Some Further References Related to the Boxall, Larson, Baxandall-Shallow, and Thompson Constant Current Circuits:

Earlier posts to this "Baxandall Super Pair" thread offered a chronological annotated list of references. It will be seen that this thread name actually applies to the ***Baxandall-Shallow constant current source*** *(#5, below).* The updated reference list below expands on this theme, with several key historical items added. As previously, some comments on the first few of the references follow. When carefully read, the comments should help in understanding this most clever circuit and the many variations.

Before any discussion, it is worthwhile noting the pros and cons of these bipolar transistor circuit developments, either as it might apply to an amplifying stage, or to a constant current source (CCS). On the pro side, there are improvements seen in the distortion of an amplifying stage, as well as an increase in the output impedance, particularly with regard to frequency. On the con side, these circuits do not address circuit linearity and/or output impedance, as they might be limited by the Early effect.

In #1 and 2, Frank S. Boxall describes a form of feedback using a compound PNP transistor connection which, upon some analysis, can be seen to have improvement properties similar to the Baxandall-Shallow circuit of 1966. Boxall's "Base Current Feedback" can also be described as a re-circulation of the transistor base current back to the emitter. It should be understood that Boxall's feedback is not *a form of global feedback around an amplifier, the latter as introduced by Harold Black of Bell Labs.*

Boxall's work predated Baxandall-Shallow by nearly a decade, and the context is actually more concerned with reducing distortion of low quality PNP output drivers in communications applications. In the patent document (#1), it does present some challenges to complete interpretation of the intended biasing (Fig. 5). The document includes expressions for distortion reduction and output impedance increase, as resulting from the feedback. In #2, Boxall further clarifies the biasing issues, showing AC-coupled feedback in Fig. 8, and in Fig. 9, presents a DC-coupled circuit which is functionally equivalent to that of the Baxandall-Shallow circuit (albeit of a NPN/PNP format).

The Roger Webster article, #3 within a Texas Instruments Communications handbook, summarizes Boxall's base current feedback methods, and reiterates the expressions for distortion reduction and output impedance increase. Webster references a work by Aldridge, which also addresses distortion reduction techniques.

In #4, Lester L. Larson provides an analysis of a composite PNP/NPN complementary pair as a functional high-gain NPN, with two such pairs operated differentially, or push-pull. The impedance characteristic of the output stage composite device is seen to be improved by a factor of β*, the gain of the driving transistor. Larson's work was independent of Baxandall-Shallow, and was part of the development of a push-pull driver for CRT displays.*

In #5, Peter J. Baxandall and E. W. Shallow discuss a single current source stage of the PNP/NPN type, having improvements similar to that of Boxall and Larson with regard to output *impedance. This is in fact the seminal paper that led to this "Baxandall Super Pair" thread. In a follow-on letter, #6, Baxandall describes a key point of the Baxandall-Shallow current source:* "The effect of collector-base capacitance in Trl, which shunts the output in the Fig. B circuit, is degenerated in the Fig. C circuit, and output capacitance values of well under 1 pF are obtained." *This point is what allows this type of stage (Boxall, Larson, or Baxandall-Shallow) to extend the effective bandwidth of a current source. Simply stated, the output capacitance of the transistor used is effectively reduced, as seen at the collector or output node.*

In #7, Jim Thompson describes an op amp with a Figure 6 NPN/PNP current source, designed to overcome the PNP IC transistor β limitations. This NPN/PNP configuration is a functional complement akin to 1/2 the Larson and to the Baxandall-Shallow setups. It was to be used many times over in other Motorola ICs of the period, in addition to discrete circuit examples within applications.

In #8, Jim Solomon offers a detailed analysis on the use of a composite complementary NPN/PNP pair ala Thompson (above), as a functional high-gain PNP pair, within the front end of what became the MC1556 IC op amp.

In #9, Tom Frederiksen describes use of the Figure 6 Thompson composite complementary pair within a high powered voltage regulator IC.

In #10 the Thompson composite complementary pair is used in Figures 9 and 10 as a current mirror employing 2N3904/3906 discrete transistors. In #11 the Thompson composite complementary pair is used in Figures 3 and 4 as a current mirror employing 2N3904/3906 discrete transistors.

In #12, Maurice Free describes the MC1595 multiplier design, which uses externally the Thompson current source scheme, within an output stage current mirror (Figs. 3 and 4).

Credits: For this July 2012 update, I am indebted to several DIYAudio friends for bringing my attention to the Boxall references. Brad Wood, Dmitri Danyuk, and Samuel Groner were all most helpful here. Brad, writing as bcarso, delineated a lot of background on tracking down the Boxall and Larson references (see also http://www.diyaudio.com/forums/solid-state/166306-origins-baxandall-super-pair.html. As per John Addis, Larson's Tektronix co-worker, Brad reports that the Larson output stage connection was internally known as the "super-alpha".

Earlier, my thanks went also to Jim Thompson for help with his MSEE thesis (#7), and to Maurice Free for help with his MSEE thesis (#12). Thanks also to an anonymous friend for providing the Larson reference, and to Ben Duncan and Morgan Jones, who also provided several references and other background information. Bob Pease has also related his independent development of this type of circuit, in #19 and 21.

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6. P. J. Baxandall, "Constant-Current Circuits," *Wireless World (Letters),* Dec. 1966, pp. 609.

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