OPTICAL RECEIVER WITH THIRD-ORDER CAPACITIVE CURRENT–CURRENT FEEDBACK

Indexing terms: Optical communications, Optical receivers

A 500 MHz optical receiver front-end with third-order overall current–current feedback has been realised. The capacitive feedback loop combines the high-bandwidth performance and the large dynamic range of a transimpedance receiver with the low noise performance of a high-impedance receiver.

Introduction: For (wideband) optical receiver front-ends the most crucial specifications are (1) large bandwidth, (2) large dynamic range, and (3) low noise performance. In conventional receivers like low-, high- and transimpedance receivers, some compromise is unavoidable with respect to these performance characteristics as schematically indicated in Figs. 1*a*, *b* and *c*. Receivers with a low input or feedback resistor suffer from poor noise performance due to thermal noise addition. Receivers with a high input or feedback resistor suffer from poor dynamic range and bandwidth performance, due to overload problems and an integrating gain function.

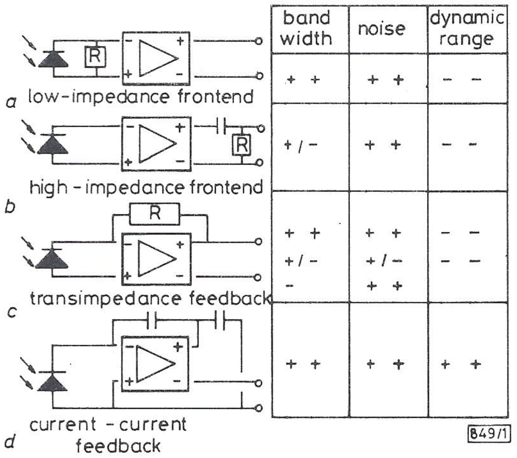

Fig. 1 *Four current classes of front-ends, reviewed on their performance*

The most important reason for these compromises is that all the discussed receivers front-ends try to convert an input current directly into an output voltage, in which case the dimension of the gain function is impedance. If a flat transfer function is required, the resistive part must always dominate. If a large bandwidth is also required the use of (noisy) low resistors seems to be unavoidable.

Current–current feedback is more flexible and allows an independent optimisation of bandwidth, noise and dynamic range (see Fig. 1*d*). Although the capacitive feedback impedances being used are highly frequency dependent, the current gain is frequency independent and fixed by the ratio: $(c_1 + c_2)/(c_1) = 1/\beta$.

The bandwidth is determined by the unity gain frequency, i.e. the frequency where loop gain (i.e. forward gain times feedback) has been reduced to one. If the forward gain is made as high as possible, the feedback factor β can easily be dimensioned appropriately with respect to desired bandwidth and gain.

The noise is mainly determined by the noise of the combination of photodiode and input FET, and no additional feedback noise is present. If the value of c_1 is low compared with the total input capacitance, the noise contribution of this input FET will not be enlarged. C_1 can therefore be dimensioned sufficiently low for any desired feedback factor β (e.g. by 0·15 pF parasitic capacitance over a sufficiently high resistor). Noise restrictions and bandwidth restrictions are thus made independent from each other.

The dynamic range is completely controlled by the feedback loop and is limited by the maximum output current and voltage of the forward amplifier that is available. Only in the LF region the forward amplifier must be able to supply relatively high voltages. Fig. 2 shows an AC diagram of a modified capacitive current–current feedback receiver. The shunt resistors R_1 and R_2 (Fig. 2) prevent the output voltage from becoming too large. If their value is sufficiently large, then their thermal noise contribution can be neglected.

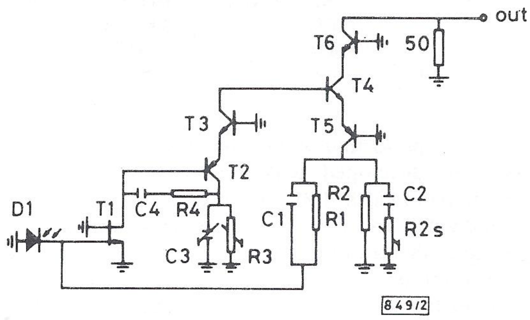

Fig. 2 *AC diagram of a third-order current–current feedback front-end*

$R_1 = 1\,k\Omega$; $R_2 = 100\,k\Omega - 10\,M\Omega$; $C_1 = 15\,pF - 1{\cdot}5\,nF$; $C_2 =$ parasitic value ($\simeq 0{\cdot}15\,pF$); T1 = BF 992 (MOSFET 900 MHz); T2, T5 = BFT 92 (PNP, 4 GHz); T3, T4, T5 = BFR 92a (NPN 4 GHz)

The stability must be controlled by compensation networks as soon as the dominant order of the forward gain becomes larger than one. This can be accomplished by phantom zeros and/or pole splitting techniques.[1] It turned out to be much easier to add phantom zeros to a capacitive current–current feedback network than to a resistive transimpedance feedback network. This obviously improves the bandwidth capability.

Realisation: Figs. 2 and 3 show a practical realisation of a current–current feedback receiver with three distinct amplifier stages. The number of stages has been made that high to arrange a high forward gain even at the highest frequencies of interest. Now, the feedback loop optimally controls the current gain and the output signal easily dominates the output noise. The gain of each stage is made as large as possible by (i) avoiding local feedback, (ii) low shunt impedances and (iii) high serial impedances. The dominant order of the current gain has been kept as low as possible by dynamic decoupling with T3, T5 and T6.

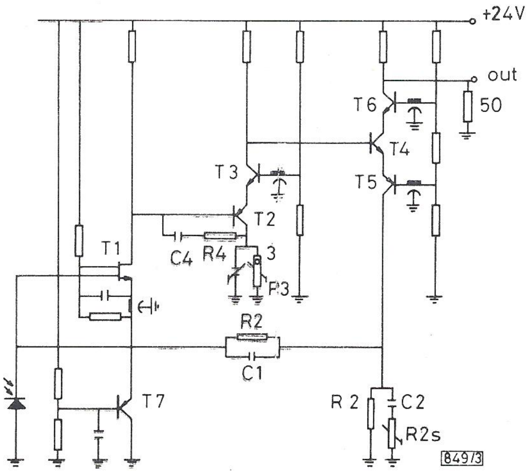

Fig. 3 *Practical realisation of a third-order current–current feedback front-end*

A dominant third-order feedback loop requires two compensation operations preferably without any loss of loop gain. A phantom zero in the feedback network (without any loop gain reduction) and a pole-splitting network in the second stage (with some reduction of loop gain at midband frequencies) control the overall stability.

This optimum design approach makes it possible to design a receiver front-end with optimal performance, according to the components that have been selected. The current gain has a maximally flat third order Butterworth frequency response. The spectral noise is almost equal to the theoretical value for a single input FET, and is extremely low in the LF range.

The gain, bandwidth and maximum input current can easily

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be dimensioned within a wide interval and turned out to be reproducible. Some realised examples with the components listed in Fig. 2, are:

Current gain	100	10000
Bandwidth	100 Hz–500 MHz	100 Hz–60 MHz
GB product	50 GHz	600 GHz
Transresistance R_1	100 kΩ	10 MΩ
Maximum input current	0·1 mA	0·001 mA

Conclusions: A high-performance negative feedback receiver front-end has been developed with relatively cheap components (500 MHz bandwidth, 100 current gain).

The good bandwidth and dynamic range performance of a transimpedance amplifier and the good noise performance of a high-impedance amplifier have been combined by using the current–current feedback principle for broadband amplifier design. This new[2] feedback principle in front-end receiver design replaces the noisy resistive feedback network of a transimpedance amplifier by a capacitive noisefree feedback network. Owing to the feedback loop, the current–current gain can have a flat frequency response and the amplifier can handle relatively large input signals.

The use of dedicated components will improve the performance even more. Enlarging the transition frequency of the input FET will enlarge the bandwidth and can reduce the receiver noise; the currently used input FET was a 900 MHz MOSFET. Enlarging of the transresistance R_1 reduces the receiver noise at 'low' frequencies (1000 MΩ transresistance seems to be realisable).

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References

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