

loads have to be current driven and where accurate low-noise termination impedances must be realized, this technique may be very useful.

I. INTRODUCTION

Several techniques have been proposed in the past for providing operational amplifiers with an additional (current-source) output so that one-sided grounded loads can be current driven. Most of them make use of the fact that the sum of the currents in the supply leads equals the output current, provided that no other connections exist with ground that carry substantial signal currents. In most op amps this condition is met.

Some of these techniques make two equal in-phase output currents available by mirroring the supply currents with respect to the positive and negative supply voltages and summing them, thus providing the possibility of realizing voltage-to-current and current-to-current converters [1], [2]. The techniques however that provide two equal but opposite output currents, thus giving the operational amplifier the character of an approximation of the network element *nullor* [3], must be considered as more versatile and accurate. Huysing has related various possibilities for realizing such circuits in a monolithic form [4], [5]. However, these circuits are not yet commercially available. This paper presents an extremely simple technique for realizing a nullor approximation with currently available operational amplifiers. This building block greatly extends op amp capabilities. An implementation is given which uses two high-quality current sources and two zener diodes. Some applications will be discussed in the final section.

II. PRINCIPLE OF OPERATION

A nullor is a theoretical two-port having zero transmission parameters so that $U_i = 0$, $I_i = 0$. The op amp can be considered as a more or less successful approximation of this network element where the input port is floating (very well isolated from its environment), and where the output port has one terminal in common with the environment, viz. the supply-voltage sources U_v , as illustrated in Fig. 1. Theoretically, output terminal D can be made floating with respect to the environment by using floating power supplies. In practice, such a course is rejected because of poor isolation of point D resulting from the large physical dimensions of the batteries and their corresponding parasitic capacitance to the environment (ground). The technique proposed here for isolating point D from the environment is depicted in Fig. 2, where the power supply is formed by two equal current sources, while the supply voltages are fixed by two zener diodes. The current sources can provide excellent isolation, while the small physical dimensions of the zener diodes ensure that the parasitic capacitances to the environment are small.

III. IMPLEMENTATION OF THE NULLOR APPROXIMATION

Fig. 3 shows a simple implementation of the op amp with a floating output port. Fig. 4 gives the symbol of the circuit that can be used in operational-circuit design.

The circuit shown as an example in Fig. 5 is a voltage-to-current converter realized with the floating op amp. It will be used to illustrate some specific properties of the implementation of Fig. 3. First we will examine *offset* effects.

The voltage across resistor R_f in Fig. 5 is exactly equal to U_s when op amp properties are ideal ($U_i = 0$, $I_i = 0$). When $U_s = 0$, it follows that $U_{R_f} = 0$. A difference ΔI between I_+ and I_- cannot cause a voltage across R_f , so that this current ΔI is forced to flow through Z_1 . A zero output current with zero input voltage requires exactly equal supply currents. In practice one can use two

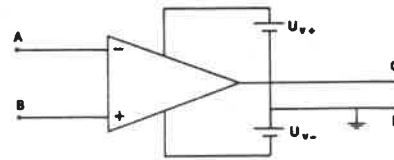


Fig. 1. Op amp with power supply. Terminal D is connected to the environment.

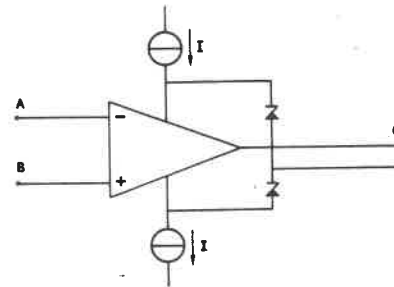


Fig. 2. Isolation of the output port from its environment by current-source power supplies.

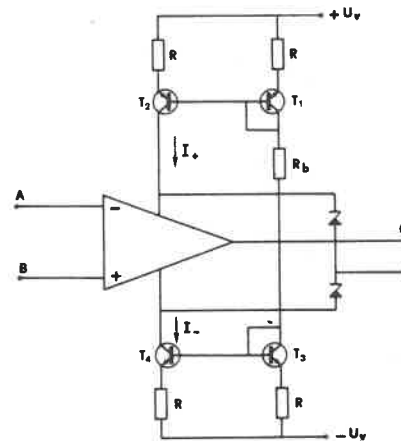


Fig. 3. Implementation of the op amp with a floating output port.

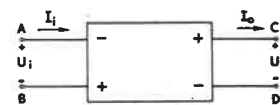


Fig. 4. Symbol of the floating op amp.

temperature-compensated, tracking and adjustable current sources. The influence of offset voltages in the upper and lower transistor duals can be kept small by means of large emitter resistors R (metal film for stability). The error output current due to inequality of the current sources will in critical cases have to be kept small with respect to the error current due to the offset drift of the amplifier. This requires fairly well-matched transistor duals in the current sources.

Except for the difference current ΔI , the output noise currents of both current sources flow through the load. For this noise contribution to be negligible it is sufficient to require the current sources to produce noise currents smaller than that of the resistor R_f . The resistors R should have large values with respect to R_f . In order to avoid large voltage drops across R , the currents I will preferably have values just large enough to supply the desired signal current to the load. Bypassing by a sufficiently large capacitor of the bases of T_1 and T_3 reduces the noise output of