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## High-Performance Discrete Building Blocks for Balanced Audio Signal Processing

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### ABSTRACT

To audio systems designers, the “fully differential op amp” is a relatively new entry. Two discrete-circuit variations on the theme are presented, one of which provides effectively floating outputs.

### 1. INTRODUCTION

Chronologically the common (single-ended) op amp was preceded by the fully differential op amp. Like the SE op amp, this circuit had a differential input and “infinite” voltage gain. Crucially though, it had two outputs operating in opposite phase. This was necessitated by requirement of DC coupled operation and the fact that being a vacuum tube circuit, its output voltage range only started tens of volts above the input common mode range. The output common mode voltage itself was not explicitly controlled. Later, solid state technology allowed the construction of p-channel devices and hence DC coupled circuits with fully overlapping input and output voltage ranges. Ground-referenced, unbalanced circuits were found to be easier to design and the balanced op amp slid out of sight. It has since led an invisible existence, mainly inside low-voltage mixed signal ICs. Only recently, an audio chip was introduced<sup>[1]</sup>.

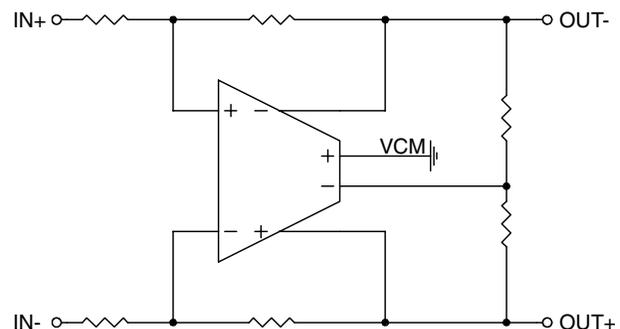
Two discrete implementations will be presented. One a very high-performance incarnation of the “classical cir-

cuit”, the other one a novel circuit capable of floating its outputs.

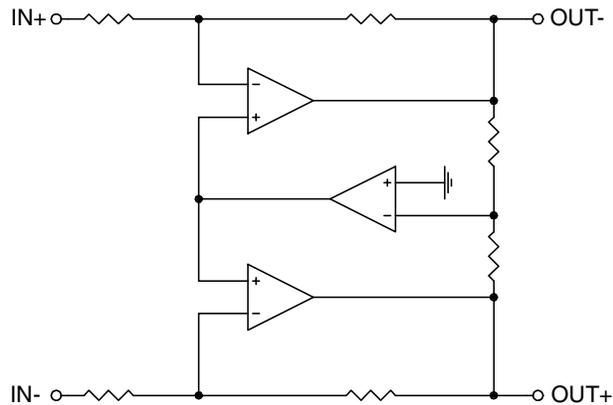
### 2. FULLY-DIFFERENTIAL OP AMP WITH COMMON-MODE FEEDBACK

#### 2.1. FD Op Amp Basics

The common mode portion of the op amp is normally operated in a gain of +1.

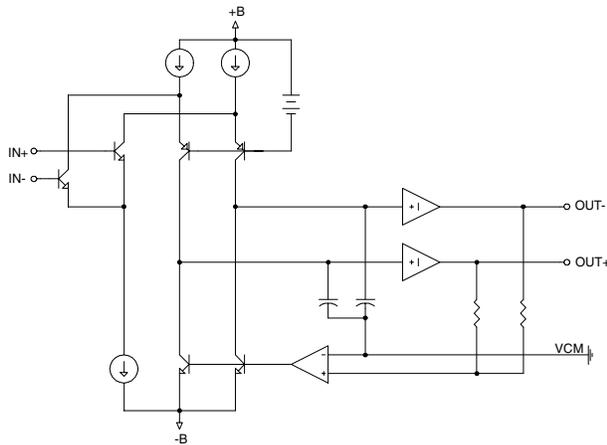


In principle, the same function could be realised with 3 op amps.



When tried out in practice, this circuit will most strongly resist any attempt made at stabilising it.

Below is a more useful principle concept of a FD op amp.



The vast majority of FD op amp designs have a folded cascode input stage, limiting practically obtainable loop gains to around 100dB. Compensation is ground-referred. From a PSRR point of view this is always a good idea but is never done in IC based SE op amps. In IC FD op amps, the compensation networks are tied to the common mode input, as this is supposed to see a low impedance reference anyway.

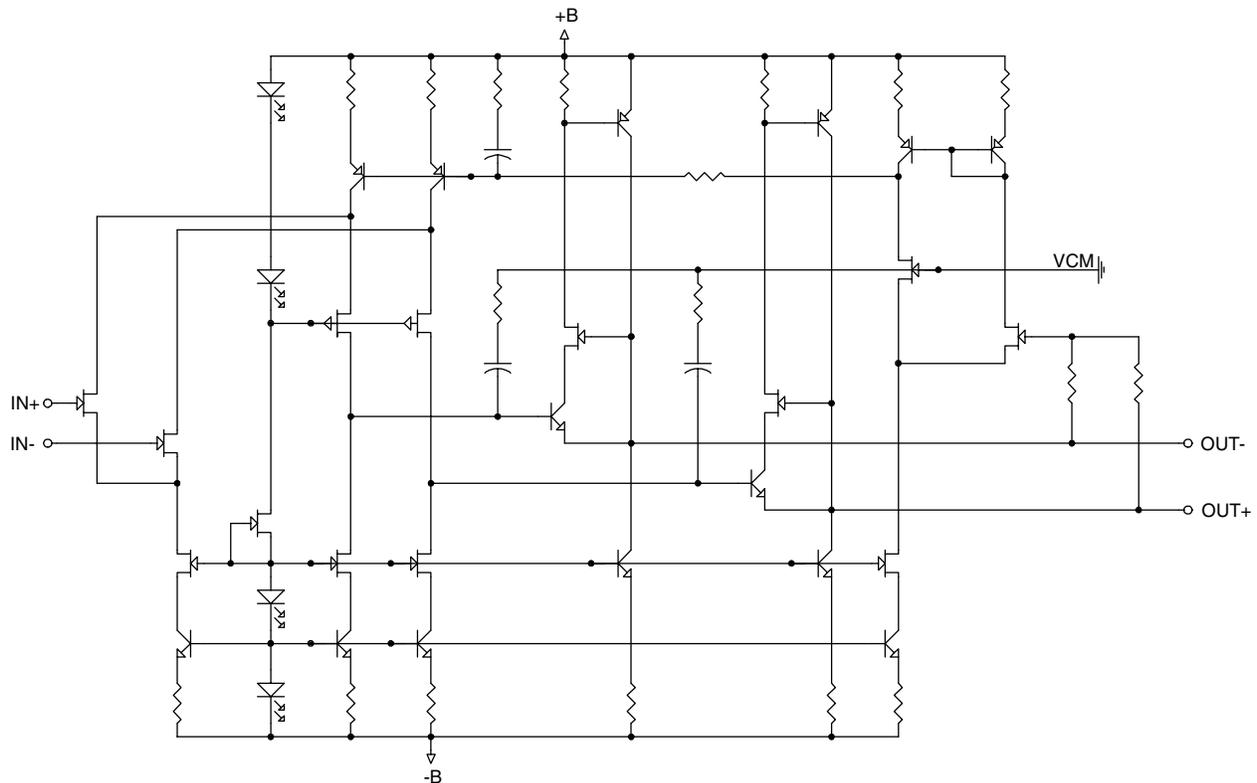
## 2.2. Common Mode Feedback Performance

Measured differentially, even simple versions will offer excellent THD figures, owing to the cancellation of even-order harmonics. Unfortunately, reality has it that at some point, someone will want to take an unbalanced feed from one output. The signal quality as measured between one output and the common mode reference should therefore be no worse than the two outputs measured differentially.

This means the common mode control loop should be a very high quality amplifier circuit in its own right.

## 2.3. Practical Realisation

The schematic of a finished FD op amp shows second order integration/compensation in the common-mode circuit to accomplish this.



Forward biased junctions are preferred as voltage references owing to their substantially lower noise voltage compared to zener references. LEDs offer practical forward voltages in addition to cheerful visuals when the circuit is powered up.

### 3. A BALANCED LINE DRIVER WITH FLOATING OUTPUTS

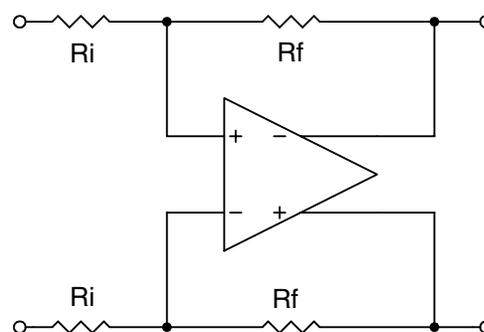
#### 3.1. Differential transconductance amplifier with differential voltage feedback

The amplifier discussed earlier follows the “transconductance times impedance followed by unity gain buffer” template. The unity gain buffer is required because without it, the output impedance would be the inverse of transconductance at best ( $A_v=1$ ). Any reduction in the load impedance seen by the transconductance stage will reduce loop gain.

The alternative to adding a buffer stage is greatly increasing transconductance. This produces an amplifier with interesting properties.

Firstly the compensation cap is located at the output of the amplifier, which means that capacitive loads can only improve stability, not detract from it. In an amplifier with voltage buffers, capacitive loads lower the second pole whereas on a transconductance stage it will lower the dominant pole.

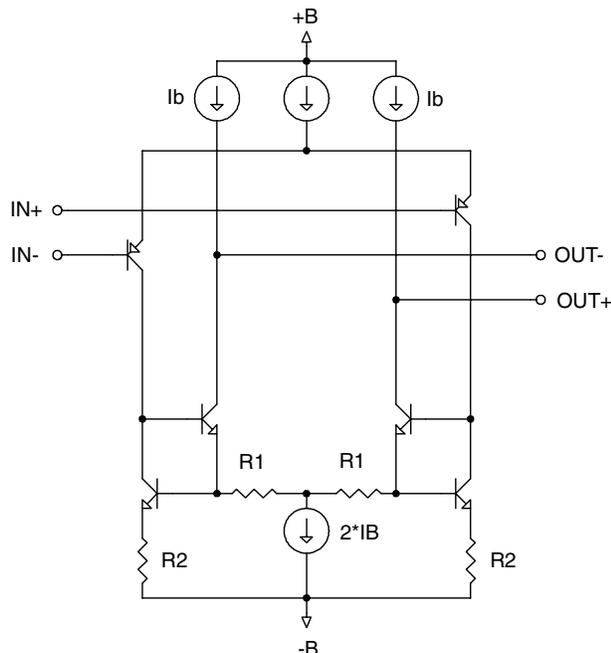
Secondly, a FD amplifier built along these lines may be operated without common mode feedback. The differential control loop will only lower the output impedance differentially, but the common mode impedance stays high. This is as much as saying the outputs will behave like a floating voltage source.



The limiting factor on common mode output impedance is the feedback network.  $Z_{OCM}$  works out as  $(R_i + R_f)/2$ .

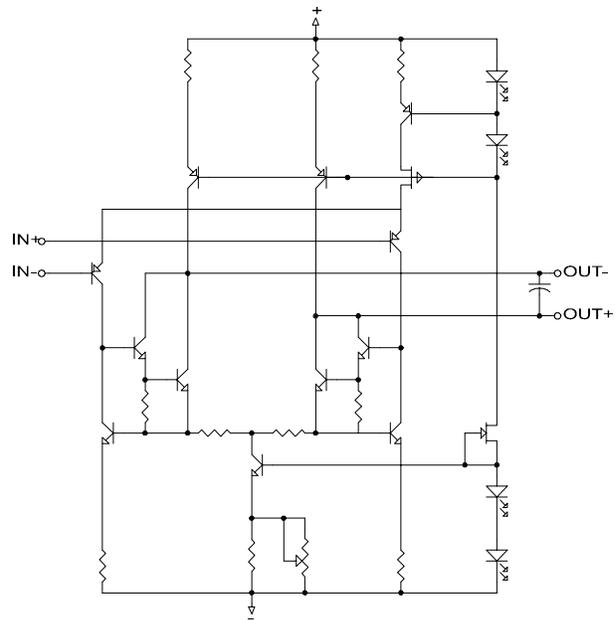
### 3.2. Circuit

The basic circuit consists of a differential pair followed by a differential current gain stage.



The top or bottom current sources will require trimming in order to constrain the common mode DC bias voltage in the event that the load doesn't have a low common mode impedance either. In that case, only the feedback network can be relied upon to keep the outputs centered.

The practical schematic is hardly more complicated than the idea.



To make a universal balanced output (ie. one that can operate in floating mode as well as fixed to ground), the bias network of the bottom current source may be made switchable between fixed bias (floating outputs) and the output from a common mode feedback amplifier.

### 3.3. Conclusion

In retrospect, one finds that existing floating output drivers invariably center around trying to make voltage-source buffers act “un-voltage-source-like” in the common mode without compromising differential output impedance too much. Most of these rely on boot-straping sense resistors (typically twice 50 ohms) placed in series with the voltage outputs<sup>[2]</sup>. Apart from increasing differential output impedance, such connections pose a limit on the common mode output impedance and its linearity at high frequencies. The author knows of one case where a balanced output stage was equipped with floating power supplies to get around the problem<sup>[3]</sup>.

In comparison to voltage-buffer based floating line drivers, the present circuit offers substantially lower differential output impedance, lower effective common-mode capacitance and unconditional stability.

This should be illustrative of how aside from thinking in “voltage” terms, thinking in “current” terms can lead to some very simple solutions to old problems.

#### 4. ACKNOWLEDGEMENTS

I would like to thank the members of the Pro Audio mailing list for their inputs concerning common mode output impedances on line drivers.

#### 5. REFERENCES

- [1] <http://focus.ti.com/docs/prod/folders/print/opa1632.html>
- [2] Hebert, Gary, *An Improved Balanced, Floating Output Driver IC*, presented at the 108th AES Convention, Feb. 2000
- [3] Frindle, Paul, communication on the Pro Audio mailing list.