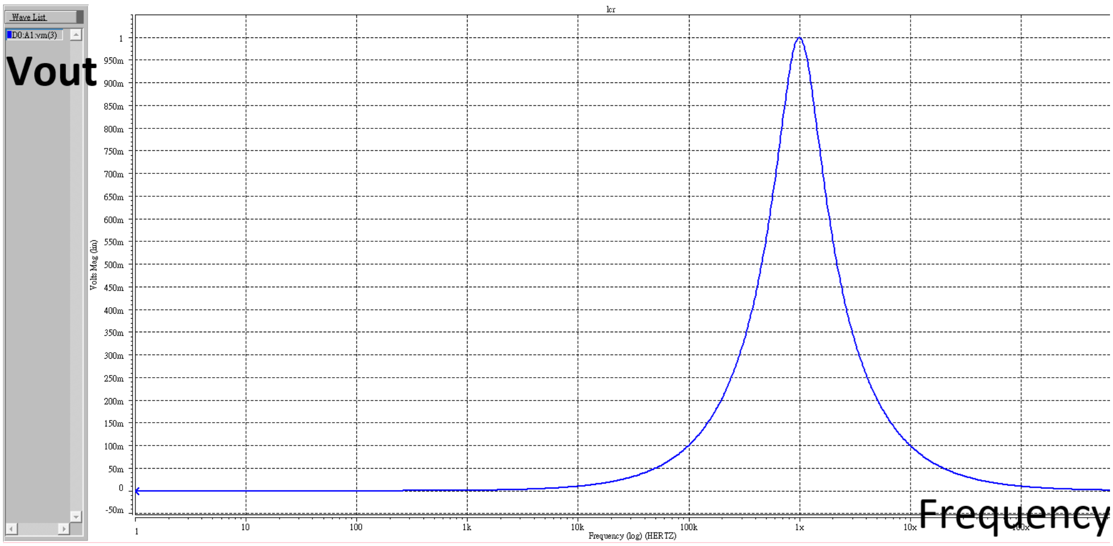

Fig. 43.2-2 The transfer function of the band pass filter in Fig. 43.2-1

The amplifier for our further experiments is in Fig. 43.2-3.

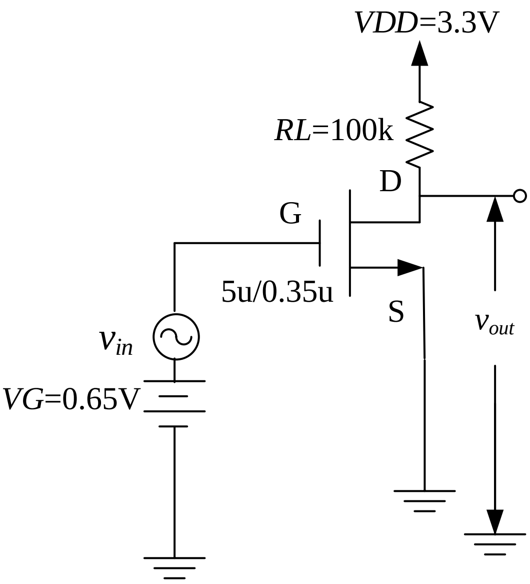

Fig. 43.2-3 An amplifier to test the high frequency input signal with noise

Experiment 43.2-2 A Testing the Amplifier in Fig. 43.2-2

In this experiment, we test the amplifier in Fig. 43.2-3 with input signal frequency at 1MHz. The program is in Table 43.2-2 and the result is Fig. 43.2-4. From the result, we can see that the amplifier can handle input signal with 1MHz frequency.

Table 43.2-2 The program of Experiment 43.2-2

```
Example 6-1
.protect
.lib 'c:\mm0355v.l' TT
.unprotect
.op
.options nomod post

VDD     1    0    3.3V
RL   1    11   100k

.param    W1=5u
M1   11   2    3    0
+nch L=0.35u       W='W1' m=1
+AD='0.95u*W1' PD='2*(0.95u+W1)'
+AS='0.95u*W1' PS='2*(0.95u+W1)'

VG  2    0    0.65v
Vin1 3   0    sin(0 0.01 1Meg)
*.AC     DEC     100  1    10000000k

*.PLOT   AC   VDB(11)
.tran 0.001u 5u
.END
```

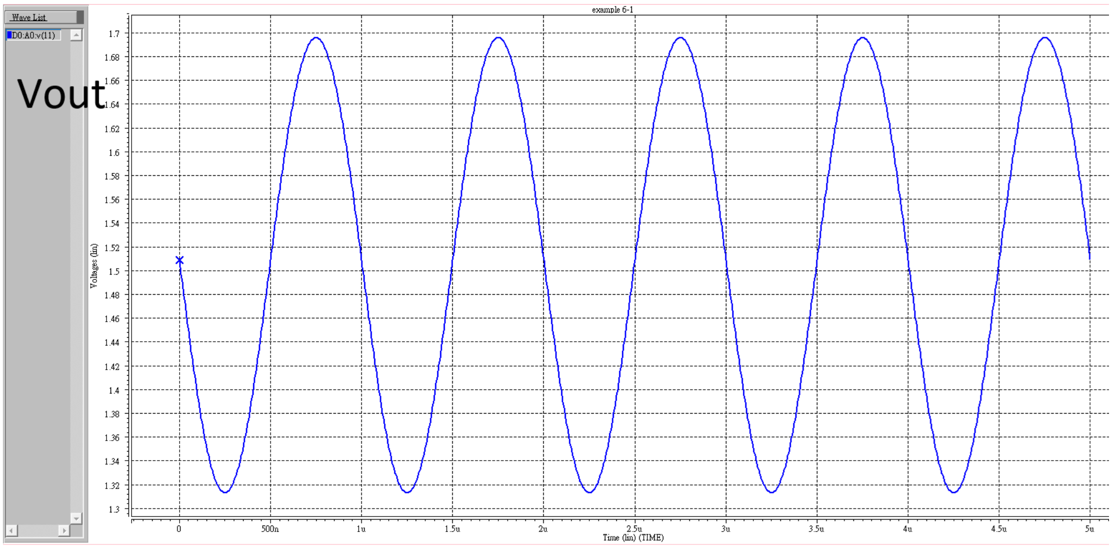

Fig. 43.2-4 The result of Experiment 43.2-2

We then add noise into the amplifier at the input terminal.

Experiment 43.2-3 The Amplifier with Noise

In this experiment, we add noise to the amplifier at the input terminal. The input signal frequency is 1MHz and the noise frequency is 10MHz. The program is in Table 43.2-3 and the result is in Fig. 43.2-5. The noise obviously produces a distorted output.

Table 43.2-3 The program of Experiment 43.2-3

```
Example 6-1
.protect
.lib 'c:\mm0355v.l' TT
.unprotect
.op
.options nomod post

VDD     1     0     3.3V
RL   1     11     100k
```

```
.param    W1=5u
M1  11   2    3    0
+nch L=0.35u       W='W1' m=1
+AD='0.95u*W1' PD='2*(0.95u+W1)'
+AS='0.95u*W1' PS='2*(0.95u+W1)'

VG  2     0     0.65v
Vin13     4     sin(0 0.01 1Meg)
Vin24     0     sin(0 0.001 10Meg)

*.AC      DEC       100  1     10000000k

*.PLOT   AC  VDB(11)
.tran 0.001u 5u
.END
```

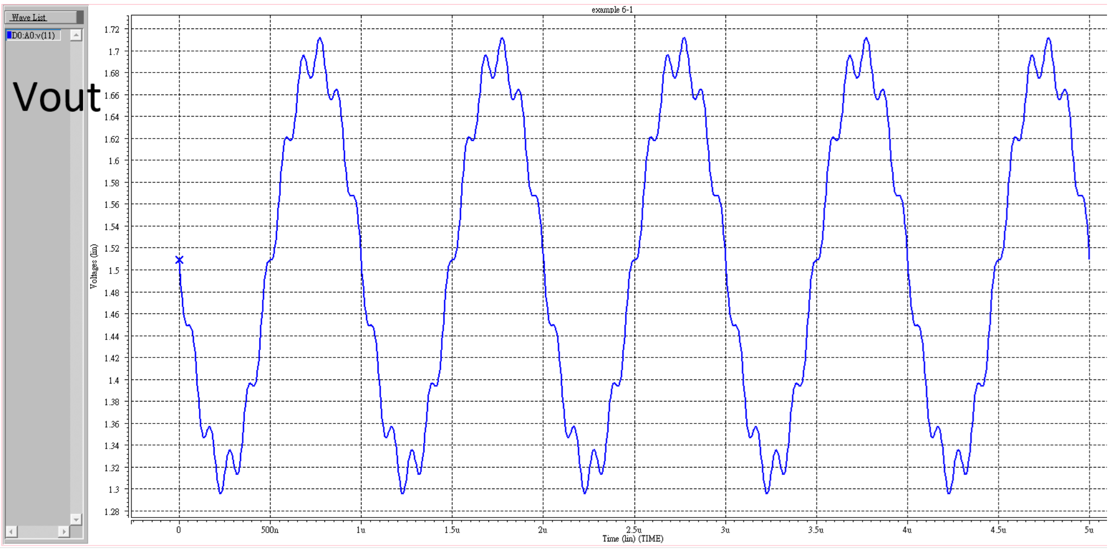

Fig. 43.2-5 The result of Experiment 43.2-3

Experiment 43.2-4 A Testing of the Amplifier with Filter Added

In this experiment, we add the band pass filter in Fig. 43.2-1 to the output terminal with L=0.16mH, C=0.16nF and R=1K.   The program is in Table 43.2-4 and the result is Fig. 42.2-6. We can see that Vout amplitude becomes very small and the noise still exists.

Table 43.2-4 The program of Experiment 43.2-4

```
Example 6-1
.protect
.lib ‘c:\mm0355v.l’ TT
.unprotect
.op
.options nomod post

VDD     1    0    3.3V
RL  1   11   100k

.param   W1=5u
M1  11   2    3    0
+nch L=0.35u       W=’W1’ m=1
+AD=’0.95u*W1’ PD=’2*(0.95u+W1)’
+AS=’0.95u*W1’ PS=’2*(0.95u+W1)’

VG  2    0    0.65v
Vin13    4    sin(0 0.01 1Meg)
Vin24    0    sin(0 0.001 10Meg)

L1      11      12      0.16mH
C1      12      13      0.16nF
R1      13      0       1k

*.AC      DEC      100  1     10000000k

*.PLOT   AC   VDB(11)
.tran 0.001u 35u
.END
```

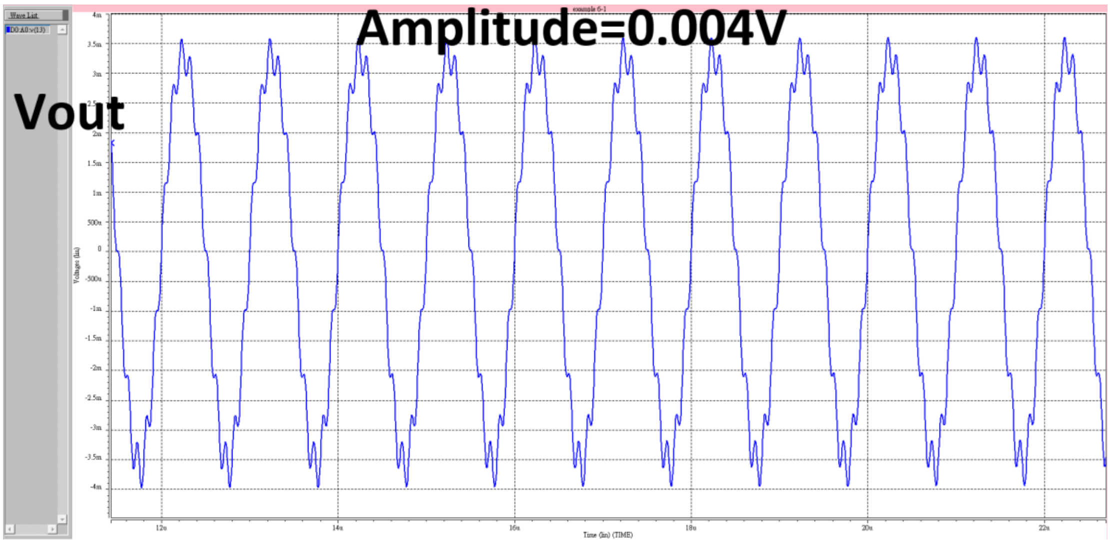

Fig. 43.2-6 The result of Experiment 43.2-4

obviously the amplitude of Vout is too small because the R in this band pass filter is 1K which is too small. Therefore, in the next experiment, we increase R from 1K to 100K.

Experiment 43.2-5 Increasing R in the Band Pass Filter from 1K to 100K.

In this experiment, we increased R in the band pass filter from 1K to 100K. The program is in Table 43.2-5 and the result is in Table 43.2-7. We can see that the amplitude of Vout is improved, but the noise still exists.

Table 43.2-5 The program of Experiment 43.2-5

```
Example 6-1
.protect
.lib ‘c:\mm0355v.l’ TT
.unprotect
.op
.options nomod post
```

```
VDD     1    0    3.3V
RL   1    11   100k

.param   W1=5u
M1   11   2    3    0
+nch L=0.35u       W='W1' m=1
+AD='0.95u*W1' PD='2*(0.95u+W1)'
+AS='0.95u*W1' PS='2*(0.95u+W1)'

VG  2     0    0.65v
Vin13     4    sin(0 0.01 1Meg)
Vin24     0    sin(0 0.001 10Meg)

L1      11      12      0.16mH
C1      12      13      0.16nF
R1      13      0       100k

*.AC     DEC      100  1     10000000k

*.PLOT   AC   VDB(11)
.tran 0.001u 35u
.END
```

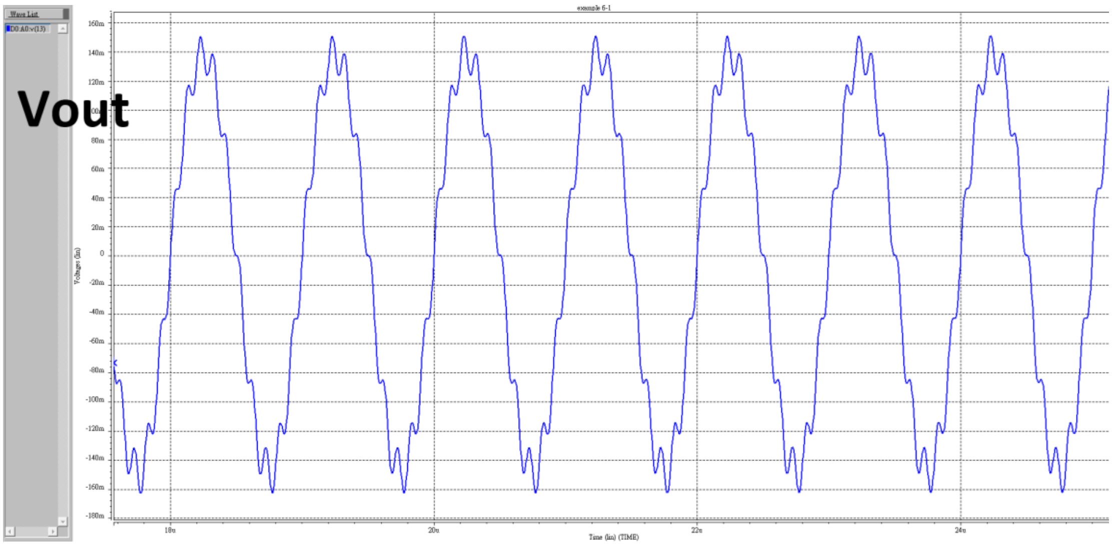

Fig. 43.2-7 The result of Experiment 43.2-7

We examined the transfer function of the band pass filter in Fig. 43-2-2, The gain of the filer at frequency equal to 1MHz is 0.01. Since the noise frequency is 1MHz, this gain is still too high and must be reduced. To do this, we decide to increase the value of Q which is equal to $\frac{1}{R}\sqrt{\frac{L}{C}}$.

Experiment 43.2-6 Testing the Filter with a Larger Q.

In this experiment, we increased the Q value of the band pass filter by increasing L and decreasing C. The parameters of the filter are as follows: L=32mH, C=0.0008nF and R=100K. The program is in Table 43.2-6 and the results are in Fig. 43.2-8 and Fig, 43.2-9.

Table 43.2-6 The program of Experiment 43.2-6

```
Example 6-1
.protect
.lib 'c:\mm0355v.l' TT
.unprotect
.op
.options nomod post

VDD     1    0    3.3V
RL  1   11   100k

.param    W1=5u
M1  11   2    3    0
+nch L=0.35u        W='W1' m=1
+AD='0.95u*W1' PD='2*(0.95u+W1)'
+AS='0.95u*W1' PS='2*(0.95u+W1)'

VG  2    0    0.65v
Vin13    4    sin(0 0.01 1Meg)
```

```
Vin24      0      sin(0 0.001 10Meg)

L1        11        12        32mH
C1        12        13        0.0008nF
R1        13        0        100k

*.AC       DEC        100  1      10000000k

*.PLOT   AC   VDB(11)
.tran 0.001u 35u
.END
```

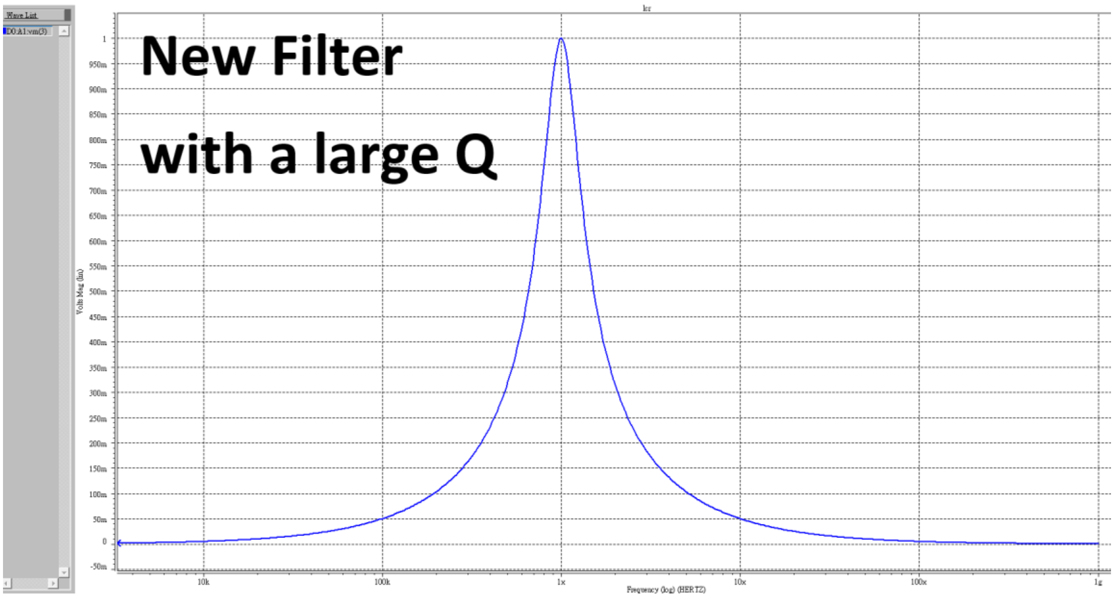

Fig. 43.2-8 The transfer function of the new band pass filter

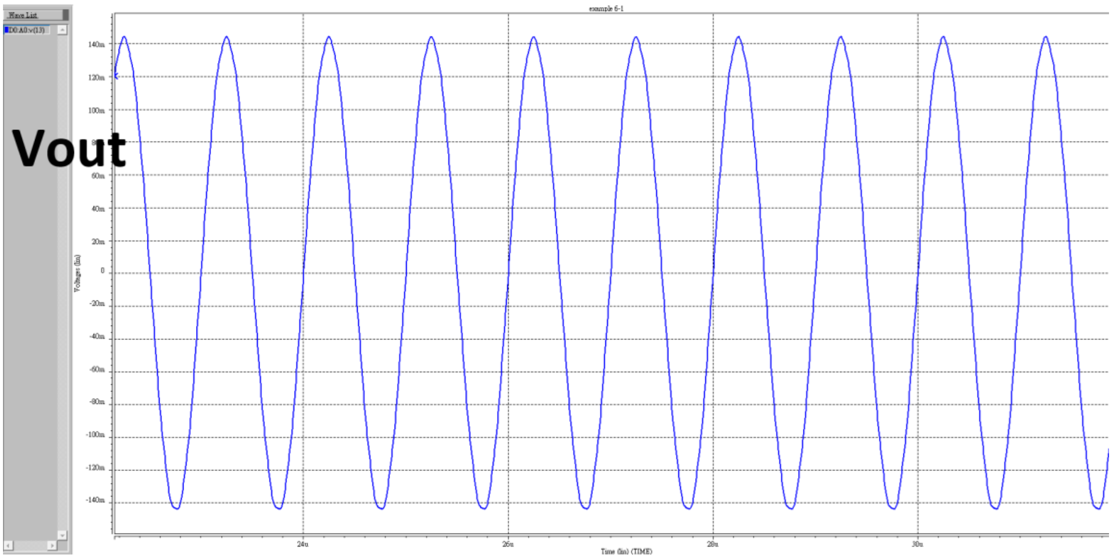

Fig. 43.2-9 The result of Experiment 43.2-8

From Fig. 43.2-8, we can see that the gain of the new bad pass filter with high Q at frequency=10MHz is 0.005. Note that the gain of the old low Q band pass filter at frequency=10M is 0.01. Thus, the noise signal is completely eliminated because of the lowered gain of the filter at 10MHz .

In conclusion, for low frequency input signals, a low pass filter can be used. We of course have to make sure that the low pass filter will significantly reduce the amplitude of the noise signal. For high frequency signals, a band pass filter with center frequency exactly equal to the input signal is needed. Besides, the bandwidth of the band pass filter should be narrow enough to filter out the noise signal. That is, a high Q of the filter is needed.

If one wants to know more about the meaning of the Q value related to filters, he may consult Chapter 11 of this lecture notes.