

Ammeter Theory of Operation

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I. AMMETER OF OPERATION

The fundamental relationship of electronics is Ohm's Law,

$$V = IR, \quad (1)$$

where V is the amount of force (Voltage) required to push mass over time (Current) through medium (Resistance). If "V" is known and "R" is known, one may calculate the current from a circuit. One possible way to do the current to voltage conversion is shown in Figure 1.

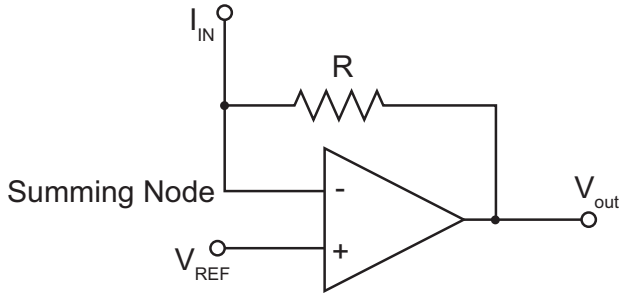


Fig. 1. The amplifier uses the concept of a "virtual short" between the input terminals to convert a current into a voltage.

A common analysis of amplifiers involves the concept of the "virtual short", meaning that the amplifier will try to match the voltage seen at the positive and negative input terminals. In Figure 1, the amplifier has a feedback through a single resistor from the output to the negative input terminal. The voltage of the output will be set so that current generated through the resistor will cause the summing node to be the same voltage as the reference input.

As an example, we will assign some arbitrary values to the circuit shown in Figure 1. Assume that the input current, I_{IN} is 1mA, and that the resistor has a value of $1k\Omega$ with the value of V_{ref} at GND, the amplifier will set a voltage on the output to match the voltage seen at the reference input. In order to match a 1mA input across a $1k\Omega$ resistor, the amplifier must produce -1V at the output

II. LOG COMPRESSION

The next ammeter presented is an ammeter that uses a "current sink" circuit concept to measure current, resulting in a unidirectional current measurement where a current flows into the ammeter device. This architecture is similar that of the PocketPico Ammeter. A conceptual schematic of a log compression ammeter is shown in Figure 2. The ammeter design is different from the resistor-based ammeter because

the feedback controls a MOSFET that is effectively a voltage-controlled current source. In the same way as the architecture presented in Figure 1. The current calculation is achieved by current summing at a CMOS amplifier input. The voltage required at the output of the amplifier to achieve a node sum of zero is the voltage representation of the current.

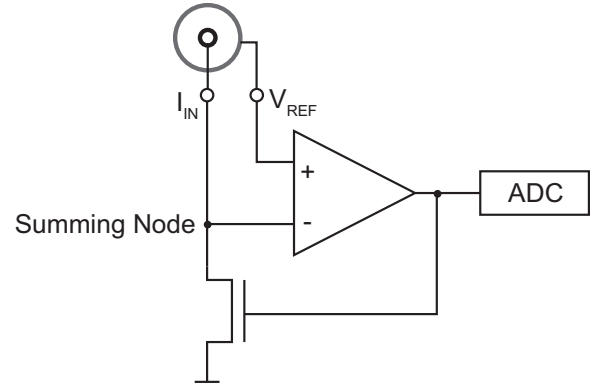


Fig. 2. Simplified circuit of the ammeter circuit.

As the current increase, the voltage at the amplifier output increases so that the current at the summing nodes cancel for V_{ref} . The equation that governs this behavior is

$$I = I_f - I_r$$

$$I_{f,r} = I_{th} \ln^2 \left(1 + e^{\frac{\kappa V_g - (1-\kappa)V_w - \kappa V_{T0} - V_{s,d}}{2U_T}} \right), \quad (2)$$

which combines all regions of operation into a single equation^{1,2}. The mathematical form of $\ln^2(1 + e^{(x/2)})$ interpolates between regions, and in saturated, subthreshold operation, (2) reduces to

$$I_f \approx \frac{W}{L} \frac{U_T^2 \mu C_{ox}}{\kappa} e^{\frac{\kappa V_{T0}}{U_T}} e^{\frac{V_{dd} - \kappa V_g + V_s}{U_T}}. \quad (3)$$

Assuming that the conditions are met to keep the device in subthreshold operation, the output will result in a log-compressed voltage representation of the current for a significantly increased dynamic range.

¹S.C. Liu, "Analog Vlsi: Circuits and Principles", Bradford Books, 2002.

²Degnan, B.P., Wunderlich, R.B., Hasler, P.E., "Passgate resistance estimation based on the compact EKV model and effective mobility" *IEEE International Symposium on Circuits and Systems*, 2009 pp. 2765-2768, 2009.