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I^2L - Efficient Bipolar LSI Extension

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Large Scale Integration in digital electronics became reality with MOSFET technology, and still today MOSFET and LSI are widely taken as synonyms. Bipolar technology had been considered unable to solve the density and power dissipation problem of LSI and consequently was assumed to be confined to low and medium density but high-performance applications and to driver and amplifier tasks in conjunction with FET's.

However, the superiority of the bipolar transistor in transconductance to capacitance ratio has stimulated and rewarded endeavors of adapting bipolar technology to Large Scale Integration both by new processing and new device/circuit techniques. In the past few years this has brought about what sometimes has been called a renaissance of bipolar technology. It might be better described as the extension of bipolar technology into the field of Large Scale Integration. A prominent new circuit/device technique serving this purpose is Integrated Injection Logic (I^2L) or Merged Transistor Logic (MTL).

In our laboratory it has evolved step by step from work on bipolar memories, where the LSI requirements of low power and high density are particularly stringent. The first breakthrough was the replacement of ohmic load devices by lateral pnp transistors giving small area loads at concurrently low power levels [1]. The second important step was the utilization of upside-down operated npn transistors reducing the isolation area requirements [1]. Then it was realized that the pnp load devices could be merged with the npn switching transistors giving a very compact superintegrated memory cell, the first device that used the principle of direct injection of minority carriers into the switching transistor [2]. After having realized that the upside-down operated transistor with its very high current gain in the now inverse mode prevents current hogging in saturated multicollector transistors, one could use it in simple merged phase splitters [3]. Finally, with collector dotting, it became a new logic circuit: Merged Transistor Logic [4], published by Berger and Wiedmann at the 1972 ISSCC in Philadelphia. A Dutch team, Hart and Slob, presented the same indepedently and differently conceived circuit at the same conference [5] under the name of Integrated Injection Logic (I^2L), which is more widely known now. After some strong initial doubts it has been realized by the community of electronic engineers that I^2L/MTL is a viable approach and that it directly attacks the dominant position of MOSFET's in LSI. Similarly to FET, it compromizes performance (upside-down npn!) for density and low power but at a better level than with FET's.

In the important field of digital computer components this has brought the big manufacturers into a certain conflict as they would not like to compete with their own well established MOSFET products. Therefore, it has been sought to fill with I^2L the performance gap between conventional bipolar circuits and FET ones. In view of the steadily improving FET performance, the original minimum I^2L operating delay of above ≈30 ns was not fully satisfactory. Consequently, technological improvements brought the operating delay down to a respectable 10 ns [6]. Single chip microprocessors of better than FET performance seem to be the first important entry in the computer logic field [7]. From this starting point, I^2L has a good chance to roll off at least part of the strong FET position. In memory, besides good performance, I^2L offers the feature of static stable cells at densities up to ≈8 k bit/chip with present technological capabilities. Just now manufacturers begin to exploit these I^2L memory possibilities [8].

A very clear situation exists in the field of linear/digital circuits. Bipolars are still the best choice for linear circuits, and I^2L fills the need of having highly dense digital circuits on the same semiconductor slice. Last not least, there is the wide field of rapidly developing new digital applications. This is the consumer market and the field of communications. Besides the density/power/speed advantages, I^2L can gain here from the advantage of being compatible with regular high speed bipolar technology and being able to provide good drivers in the frequent interfaces.

One of the general arguments against I^2L is that FET's are rapidly improving and thus the I^2L advantage would vanish. This overlooks the fact that the necessary technological innovations usually serve both bipolars and FET's about the same way, and that FET's cannot surpass the theoretical limit of transconductance $I/kT_{/q}$ at which bipolars already have been operating [9].

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