EE321 Lab 7 - A better transistor amplifier

24th May 2005

1 Purpose

The purpose of this experiment is to use the transistor to make a better amplifier.

2 Overview

Last week, we looked at a simple transistor amplifier. It had some problems that make it unsatisfactory for production. Most notably, the bias point very beta and temperature dependent, and the distortion was high.

This week, we will build and test a better design, that should work reliably in production, over a wide range of beta. It should also have less distortion, at the expense of gain.

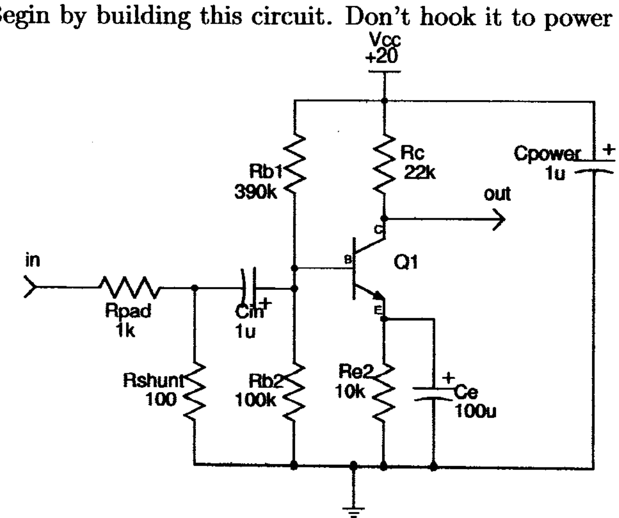
You will build and test two versions of the amplifier. They differ by one capacitor. The first will have high gain and distortion comparable to last time. The second will have lower gain and almost no distortion.

3 Parts and equipment needed

- PN2222 transistor (in the bin incorrectly marked "2N2222")
- Resistors: 100, 1k, 10k, 22k, 100k, 390k
- Capacitors: 1uf (2), 100uf
- scope, signal generator, and power supply on the bench

4 Procedure

Begin by building this circuit. Don't hook it to power yet.



1. Before applying power, connect and set the scope:
   (a) Channel 1 to the base. Set it to:
      i. 1 volts/division
      ii. DC coupled
      iii. 20 MHz bandwidth
      iv. zero level at ~~bottom of screen~~ 1 box below center.
   (b) Set channel 2 to:
      i. 5 volts/division
      ii. DC coupled
      iii. 20 MHz bandwidth
      iv. zero level ~~one box above the bottom.~~ centered
      v. leave it unconnected for now
   (c) Time base to:
      i. .5 milliseconds per division, so later you will see 5 cycles of 1 kHz
      ii. Trigger to:
         A. Channel 2
         B. AC coupled
         C. Level to 0.

2. Before connecting to the circuit, use both the DVM and scope (channel 2) to set the power supply to 20 volts.

3. Connect power to the circuit. Use the scope to verify that the operating point of the transistor is correct:
   (a) $V_C = 13$
   (b) $V_E = 3.2$
   (c) $V_B = 3.9$

4. Set the signal generator to 1 KHz, so you get .01 volts p-p at the base. The purpose of the voltage divider on the input is to achieve this low level.

5. Apply it to the input of the amplifier. Measure the output level and compute the voltage gain. Set the scope to so both waveforms nearly fill the screen. Include a print of the scope screen.

6. Turn up the level to see it clip, then turn it down to just below clipping. Print the waveform.

7. Modify your amplifier by removing Ce.

8. Remove the resistor Rshunt. Set the signal generator for 1 volt p-p at the base. Measure the output level and compute the gain. It should have less gain and less distortion than before. Print the waveform.

9. Increase the input level so the amplifier clips. Set it to just below clipping. It should not be distorted. Print the waveform.

10. Increase the input level to 10 volts p-p. It should be clipping significantly. Print the waveform. Can you explain the strange clipping on the negative peak? Reset the scope, both channels DC coupled, 5 volts per division, position with no signal to one box up from the bottom. Reconnect to your circuit and view the waveform. Print it. Does this help you explain the strange clipping on the negative peak? Try it again at 20 volts p-p input. Print it. How bad does it get?

5 Your report

5.1 Executive summary (on cover)

Show a schematic of your circuit, with the important measurements. The important measurements are: operating point (collector, base, and emitter voltages), gain with emitter bypass, maximum output level without clipping with emitter bypass, gain without emitter bypass, maximum output level without emitter bypass. (7 numbers). This should be shown in a chart with 3 columns. The 3 columns are: measured, calculated, and simulated.

5.2 More detailed summary

Write a paragraph on what you learned, and point out any surprises. Does it do what you expect? Explain. Limit this section to one page.

5.3 Journal

Your report should include a journal of what you did, with enough detail that someone else can repeat your experiment, complete with mistakes.

5.4 Analysis

Based on the theory, calculate what all of the parameters you measured should be. Compare that to your measurements.

5.5 Simulation

Normally you would simulate before building it, but this time you can do it later.

Use a simulator to show the operating point, gain, and waveforms. I have attached my simulation run. Follow it and make the same measurements, substituting the beta (bf) and saturation current (is) of your transistor. You should have these numbers from a previous lab.

Use this model for the transistor:

```
.model 2n2222 npn (is=19f bf=150 vaf=100)
```

```
get lab7s.ckt
* gnetlist -g spice-sdb lab7s.sch
list
*****************************************************************
* Spice file generated by gnetlist                              *
* spice-sdb version 10.9.2004 by SDB --                         *
* provides advanced spice netlisting capability.                *
* Documentation at http://www.brorson.com/gEDA/SPICE/           *
*****************************************************************
```

This netlist came from a schematic — You can type in: gnucap> build

\> } enter the circuit

\>

\>

\> blank line to exit

```
Q1 ( 2 1 3 )  2N2222  area= 1.
Cpower ( 4 0 )  1.u
Rpad ( 5 6 )  1.K
Rb2 ( 0 1 )  100.K
Rb1 ( 1 4 )  390.K
Cin ( 1 6 )  1.u
Rshunt ( 0 6 )  100.
Rc ( 2 4 )  22.K
Ce ( 3 0 )  100.u
Re2 ( 0 3 )  10.K
Vcc ( 4 0 )  DC  20.
Vin ( 5 0 ) GENERATOR
```

Most of this was computer generated — You type: ".model 2n2222 npn IS=19f BF=150 VAF=100"

```
.model  2n2222  npn  (level=1  kf= 0.  af= 1.  bf= 150.  br= 1.  is= 19.f  nf= 1.  nr= 1.  vaf=
100.  isc= 0.  c4= 0.  nc= 2.  ise= 0.  c2= 0.  ne= 1.5  rb= 0.  rbm= 0.  re= 0.  rc= 0.  cjc= 0
.  cje= 0.  cjs= 0.  fc= 0.5  mjc= 0.33  mje= 0.33  mjs= 0.  vjc= 0.75  vje= 0.75  vjs= 0.75  xc
jc= 1.  itf= 0.  ptf= 0.  tf= 0.  tr= 0.  xtf= 0.  xtb= 0.  xti= 3.  eg= 1.11)
*+()
print op v(nodes)
op
#          v(1)       v(2)       v(3)       v(4)       v(5)       v(6)
 300.15    3.9211     12.755     3.3135     20.        0.         0.
width out=80
print op vce(q1) vbe(q1)
op
#          vce(Q1)    vbe(Q1)
 300.15    9.4412     0.60758
```

Operating point

```
print ic(q1) ib(q1)
print op ic(q1) ib(q1)
op
#          ic(Q1)     ib(Q1)
 300.15    329.33u    2.0173u
print gm(q1)
print op gm(q1)
op
#          gm(Q1)
 300.15    0.01273
```

Gain = 262

AC Analysis — GAIN

```
print ac v(nodes)
ac 1k
#Freq      v(1)       v(2)       v(3)       v(4)       v(5)       v(6)
 1.K       0.090137   23.664     0.0017231  10.754n    1.         0.090167
fault ce=0
op
#          gm(Q1)
 300.15    0.01273
ac 1k
#Freq      v(1)       v(2)       v(3)       v(4)       v(5)       v(6)
 1.K       0.0908     0.19674    0.090029   87.1p      1.         0.0908
unfault
plot tran v(2)(0,20)
tran 0 .001 .00001
```

Temporarily set C_E to 0

Do op again to set bias — "power on"

AC analysis

Gain = 2.17

ON TO transient analysis

set C_E back to old value

```
get lab7s.ckt
* gnetlist -g spice-sdb lab7s.sch
list
*********************************************************
* Spice file generated by gnetlist                      *
* spice-sdb version 10.9.2004 by SDB --                 *
* provides advanced spice netlisting capability.        *
* Documentation at http://www.brorson.com/gEDA/SPICE/   *
*********************************************************
Q1 ( 2 1 3 )  2N2222  area= 1.
Cpower ( 4 0 )  1.u
Rpad ( 5 6 )  1.K
Rb2 ( 0 1 )  100.K
Rb1 ( 1 4 )  390.K
Cin ( 1 6 )  1.u
Rshunt ( 0 6 )  100.
Rc ( 2 4 )  22.K
Ce ( 3 0 )  100.u
Re2 ( 0 3 )  10.K
Vcc ( 4 0 )  DC  20.
Vin ( 5 0 ) GENERATOR
.model  2n2222  npn  (level=1  kf= 0.  af= 1.  bf= 150.  br= 1.  is= 19.f  nf= 1.  nr= 1.  v
af= 100.  isc= 0.  c4= 0.  nc= 2.  ise= 0.  c2= 0.  ne= 1.5  rb= 0.  rbm= 0.  re= 0.  rc= 0.
  cjc= 0.  cje= 0.  cjs= 0.  fc= 0.5  mjc= 0.33  mje= 0.33  mjs= 0.  vjc= 0.75  vje= 0.75  v
js= 0.75  xcjc= 1.  itf= 0.  ptf= 0.  tf= 0.  tr= 0.  xtf= 0.  xtb= 0.  xti= 3.  eg= 1.11)
*+()
print op v(nodes)
op
#            v(1)         v(2)         v(3)         v(4)         v(5)         v(6)
 300.15      3.9211       12.755       3.3135       20.          0.           0.
width out=80
print op vce(q1) vbe(q1)
op
#            vce(Q1)      vbe(Q1)
 300.15      9.4412       0.60758
print ic(q1) ib(q1)
print op ic(q1) ib(q1)
op
#            ic(Q1)       ib(Q1)
 300.15      329.33u      2.0173u
print gm(q1)
print op gm(q1)
op
#            gm(Q1)
 300.15      0.01273
print ac v(nodes)
ac 1k
#Freq        v(1)         v(2)         v(3)         v(4)         v(5)         v(6)
 1.K         0.090137     23.664       0.0017231    10.754n      1.           0.090167
fault ce=0
op
#            gm(Q1)
 300.15      0.01273
ac 1k
#Freq        v(1)         v(2)         v(3)         v(4)         v(5)         v(6)
 1.K         0.0908       0.19674      0.090029     87.1p        1.           0.0908
unfault
plot tran v(2)(0,20)
tran 0 .001 .00001
v(2)    0.          5.           10.         15.          20.
        +-----------+------------+-----------+------------+
0.      |           .            .      *    .            |
10.u    |       *   .            .           .            |
20.u    |       *   .            .           .            |
30.u    |       *   .            .           .            |
40.u    |       *   .            .           .            |
50.u    |       *   .            .           .            |
60.u    |       *   .            .           .            |
70.u    |       *   .            .           .            |
80.u    |       *   .            .           .            |
90.u    |       *   .            .           .            |
100.u   |       *   .            .           .            |
110.u   |       *   .            .           .            |
120.u   |       *   .            .           .            |
130.u   |       *   .            .           .            |
140.u   |       *   .            .           .            |
150.u   |       *   .            .           .            |
160.u   |       *   .            .           .            |
170.u   |       *   .            .           .            |
180.u   |       *   .            .           .            |
190.u   |       *   .            .           .            |
200.u   |       *   .            .           .            |
210.u   |       *   .            .           .            |
220.u   |       *   .            .           .            |
230.u   |       *   .            .           .            |
240.u   |       *   .            .           .            |
250.u   |       *   .            .           .            |
260.u   |       *   .            .           .            |
270.u   |       *   .            .           .            |
280.u   |       *   .            .           .            |
290.u   |       *   .            .           .            |
300.u   |       *   .            .           .            |
310.u   |       *   .            .           .            |
320.u   |       *   .            .           .            |
330.u   |       *   .            .           .            |
340.u   |       *   .            .           .            |
350.u   |       *   .            .           .            |
360.u   |       *   .            .           .            |
370.u   |       *   .            .           .            |
380.u   |       *   .            .           .            |
390.u   |       *   .            .           .            |
400.u   |       *   .            .           .            |
410.u   |       *   .            .           .            |
420.u   |       *   .            .           .            |
430.u   |       *   .            .           .            |
440.u   |       *   .            .           .            |
450.u   |       *   .            .           .            |
460.u   |       *   .            .           .            |
470.u   |       *   .            .           .            |
480.u   |       *   .            .           .            |
490.u   |       *   .            .           .            |
500.u   |       *   .            .           .            |
510.u   |       *   .            .           .            |
520.u   |       *   .            .           .            |
530.u   |       *   .            .           .            |
540.u   |       *   .            .           .            |
550.u   |       *   .            .           .            |
560.u   |       *   .            .           .            |
570.u   |       *   .            .           .            |
```

?

I forgot to set input

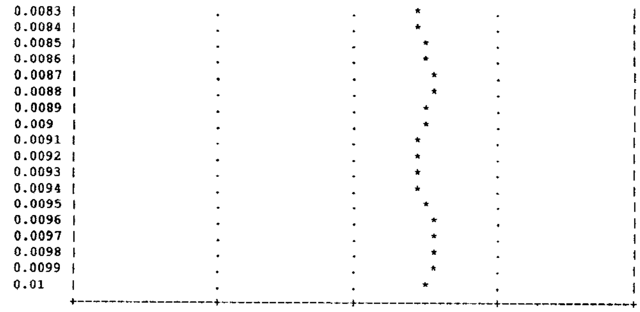
page of errors omitted.

gen ampl=.01

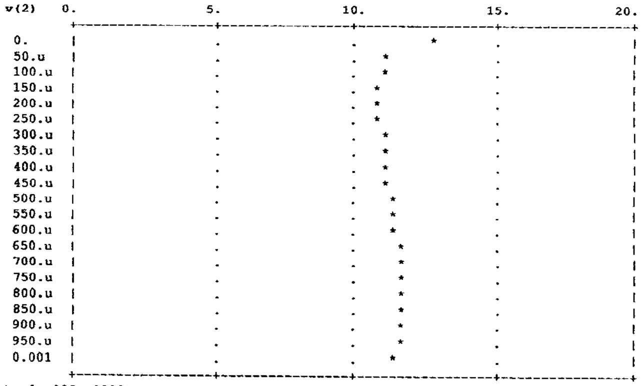
```
0.007   |           .            .    *      .            |
0.0071  |           .            .    *      .            |
0.0072  |           .            .    *      .            |
0.0073  |           .            .    *      .            |
0.0074  |           .            .    *      .            |
0.0075  |           .            .    *      .            |
0.0076  |           .            .    *      .            |
0.0077  |           .            .     *     .            |
0.0078  |           .            .     *     .            |
0.0079  |           .            .     *     .            |
0.008   |           .            .     *     .            |
0.0081  |           .            .     *     .            |
0.0082  |           .            .     *     .            |
0.0083  |           .            .     *     .            |
0.0084  |           .            .     *     .            |
0.0085  |           .            .     *     .            |
0.0086  |           .            .     *     .            |
0.0087  |           .            .     *     .            |
0.0088  |           .            .     *     .            |
0.0089  |           .            .     *     .            |
0.009   |           .            .     *     .            |
0.0091  |           .            .     *     .            |
0.0092  |           .            .     *     .            |
0.0093  |           .            .     *     .            |
0.0094  |           .            .     *     .            |
0.0095  |           .            .     *     .            |
0.0096  |           .            .     *     .            |
0.0097  |           .            .     *     .            |
0.0098  |           .            .     *     .            |
0.0099  |           .            .     *     .            |
0.01    |           .            .     *     .            |
        +-----------+------------+-----------+------------+
gen freq=1k
tr 0
v(2)    0.          5.           10.         15.          20.
        +-----------+------------+-----------+------------+
0.      |           .            .      *    .            |
100.u   |           .            .  *        .            |
200.u   |           .            . *         .            |
300.u   |           .            .  *        .            |
400.u   |           .            .  *        .            |
500.u   |           .            .  *        .            |
600.u   |           .            .  *        .            |
700.u   |           .            .   *       .            |
800.u   |           .            .   *       .            |
900.u   |           .            .   *       .            |
0.001   |           .            .  *        .            |
0.0011  |           .            .  *        .            |
0.0012  |           .            .  *        .            |
0.0013  |           .            .  *        .            |
0.0014  |           .            .  *        .            |
0.0015  |           .            .   *       .            |
0.0016  |           .            .   *       .            |
0.0017  |           .            .    *      .            |
0.0018  |           .            .    *      .            |
0.0019  |           .            .    *      .            |
0.002   |           .            .   *       .            |
0.0021  |           .            .   *       .            |
0.0022  |           .            .  *        .            |
0.0023  |           .            .   *       .            |
0.0024  |           .            .   *       .            |
0.0025  |           .            .    *      .            |
0.0026  |           .            .    *      .            |
0.0027  |           .            .    *      .            |
0.0028  |           .            .    *      .            |
0.0029  |           .            .    *      .            |
0.003   |           .            .    *      .            |
0.0031  |           .            .   *       .            |
0.0032  |           .            .   *       .            |
0.0033  |           .            .   *       .            |
0.0034  |           .            .    *      .            |
0.0035  |           .            .    *      .            |
0.0036  |           .            .    *      .            |
0.0037  |           .            .    *      .            |
0.0038  |           .            .    *      .            |
0.0039  |           .            .    *      .            |
0.004   |           .            .    *      .            |
0.0041  |           .            .    *      .            |
0.0042  |           .            .    *      .            |
0.0043  |           .            .    *      .            |
0.0044  |           .            .    *      .            |
0.0045  |           .            .    *      .            |
0.0046  |           .            .    *      .            |
0.0047  |           .            .     *     .            |
0.0048  |           .            .     *     .            |
0.0049  |           .            .    *      .            |
0.005   |           .            .    *      .            |
0.0051  |           .            .    *      .            |
0.0052  |           .            .    *      .            |
0.0053  |           .            .    *      .            |
0.0054  |           .            .    *      .            |
0.0055  |           .            .    *      .            |
0.0056  |           .            .     *     .            |
0.0057  |           .            .     *     .            |
0.0058  |           .            .     *     .            |
0.0059  |           .            .     *     .            |
0.006   |           .            .    *      .            |
0.0061  |           .            .    *      .            |
0.0062  |           .            .   *       .            |
0.0063  |           .            .   *       .            |
0.0064  |           .            .    *      .            |
0.0065  |           .            .    *      .            |
0.0066  |           .            .     *     .            |
0.0067  |           .            .     *     .            |
0.0068  |           .            .     *     .            |
0.0069  |           .            .     *     .            |
0.007   |           .            .    *      .            |
0.0071  |           .            .    *      .            |
0.0072  |           .            .    *      .            |
0.0073  |           .            .    *      .            |
0.0074  |           .            .    *      .            |
0.0075  |           .            .     *     .            |
0.0076  |           .            .     *     .            |
0.0077  |           .            .     *     .            |
0.0078  |           .            .     *     .            |
0.0079  |           .            .     *     .            |
0.008   |           .            .    *      .            |
0.0081  |           .            .    *      .            |
0.0082  |           .            .    *      .            |
```

Got it Now.

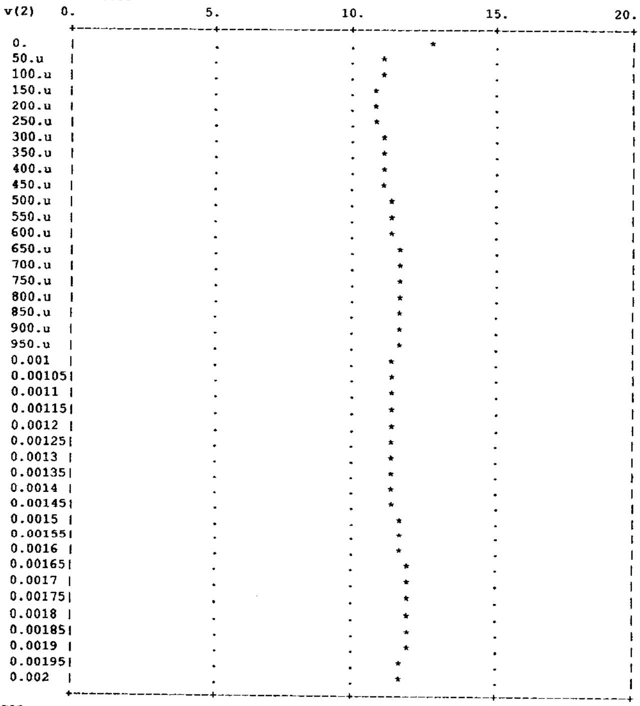
Level too low



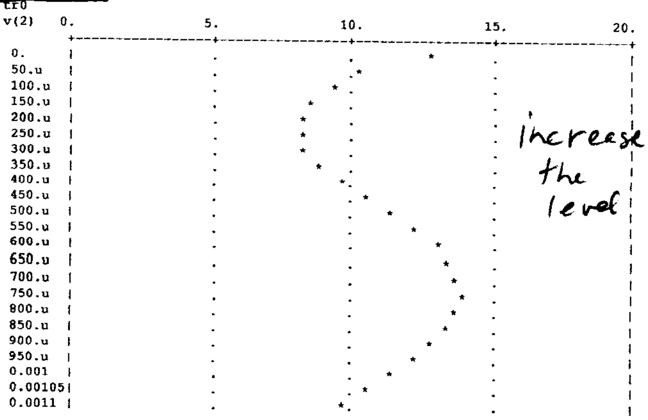
tr 0 .001 .00005



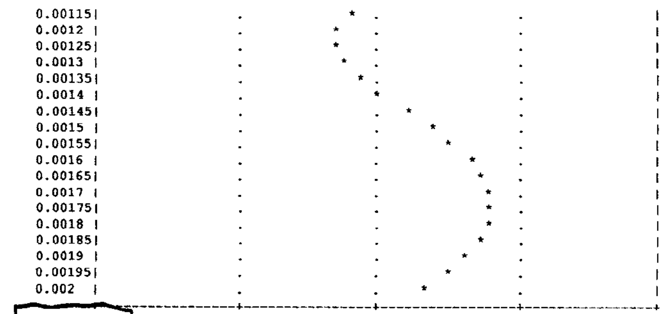
tr 0 .002 .00005



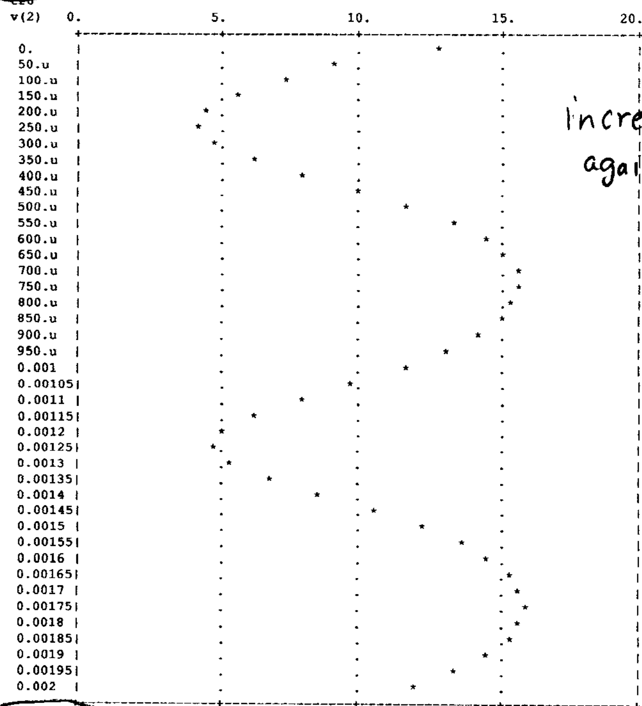
gen
freq= 1.K ampl= 0.01 phase= 0. max= 1. min= 0. offset= 0.
+ init= 0. rise= 1.p fall= 1.p delay= 0. width= 0. period= 0.
gen ampl=.1
tr0



Increase the level

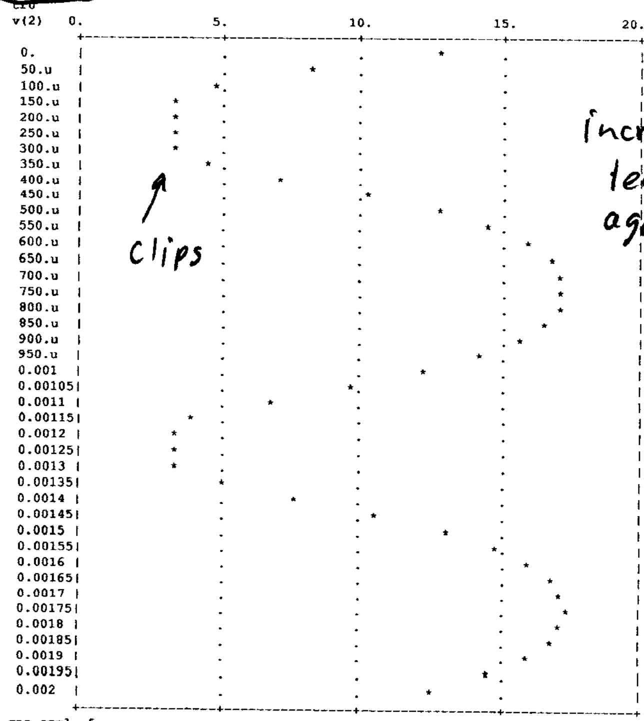


gen ampl=.2
tr0



increase again

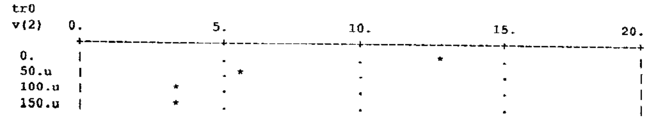
gen ampl=.3
tr0

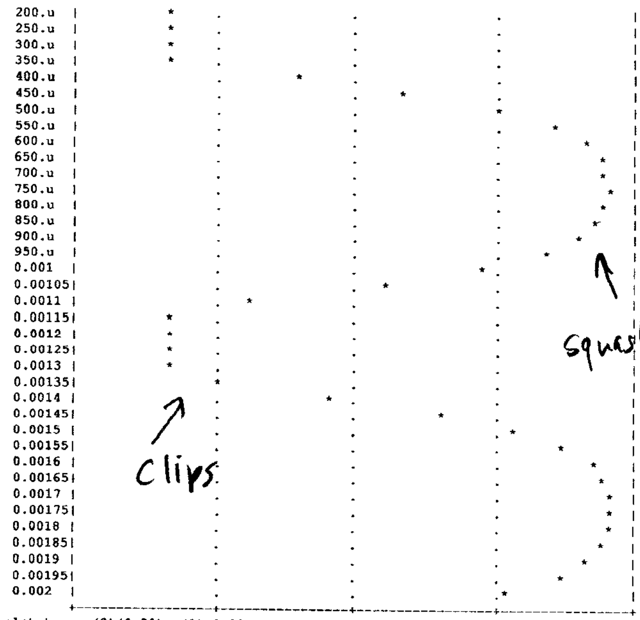


Clips

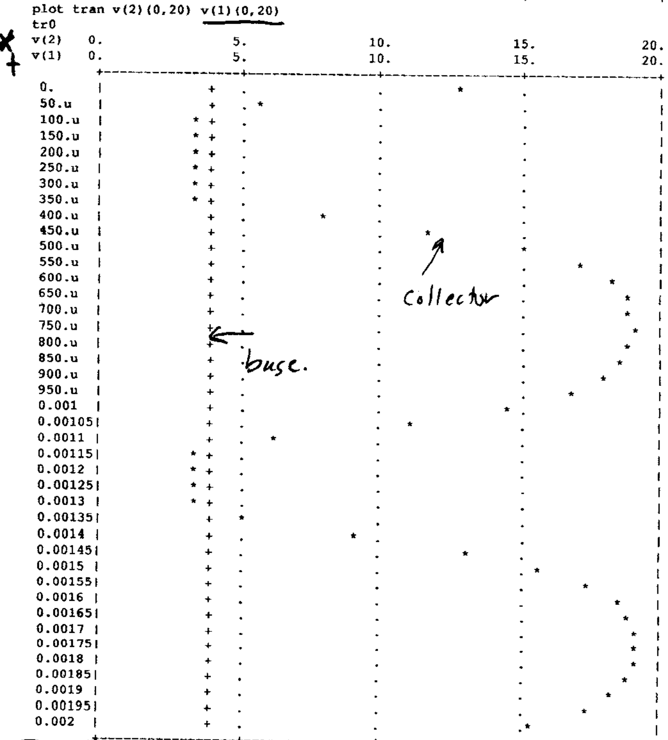
Increase level again.

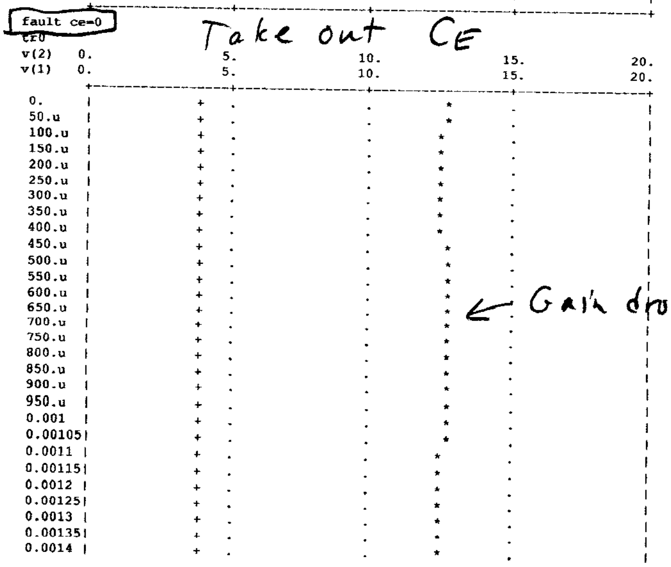
gen ampl=.5
tr0

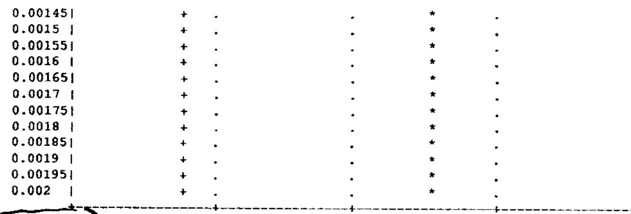


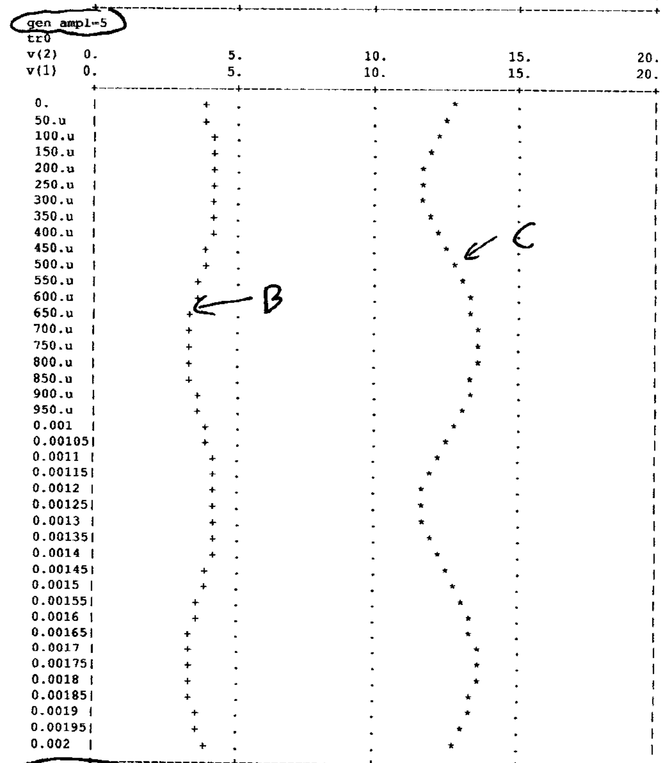


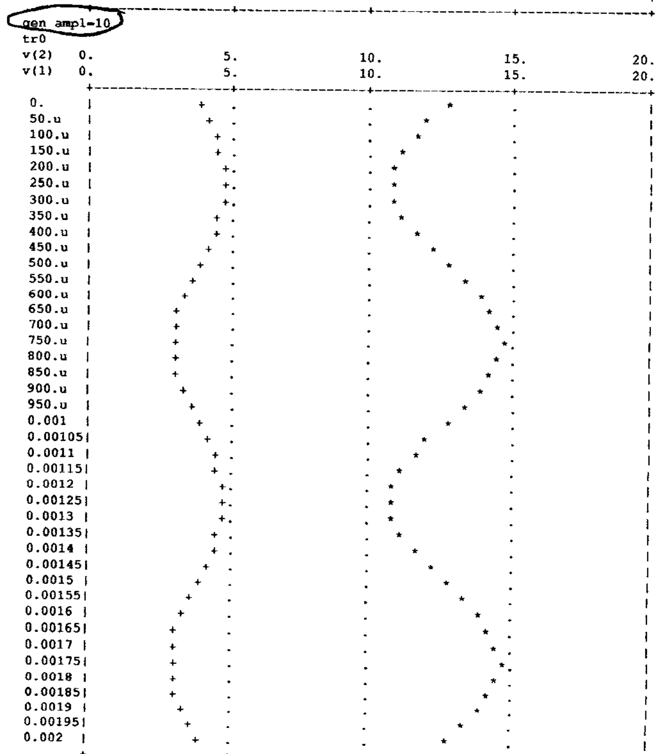
plot tran v(2)(0,20) v(1)(0,20)

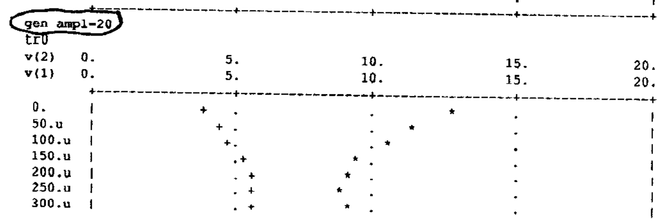


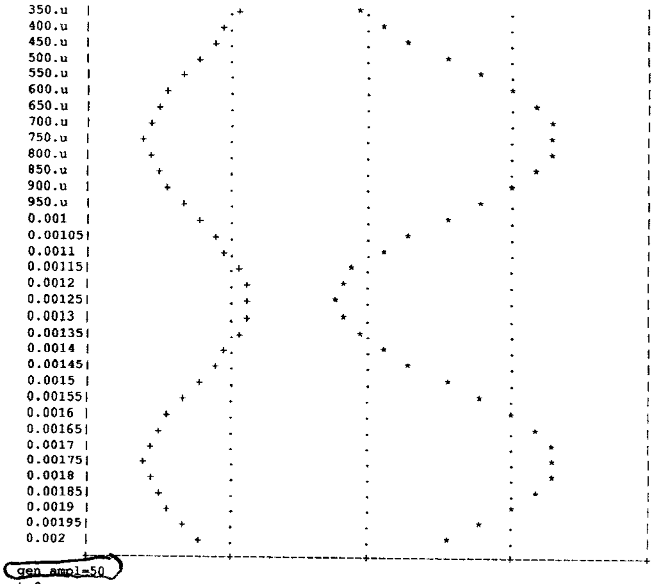












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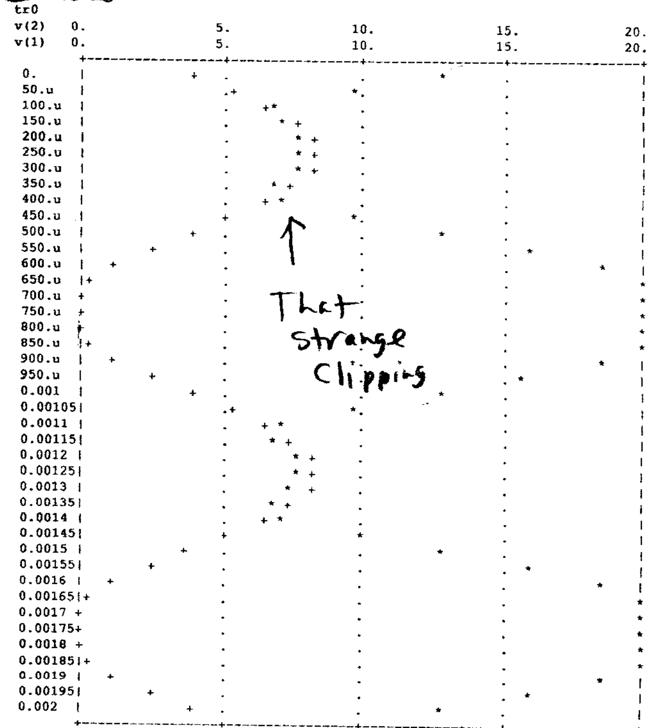

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