*=============BiCMOS_MIRROR_CASCODE=============================

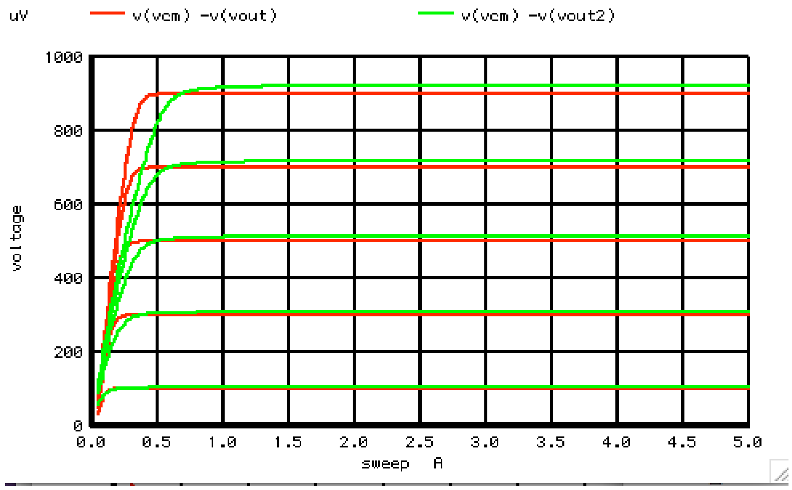
The early voltage of CMOS transistors is not very high
for short channel lengths. As a result, CMOS transistors
are usually in series which cascode stages. The quality
of a current mirror stage could include the following.

1)How high is the output impedance?
2)How good is the current match?
3)What is the current dynamic range?
4)How low can the output swing?
5)How much supply voltage is required?
6)How much silicon area is required?

A simple CMOS cascode mirror shown below on the right
is being simulated next to a BiCMOS Cascode current
mirror on the left. This BiCMOS current mirror
is being used as a standard for comparison.
Both are being done using about the same area.

```
======================================================================
*
*                        __________________/\  /\  /\__
*  IIN  ____________    |   ROUT             \/  \/    |
*     _|_       _|_ |   |_/\  /\  /\__   ROUT2   VOUT2 |
*    / _ \     /VCC\|  _|_  \/  \/   |                 |
*    \/ \/     \___/| /OUT\          |                 |
*    /\_/\      _|_ | \___/    VOUT  |    _|_          |
*    \___/      /// |  _|_           |   /BIN\         |
*      | VG         |  ///           |   \___/ VG2     |
*      |_____  MN2  |      __________|     |_____      |
*      |_   |      _|    _| MN3         MN4|_   |     _|
*   MN1  ||_|____||____||                ____||_|___|| MN5
*     ___||   |  ||___ ||___              ___||     ||___
*      <-||   |  ||->  ||->                <-||     ||->
*  VCN1|     _|_    |     |VCN2   VDN6 ____|           |VDN7
*      |  C1 ___    |     |           |   _|MN6 VG3   _|
*      |_     |     |    _|           |_||__________|| MN7
*   QN1  `|___|_____|__|'   QN2   _|_   ||__        ||__
*      <-'|     VB     |`->      /VAJ\  ||->        ||->
*      |__________________|      \___/     |___________|
*          _|_                    _|_     _|_
*          ///   BiCMOS           ///     ///  CMOS Only
======================================================================
```

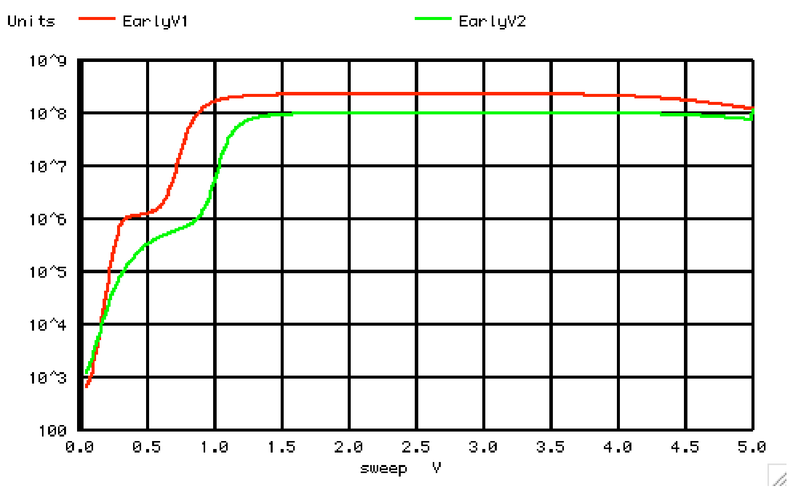
Both current mirrors have high output impedance.
The BiCMOS current mirror is coming a lot closer
to perfection since for their size bipolar transistors
have much better match, much higher early voltage,
much lower resistances, and much higher current
dynamic range. Having this BiCMOS output as a background
makes it easy to see whether any adjust in L or W
improve the CMOS current mirror. What does it take
for instance for the CMOS only stage to swing closer
to ground? Well it takes area.



Spice has a derivative function which can make it possible to view the effective early voltage of each stage.

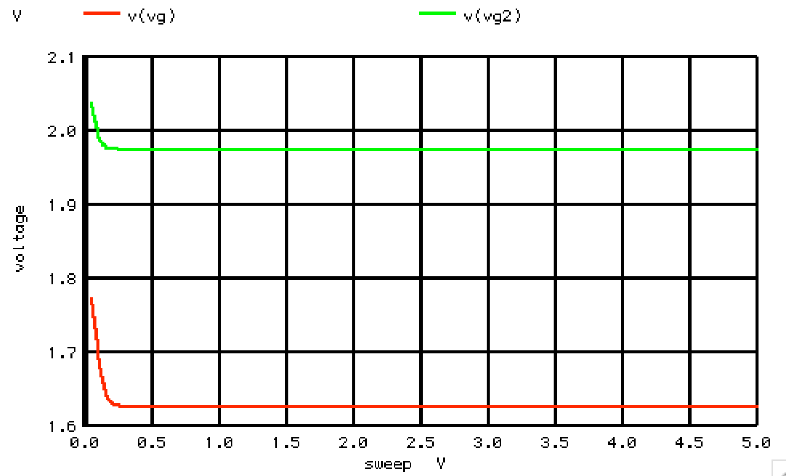
```
let      EarlyV1 =     1/deriv(v(vcm) -v(vout))
let      EarlyV2 =     1/deriv(v(vcm) -v(vout2))
```

The early voltages of both current mirrors are pretty high. When the output stage's voltage drops, the CMOS cascodes are going from current mode to resistor mode, and this shows up on the early voltage plots.



This CMOS cascode stage is making no effort to lower the required supply voltage. Two threshold voltages are required compared to the BiCMOS's need of a diode and a threshold.

```
*
*                       _________________/\  /\  /\__
*  IIN  ____________    |  ROUT           \/  \/    |
*      _|_       _|_   |_/\  /\  /\__   ROUT2   VOUT2 |
*     / _ \     /VCC\  |   \/  \/   |                 |
*     \/ \/     \___/ /OUT\         |                 |
*     /\_/\      _|_  \___/   VOUT  |      _|_        |
*     \___/      ///   _|_          |     /BIN\       |
*       |  VG          ///          |     \___/ VG2   |
*       |_____  MN2  |      ________|       |_____    |
*       |    |       |     _| MN3      MN4  |    |    |
*  MN1  |_ || |______||____||_               _||_|___||_ MN5
*      ___||_|  |    ||___ ||___           ___||      ||___
*      <- ||    |    ||->  ||->            <- ||      ||->
*  VCN1 |      _|_    |      |VCN2   VDN6 ____|       |VDN7
*       |  C1  ___    |      |           |    |MN6 VG3 |
*       |_      |     |     _|           |_ ||_______ _|MN7
*  QN1    `  |__|_____|___|'   QN2    _|_  ||______||
*      <-'|    VB      |`->       /VAJ\  ||->     ||->
*       |__________________|       \___/   |________|
*                 _|_               _|_   _|_
*                 ///   BiCMOS      ///   ///  CMOS Only
```



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What is not being plotted is current dynamic range because CMOS operation may be questionable in the subthresshold region. Bipolar transistors in a BiCMOS process can work from several milliamps to pico-amps.

===========Full_Netlist_For_Copy_Paste========================

```
BiCMOS_MIRROR_TESTS_0
*
*                       _________________/\  /\  /\__
*  IIN  ____________    |  ROUT           \/  \/    |
*      _|_       _|_   |_/\  /\  /\__   ROUT2   VOUT2 |
*     / _ \     /VCC\  |   \/  \/   |                 |
*     \/ \/     \___/ /OUT\         |                 |
*     /\_/\      _|_  \___/   VOUT  |      _|_        |
*     \___/      ///   _|_          |     /BIN\       |
*       |  VG          ///          |     \___/ VG2   |
*       |_____  MN2  |      ________|       |_____    |
*       |    |       |     _| MN3      MN4  |    |    |
*  MN1  |_ || |______||____||_               _||_|___||_ MN5
*      ___||_|  |    ||___ ||___           ___||      ||___
*      <- ||    |    ||->  ||->            <- ||      ||->
*  VCN1 |      _|_    |      |VCN2   VDN6 ____|       |VDN7
*       |  C1  ___    |      |           |    |MN6 VG3 |
*       |_      |     |     _|           |_ ||_______ _|MN7
*  QN1    `  |__|_____|___|'   QN2    _|_  ||______||
*      <-'|    VB      |`->       /VAJ\  ||->     ||->
*       |__________________|       \___/   |________|
*                 _|_               _|_   _|_
*                 ///               ///   ///
*
*
VCC        VCC     0       DC      5V
RIN        VCC     VCC2    1
```

```
IIN       VCC2   VG     DC     100u
VCM       VCM    0      DC     5V
IB        VB     0      DC     1u
BIN       VCC    VG2    I      = v(vcc)-v(vcc2)
ROUT      VCM    VOUT          1
C1        VG     VB            1p
IA        VB2    0      600u
MN1       VG     VG     VCN1   0      NMOSC   W=100u  L=1u
MN2       VCC2   VG     VB     0      NMOSC   W=30u   L=1u
MN3       VOUT   VG     VCN2   0      NMOSC   W=100u  L=1u
MN4       VG2    VG2    VDN6   0      NMOSC   W=100u  L=1u
MN5       VOUT2  VG2    VDN7   0      NMOSC   W=100u  L=1u
MN6       VDN6   VDN6   0      0      NMOSC   W=100u  L=1u
MN7       VDN7   VDN6   0      0      NMOSC   W=100u  L=1u
VAJ       VG3    0      DC     2
ROUT2     VCM    VOUT2         1
*MN1      VG     VG     VCN1   0      NMOSC   W=300u  L=1u AD=7p AS=7p PD=10u PS=10u
QN1       VCN1   VB     0      NPNV   10.00
QN2       VCN2   VB     0      NPNV   10.00
.model    NPN1   NPN(   BF=2100       VAF=216 )
.control
*DC       SOURC1 VSTART VSTOP  VSTEP  SOURC2 START2 STOP2  STEP2
 dc       vcm    .05V   5V     .01V   iin    100uA  1000uA 200uA
 plot     v(vcm) -v(vout)      v(vcm) -v(vout2)
*DC       SOURC1 VSTART VSTOP  VSTEP  SOURC2 START2 STOP2  STEP2
 dc       vcm    .05V    5V    .01V
 let      EarlyV1 =     1/deriv(v(vcm) -v(vout))
 let      EarlyV2 =     1/deriv(v(vcm) -v(vout2))
 plot     EarlyV1       EarlyV2        ylog
 plot     v(vg)   v(vg2)
.endc

.MODEL    NPNV     NPN(
+ IS=15.51E-18     NF=1.005     BF=110      VAF=130.2    IKF=0.0057
+                  NR=1.006     BR=0.4822   VAR=4.286    IKR=0.0002472
+ ISE=9.15E-17     NE=2
+ ISC=1E-21        NC=2
+ RB=732           RBM=441.2                             IRB=7.5E-04
+ RE=15.33         RC=109.1
+ CJE=1.727E-14    VJE=0.6408   MJE=0.2563
+ CJC=1.826E-14    VJC=0.6399   MJC=0.3531
+ CJS=2.939E-14    VJS=0.3488   MJS=0.1813  XCJC=0.4201
+ TF=1.65E-11      XTF=1.25     VTF=1       ITF=0.003532
+ TR=6E-09         FC=0.88      PTF=205
+ KF=1.000E-16     AF=1
+ XTB=2            EG=1.11      XTI=5       TNOM=25       )
.model             NMOSC               NMOS(
+ Level=  8        Tnom=27.0
*------------------Process-----------------------------------------
+ tox=160e-10      xj=0.25e-06         nch=0.5e+17
*------------------V_threshold-------------------------------------
+ vth0=0.72        nlx=0.12e-06
*------------------Bulk--------------------------------------------
+ k1=1.04          k2=-1.209E-01
+ cdsc=-2.4E-4     cdscd=-1.506E-04    cdscb=-2.219E-04
*------------------mobility----------------------------------------
+ u0=678           ua=8.964e-10
+ ub=1.472e-18     uc=-4.441E-17       vsat=86000
*------------------Subthresshold-----------------------------------
+ nfactor=1.8
+ cit=-5.0E-04     voff=-7.862E-02
+ eta0=4.441e-16   etab=-2.E-01        dsub=0.7
*------------------Hot electrons-----------------------------------
* alpha0=1.61e-05  beta0=36.68
*------------------VAF---------------------------------------------
+ lint=.12e-06     pclm=.19            pscbe1=3.79e+08   pscbe2=9.4e-05
+ delta=0.01655    pvag=0.4484
*------------------Bulk_diode--------------------------------------
+ js=5.858e-08
*------------------Resistance--------------------------------------
+ rsh=70           rdsw=375
+ wr=0.7586        prwb=0              prwg=-4.441E-17
*------------------Capacitance-------------------------------------
+ cj=0.0002424     cjsw=2.73e-10       mj=0.3551           mjsw=0.3873
+ cgso=9e-13       cgdo=9e-13          cgbo=7e-10
+ pb=0.5614        pbsw=0.8            xpart=0
+ dlc=5e-08        dwc=1.5e-07
*------------------BulkChargeEffect--------------------------------
* a0=0.7           a1=0                a2=1                 ags=0.05583
* b0=6.305e-08     b1=6.579e-08         keta=-1.531E-02
*------------------ShortChannel------------------------------------
+ dvt0=2.2         dvt1=0.53           dvt2=-1.521E-01      drout=0.76
+ pdiblcb=.4       pdiblc1=0.00886     pdiblc2=0.00029
*------------------NarrowChannel-----------------------------------
```

```
+ w0=2.6e-04        wint=0.16e-06
+ ww=-9.525E-14     wwn=1.0
+ dvt0w=0           dvt1w=5.3e6         dvt2w=-1.E-01
+ k3=2.53           k3b=-5              dwg=0                dwb=0
*------------------Noise--------------------------------------------------
* af=1              kf=1e-28            ef=0.95
*------------------Temperature--------------------------------------------
* pvsat=0           ute=-1.258E+00      kt1=-3.85E-01
* kt1l=0            kt2=-3.098E-02      ua1=5.705e-09
* ub1=-1.147E-17    uc1=-1.302E-01      at=20380
* prt=-3.287E+02    lk1=0               lk2=0
* lvsat=0           la0=0               lags=0             lute=0
* luc=0                                                                  )
.end
```

4.11.10_4.54PM

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