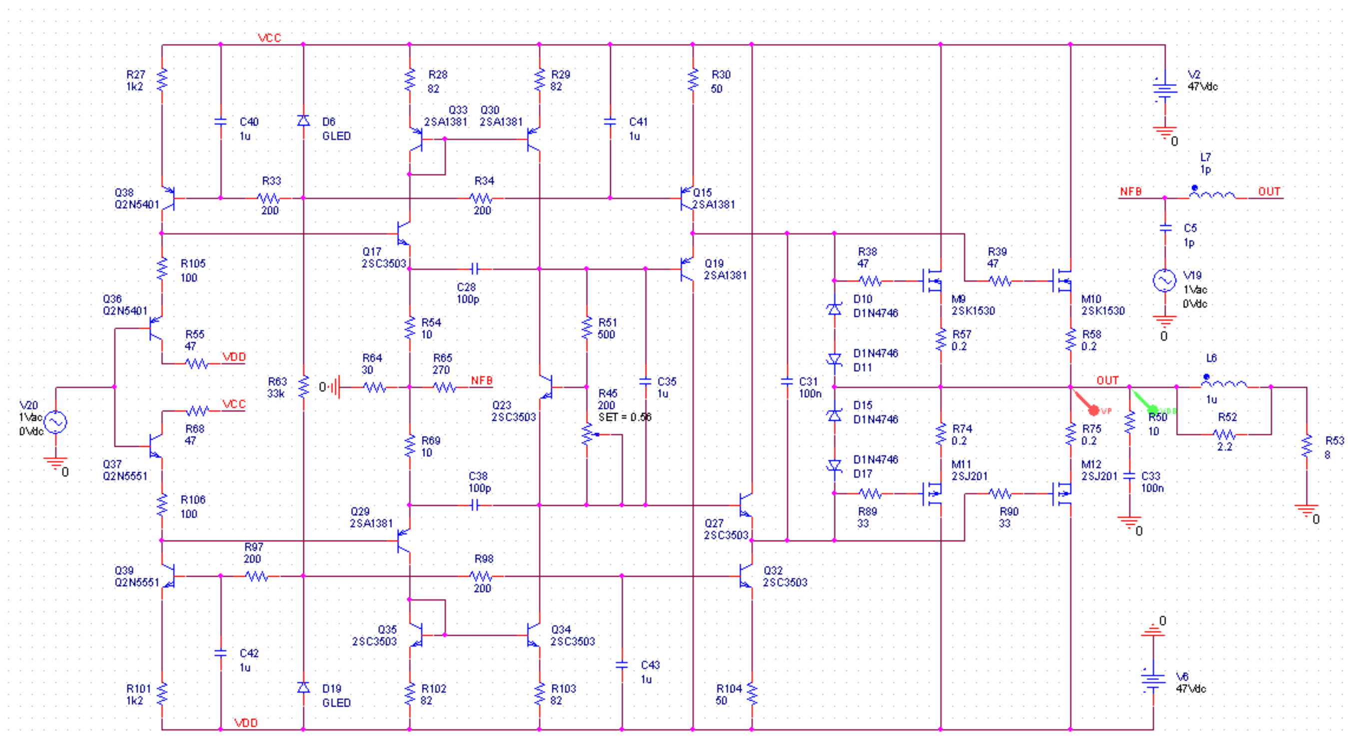
Let's take a look at an OPS implementation that would fit the pole-zero cancellation requirements. We already mentioned that the OPS has to have gain, to compensate for the limited output swing of a conventional opamp.

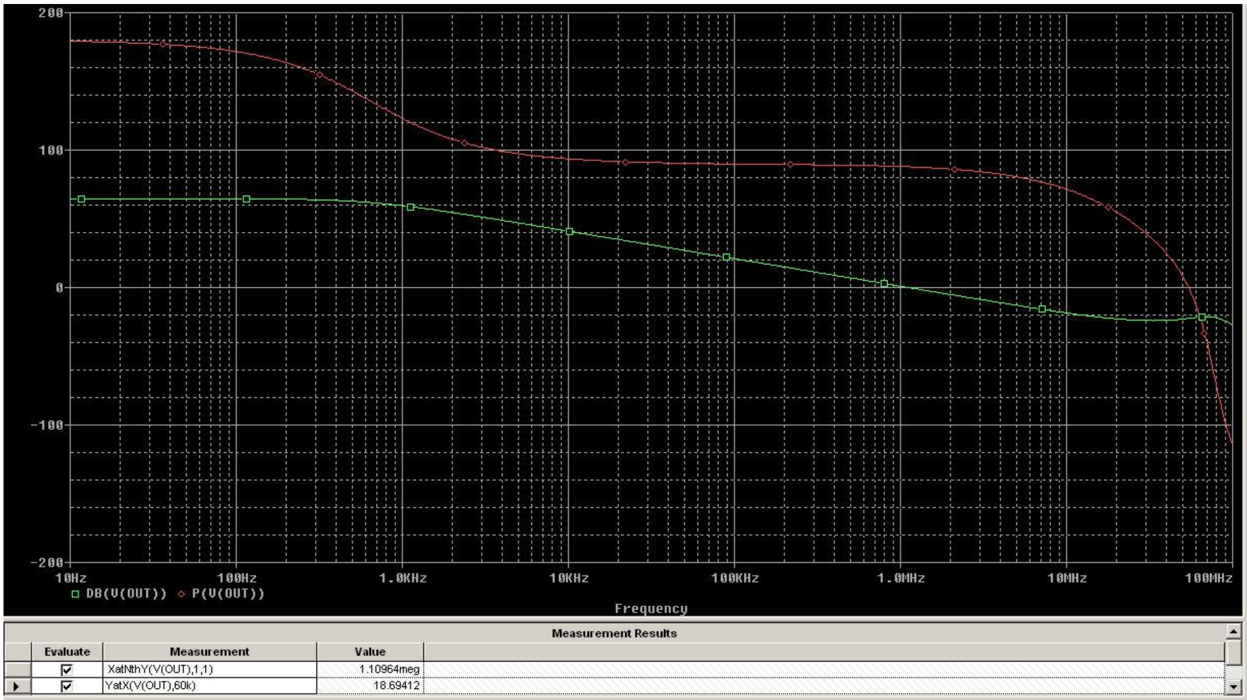
First question is: bipolar or MOSFET? A MOSFET output stage makes sense here, and that's because we need to push the ULGF as high as possible; bipolar output stages are limited to the bipolar power devices $F_T$ of 30MHz or less.

The output stage doesn't necessary need to have a local feedback loop, although it's not a bad idea to implement one to keep things tight under control. A current feedback configuration would certainly help here.

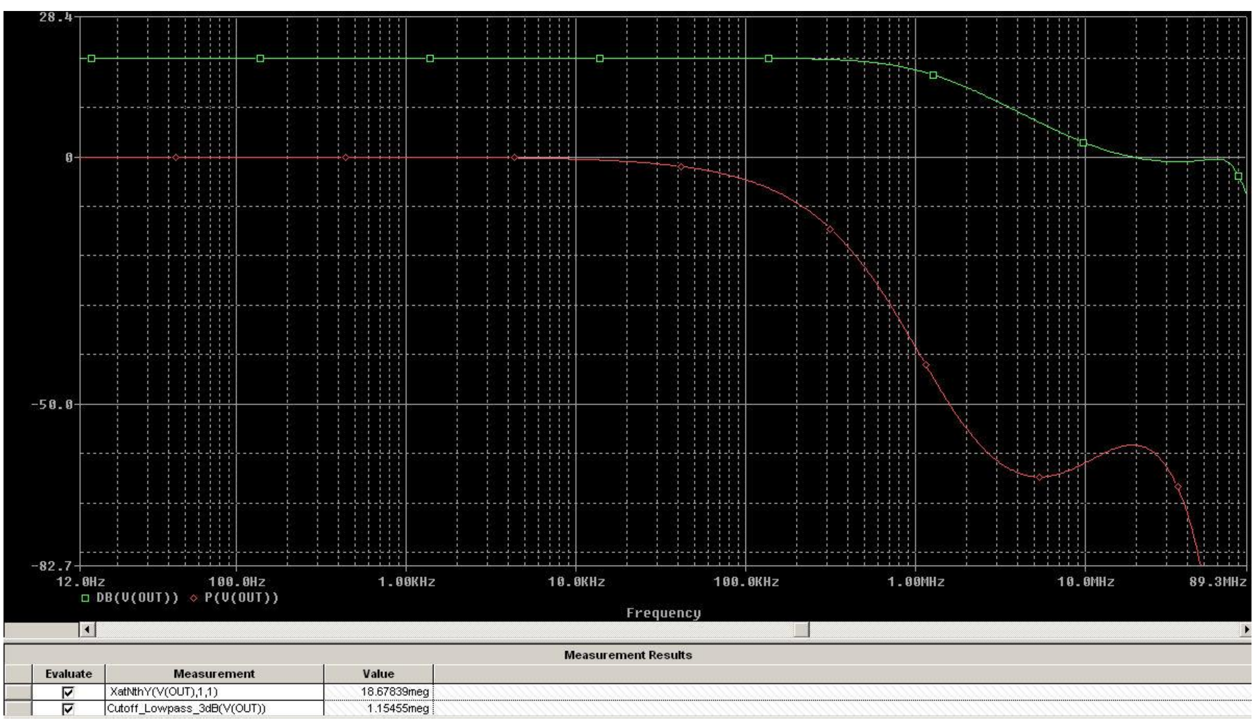
Take a look at the schematic below; it's a current feedback configuration, simplified to the bone. All we need is to have this OPS provide a 20dB of gain, and an as high as possible GBW. Of course, the local (current) feedback loop has to be stable.




Fed at +/-47V, this output stage delivers 100W into a 8ohm load, with enough juice to support any 8ohm speaker impedance dip. The OPS gain is set to 10 by the R55/R64 ratio and it's miller compensated for a healthy 1.1MHz ULGF:



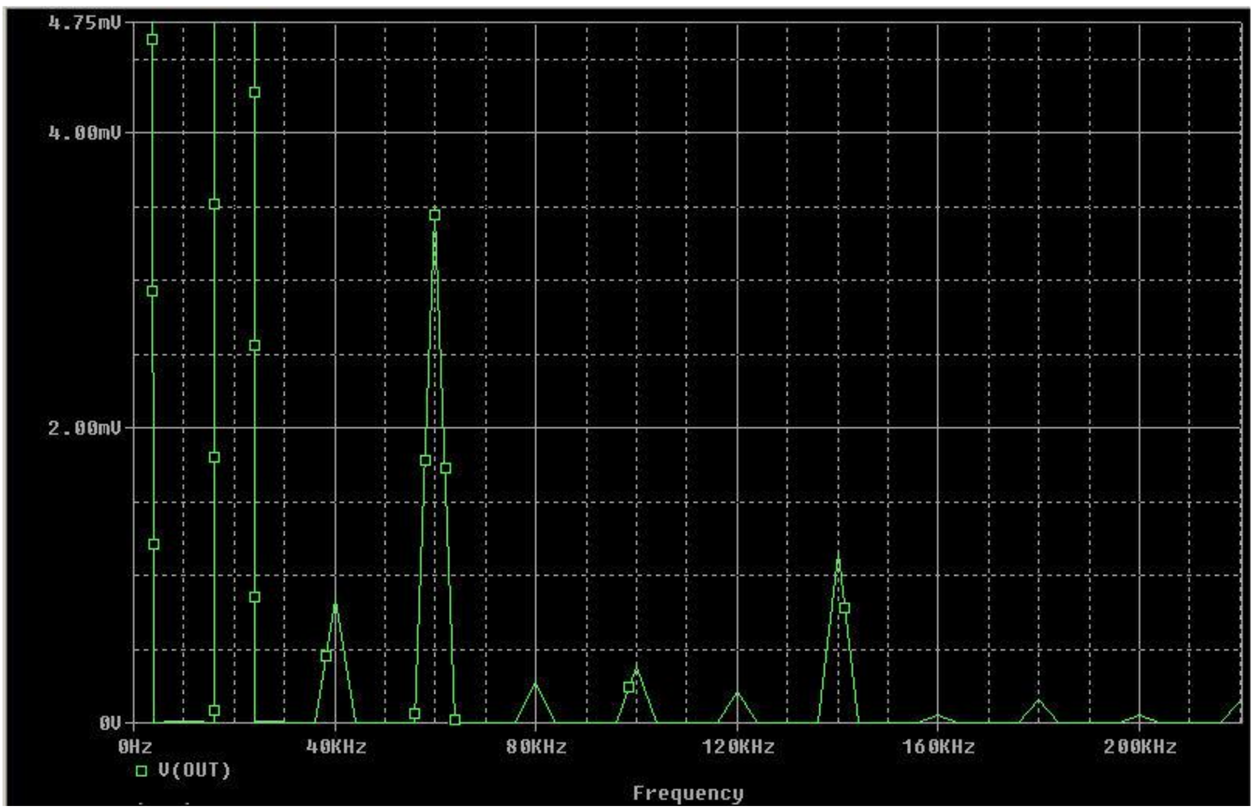

It is perhaps important to note that the OPS ULGF is NOT the closed loop GBW (that has to be much higher, to fulfill to pole-zero cancellation requirements). Here's the closed loop frequency and phase response:



The 3dB bandwidth is 1.1MHz, while the UGF is 18.7MHz. Less than we were looking after in the previous analysis (2.5MHz/25MHz) but we'll try to fine tune to accommodate this OPS in the global feedback loop.

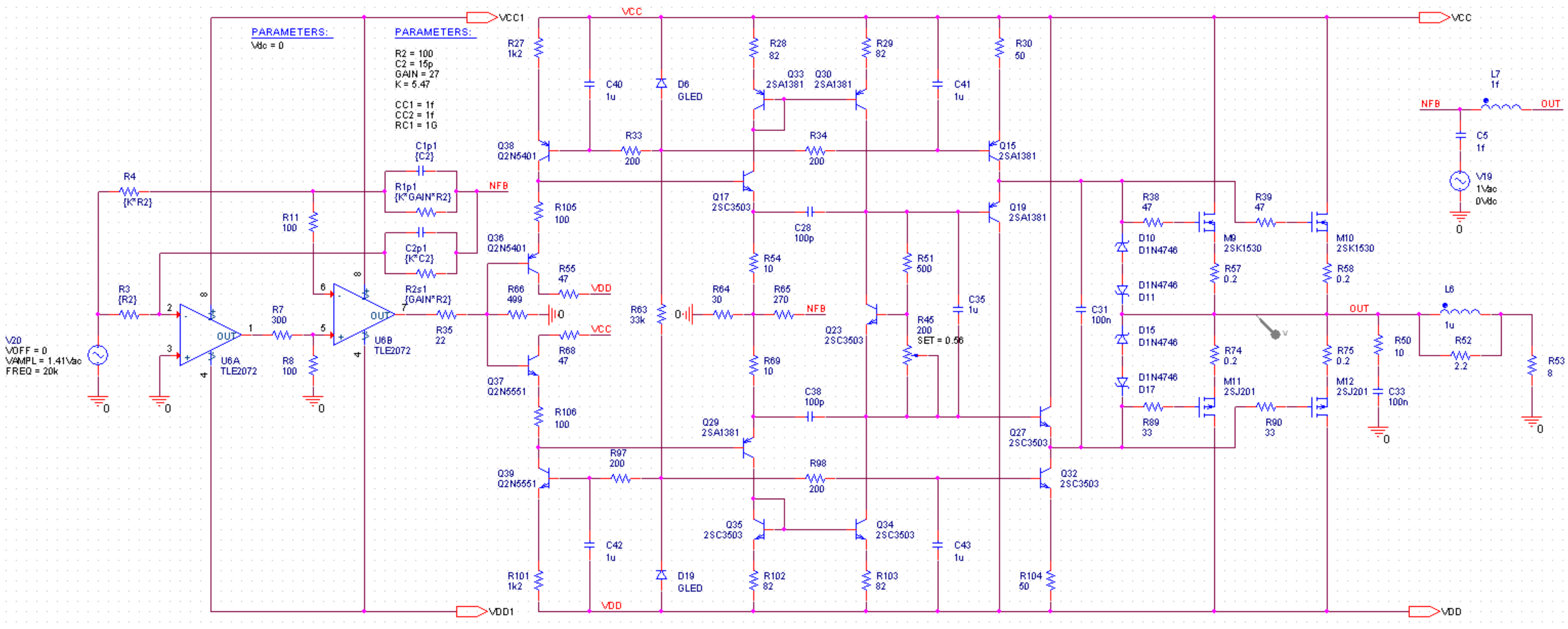
Fed at +/-47V, the current feedback OPS distortions at 20KHz and 100W/8ohm (80Vpp) are simulating at around 0.01%. Based on the previous experience with the YAP and AURA amps, it is expected to be larger in the real world, perhaps as high as 0.02%. But let's keep things in the simulation realm, for the moment.

The distortion spectra is pretty typical for a class AB amp: mostly 3rd harmonic with a little of 2nd and decreasing higher harmonics:



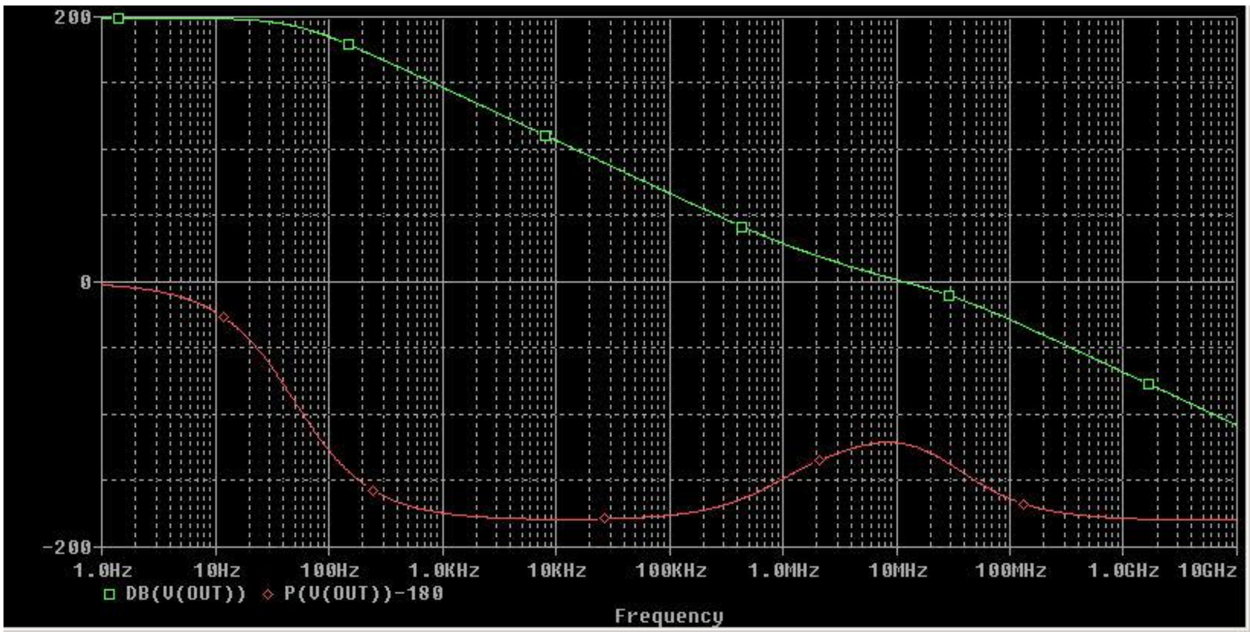

Now it's time to close the loops across both the OPS and the input pole-zero cancellation circuitry. On the next page you'll find the full amp schematic. VCC/VDD are +/-47V while VCC1/VDD1 are +/-15V. A small 22ohm resistor was added to isolate the opamp output from the OPS input capacitance.

As you see, the overall amp schematic is not overly complicated, at least from a simulation perspective. But bear in mind that, so far, this amp is missing lots of features like clipping protection, overload protection, DC servo, etc… It is expected that these features will add significant complexity to any practical implementation but, as already said, let's keep things in the ideal world for the moment.



PARAMETERS:
Vdc = 0
PARAMETERS:
R2 = 100
C2 = 15p
GAIN = 27
K = 5.47
CC1 = 1f
CC2 = 1f
RC1 = 1G
V20
VOFF = 0
VAMPL = 1.41Vac
FREQ = 20k
R4 {K*R2}
R3 {R2}
U6A TLE2072
R7 300
R8 100
R11 100
U6B TLE2072
C1p1 {C2}
R1p1 {K*GAIN*R2}
C2p1 {K*C2}
R2s1 {GAIN*R2}
R35 22
NFB
VCC1
VDD1
VCC
VDD
R27 1k2
Q38 Q2N5401
C40 1u
R33 200
D6 GLED
R105 100
Q36 Q2N5401
R55 47
R66 499
R68 47
Q37 Q2N5551
R106 100
Q39 Q2N5551
R97 200
C42 1u
R101 1k2
D19 GLED
R63 33k
R64 30
R65 270
R28 82
R29 82
Q33 2SA1381
Q30 2SA1381
R34 200
Q17 2SC3503
C28 100p
R54 10
R69 10
C38 100p
Q29 2SA1381
R98 200
Q35 2SC3503
Q34 2SC3503
R102 82
R103 82
C41 1u
C43 1u
Q23 2SC3503
R51 500
R45 200
SET = 0.56
C35 1u
R30 50
Q15 2SA1381
Q19 2SA1381
Q27 2SC3503
Q32 2SC3503
R104 50
C31 100n
R38 47
D10 D1N4746
D1N4746 D11
D15 D1N4746
D1N4746 D17
R89 33
M9 2SK1530
R57 0.2
R74 0.2
M11 2SJ201
R39 47
R90 33
M10 2SK1530
R58 0.2
R75 0.2
M12 2SJ201
OUT
R50 10
C33 100n
L6 1u
R52 2.2
R53 8
L7 1f
C5 1f
V19 1Vac 0Vdc
0

After tweaking a little the pole-zero cancellation variables (C2 and K) here are the final results. The loop gain (please note that, for the purpose of this simulation exercise, all feedback loops are broken at the output node as per the schematic) shows an ULGF of 12MHz and a phase margin of 58 degrees. With this, the loop gain available to kill the 3$^{rd}$ harmonic (dominant, as seen in the OPS output spectra) is no less than 76dB. This is a huge value, an x100 (or 40dB) improvement over what can be done in a conventional Miller or TPC/TMC compensated amp!




Measurement Results

| Evaluate | Measurement | Value |
|---|---|---|
| ☑ | XatNthY(DB(V(OUT)),0,1) | 11.86314meg |
| ☑ | PhaseMargin(DB(V(OUT)),P(V(OUT))... | 57.79037 |
| ☑ | DB(YatX(V(OUT), 60k)) | 75.83944 |

The phase margin of 58 degrees can certainly made larger, if we can push the OPS GBW higher. But for all practical reasons, 58 degrees is good enough. Further analysis shows that for a 40V output, the phase margin is still over 50 degrees, so we should not expect any transient instabilities.

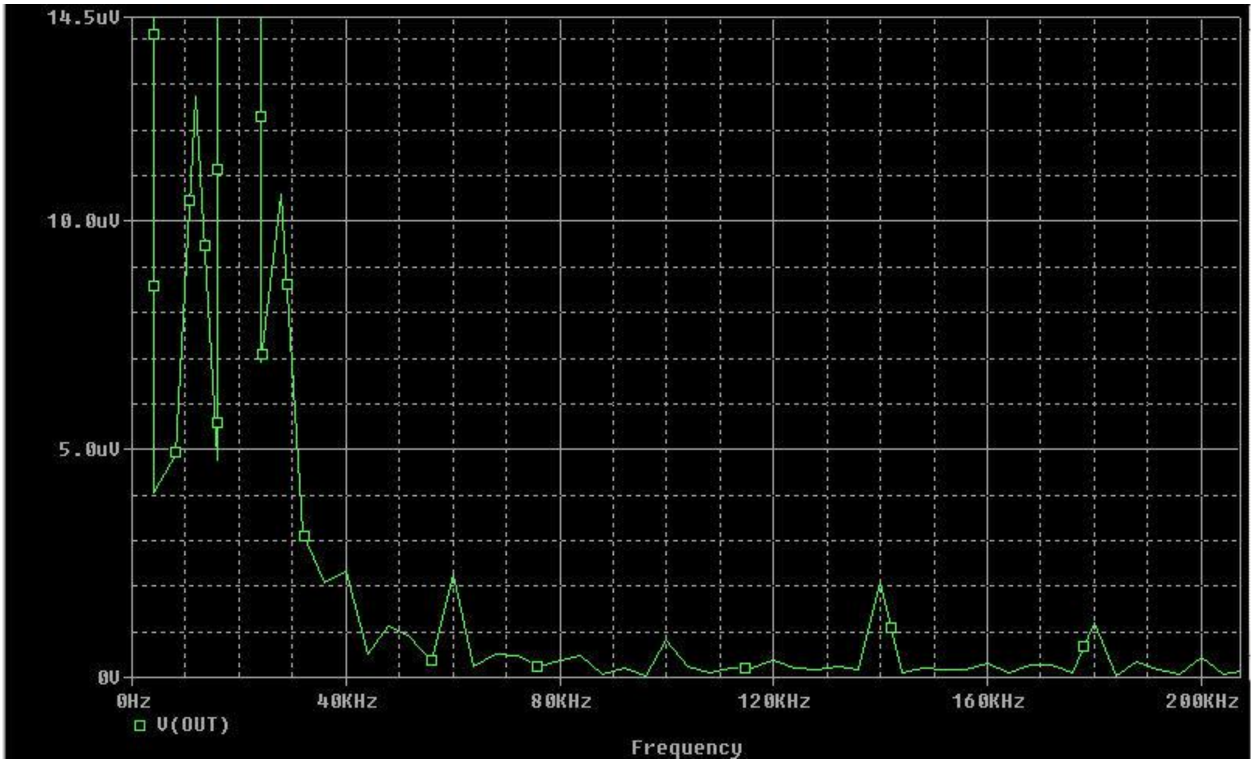
On the other side, as already mentioned, the amp is clearly conditionally stable. This raises another practical complication, how do we protect this amp during power on and power off, so that it won't oscillate on the trajectory? All these are tough questions that I'll try to eventually address. For the moment, note that the phase dip is non-negotiable. Bode integrals are telling there's no way to get along without such a phase dip, if you start rolling the frequency response at 40dB/decade (as we do here).

And now (drums rolling) let's take a look what those 74dB of 60KHz loop gain are doing to the distortions:

```
    X_U6A.VPSR   0.000E+00

    TOTAL POWER DISSIPATION   7.45E+01  WATTS


**** 09/12/11 08:22:54 ******* PSpice 16.3.0 (June 2009) ****** ID# 0 ********

 ** Profile: "SCHEMATIC-tran-sine"  [ D:\Cadence\Designs\Tests\PZCANCEL\02\pzcancel-pspicefile


 ****     FOURIER ANALYSIS                 TEMPERATURE =   27.000 DEG C


******************************************************************************



FOURIER COMPONENTS OF TRANSIENT RESPONSE V(OUT)



 DC COMPONENT =  -1.372899E-02

 HARMONIC    FREQUENCY    FOURIER    NORMALIZED    PHASE       NORMALIZED
    NO         (HZ)      COMPONENT    COMPONENT    (DEG)       PHASE (DEG)

     1      2.000E+04    3.806E+01   1.000E+00    1.784E+02    0.000E+00
     2      4.000E+04    2.265E-06   5.951E-08   -1.028E+02   -4.596E+02
     3      6.000E+04    6.898E-07   1.812E-08    3.334E+01   -5.019E+02
     4      8.000E+04    6.678E-07   1.755E-08   -1.027E+02   -8.163E+02
     5      1.000E+05    4.054E-07   1.065E-08   -4.369E+01   -9.357E+02
     6      1.200E+05    3.215E-07   8.447E-09   -1.045E+02   -1.175E+03
     7      1.400E+05    1.728E-06   4.541E-08    1.155E+02   -1.133E+03
     8      1.600E+05    5.511E-07   1.448E-08   -8.872E+01   -1.516E+03
     9      1.800E+05    6.909E-07   1.816E-08    1.209E+02   -1.485E+03
    10      2.000E+05    2.566E-07   6.742E-09   -7.029E+01   -1.854E+03


     TOTAL HARMONIC DISTORTION =   8.372104E-06 PERCENT
```

That would be 0.08ppm of THD20, which is simply insane. We can safely assume this value as lacking any relationship to the real world, but otherwise shows the power of this pole-zero cancellation configuration.

Also take a look at the spectrum:




The peaks adjacent to the 20KHz fundamental are simulation artifacts (they are non-harmonic, a physical impossibility). The 3rd harmonic is now only 2uV, and so is the 7th.

Ok, after this simulation galore (intended only for the purpose of illustrating the pole-zero cancellation features and capability) let's take a closer look on what could be implemented in practice.

Certainly, building such an amp is very difficult. The ULGF of 11MHz calls for a RF technology implementation, hence the title in the article.

To be continued…