

## Appendix 3.2: Letters from John Addis on Cascode Amplifier

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**From:** John Addis, Portland, Ore., 23.02.2002

Erik,

I have read your 8 page paper. If the only question is whether you can ignore the common base stage's base resistance which is transformed into an inductance, the answer in general is no. If there is negligible  $C_{cb}$  in  $Q_1$ , this is possible though, because the collector of  $Q_1$  will simply be a perfect current source and insensitive to collector voltage.

As far as simulations go, it would be unwise just to take a transistor from the library and use it to get simulation results equal to the algebra. The transistor capacitances are all voltage dependent. Set the them all to zero, set the base resistance and collector resistance to zero (i.e. use a default transistor instead of a 2N3648 and specify  $r_b = 0$ ,  $r_c = 0$ ,  $C_{jc} = 0$ ,  $C_{je} = 0$ ,  $\tau_f = 0$ ). Now use ideal capacitors to build up a transistor with exactly the right values (i.e., make your own  $C_\pi$ ,  $C_\mu$ ). Add base resistance external to the default transistor.

Another tip, the biasing of your Fig. 5 circuit is too critical because  $I_c$  is exponentially dependent on  $V_{be}$ . Use an ideal current source from  $Q_1$  emitter to ground and connect  $Q_1$  emitter to  $R_{e1}$  and  $C_{e1}$  with a 1 F capacitor.

You have a 1 V input step, but a 1 V input step with a  $50\ \Omega$  emitter resistor would create a 20 mA current step, not a linear result with a 10 mA standing current. The transistor's characteristics will change over this level, affecting your results. If you do as suggested with a fixed 10 mA current source and a 1 F capacitor, you can put in an arbitrarily small step.

Perhaps you are asking something else, in which case I would remind you that there are errors in any textbook. E-mail Dennis for an errata sheet.

A general comment: There is a tendency to depend on algebra when there is an absence of real world components. The engineers of India do great mathematical analysis of fields and transmission lines. The reason is probably the difficulty in finding test equipment to measure stuff.

People who have had the privilege of designing ICs do not even look at the algebra. For one reason, the transistor is far more complex than the algebra would allow and for another reason, the result is so non-ideal because of that many simplifying assumptions (i.e., over what band of frequencies is the analysis important, because it certainly changes with frequency).

What I have done, as my fellow engineers have done, is to ignore the algebra and do our tests on transistor models supplied by IC manufacturers. For example, if I were to design a T-coil (I would not anymore), I would put a perfect current source into the input (bypassed with a 1 H inductor to the correct bias voltage) and have SPICE tell me what the real input impedance would be. This would include the fact that the base resistance is distributed, that the circuit is affected by what is connected to other terminals, etc., etc.. Plot the input impedance vs. frequency ( $V_{in} = r_{in}$  if input current is 1 A). Then I could design a T-coil for what SPICE says the input impedance is. Use the algebra for the T-coil design, but then modifying it if I found that I could

not make such a T-coil. For anything above 1 GHz, it is unlikely that a T-coil would even work because of its unrealisability<sup>1</sup>.

I note also that you have stuck with Carl's use of a  $C$  across the input transistor's emitter. In IC design, that is not a component you want to use. It turns out that eliminating the  $C$  raises the input impedance somewhat, causing the desired T-coil (or other) peaking to be a little different, but you gain back what you lose in emitter peaking by having a higher input impedance. It really does not matter that the  $C_e$  is not there. The bandwidth is the same, and the circuit takes up less space and has less parasites associated with it. This is a perfect example of getting boxed into an idea for algebraic reasons which in the end just cause you trouble.

Also on a philosophical bent: There is ample opportunity to adjust peaking if you build a feedback amplifier. The advantage of feedback is that you cure all those nasty thermal effects, improve the linearity and reduce the amplifier dependence on the transistor consistency. The cascode is a circuit which I used last in 1979 and not since. The real gain in performance since then, aside from better devices, is in the creation of new topologies.

Another point about your Fig. 5 circuit:  $C_{e2}$  in your case would be far more trouble than it is worth. A 2 nH of stray inductance (0.1" of lead length) would cause a resonance at 393 MHz which would blow all those pretty curves out the window.

Looks like you are using PSpice for Windows...right? PSpice library models are not very good.

More comments upon request.

Regards,

John

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**From:** John Addis, Portland, Ore., 24.02.2002

Erik,

I remember that one of the very first technical papers I wrote was in about 1967 and it dealt with essentially the problem you wrote to me about. The impedance seen looking into the emitter causes oscillations under some circumstances. The problem is that the base of the upper stage has finite lead length (i.e., inductance). When this base lead inductance is transformed into the emitter you have something that rises in impedance at 12 dB/octave. I remember that I wrote that the cure for this and the way to make the transient response work was to put a relatively large resistance in the base (of  $Q_2$ , Fig. 3.4.1, see also Fig. 3.4.7; [note by E.M.]). This forces the impedance to be dominantly an inductance when transformed. Then the large resistor (e.g., 200  $\Omega$ ) is bypassed with a small capacitor. This brings the base impedance down at 6 dB/octave, which, when transformed to the emitter, is just a resistance and therefore useful in damping the transient response.

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<sup>1</sup> John is referring to the realizability of conventional cylindrical coils. However, the reader should be aware that there are working examples of inductances and T-coils in the form of planar structures on hybrids and also realizations using bond wires within integrated circuits, working up to 5–6 GHz.

The trick is to make the capacitance as large as possible without having it resonate with the total base lead inductance within the frequency of interest. This usually turned out to be 1–2 pF. This was a better way of getting resistance into the emitter than using a resistor, which would have lead length and hence inductance, which is what you are trying to get rid of.

The discovery was significant enough that I still had people referring to the paper 25 years later!

John

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**From:** John Addis, Portland, Ore., 26.02.2002

Erik,

You write: “His (Peter’s) way of explaining things from simple ideas to ever more complex circuitry is, in my opinion, of great help to a newcomer. From my own experience, I was always more successful at learning if I was able to put the development of things into a historical perspective.”

I agree completely. That is how we learn the best.

By the way, I was not suggesting that you build an actual circuit, although that might be instructive. I was indicating that you should be mindful of what happens when you build a discrete circuit, i.e., lead inductance at 20 nH/inch. Hence it is important to think about the consequences of putting in components to solve problems.

For example, the large bypass cap (I believe it was 500 pF) which was used to bypass the interstage resistance (which is necessary for thermal balance) has a few nH of inductance at least. That needs to be modeled eventually, although maybe not in the first analysis. Now suppose that this inductance and the effective inductance at the emitter of  $Q_2$  is just a little too large for good transient response.

What do you do?

Do you add a discrete resistor to damp the response? That component would add its own inductance, making the problem worse and the required damping resistance even greater. No. You add the  $200\ \Omega$  bypassed by 1–2 pF in the base of  $Q_2$ . The  $200\ \Omega$  provides bias and the 1–2 pF provides a declining impedance (with frequency) in the base of  $Q_2$ . When transformed to the emitter of  $Q_2$ , this provides the damping without adding any inductance at all so long as the resonant frequency of the 1–2 pF cap and all the associated lead inductance is high enough. This is a better solution because the  $C$  is variable and the  $f_T$  of the transistor makes base lead inductance less critical than in the emitter. You can always make the 1–2 pF small enough that the resonant frequency is high enough.

Yes, you have my permission to include anything which I write to you.

John

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**From:** John Addis, Portland, Ore., 20.03.2002

Erik,

...the resistor should go to a voltage source as you suspected, and then the capacitor can go either to ground, the voltage source, or the base on the other half of the differential amplifier.

The idea behind the capacitor is to get rid of the effects of the inevitable stray inductance in the real circuit. To see its effect, try 10 nH in series with the base and without any  $R$  or  $C$ . Compare this with 20 nH,  $250\ \Omega$ , and various values of  $C$ . The change from 10 nH to 20 nH accounts for the fact that the  $C$  has 10 nH of stray inductance.

I will read your new paper. It looks like Carl found something I overlooked.

John

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