

## Ultra low noise current sources

C.Ciofi, R.Giannetti, V.Dattilo, B.Neri.

Dipartimento di Ingegneria dell' informazione: Elettronica, Informatica, Telecomunicazioni  
v. Diotisalvi 2, I-56126 PISA (Italy)  
Phone +39 50 568538 Fax +39 50 568522 E-mail: ciofi@iet.unipi.it

**Abstract** - *The current sources which are normally used in research laboratories are not suitable for low noise measurement systems because of the unacceptable level of low frequency noise which they introduce in the measurement chain. The most important source of low frequency noise in such instruments is the solid state device (usually a Zener diode) which is used as voltage reference. By using a novel circuit topology in which a lead battery which does not supply current is used as voltage reference, we have been able to design an ultra low noise current source characterized by a low-frequency noise level some orders of magnitude lower than that of similar commercial instrumentation. The design, realization and testing of such current source is presented in this paper.*

### I. INTRODUCTION.

In low frequency noise measurement systems ( $f < 10$  Hz), it is often the case that the device under test need to be biased at constant current. Traditional solid state current sources can not be used to this purpose because of the high level of noise which they introduce. Sometimes a battery together with a high value series resistor can be used to simulate a current source. However, such solution becomes impracticable when the current which must be supplied is in the range of hundreds of mA or more. Moreover, the noise produced by the battery dramatically increases if the supplied current overcomes a certain value  $I_{MAX}$ , which depends on the type and the capacity of the battery [1]. Normally  $I_{MAX}$  is of the order of magnitude of the current at which one hundred hours are sufficient to completely discharge the battery. Finally, it is not possible to maintain the supplied current constant because of the discharge of the battery during the measurements. To overcome the above mentioned problems, purposely

designed ultra low noise current sources must be developed.

The topology and the principles of operation of a rather simple ultra low noise solid state current source are described in this paper. By means of an accurate selection of the active and passive components, it has been possible to obtain, in the very low frequency range, a noise level which is orders of magnitude lower than that of instrumentation of the same type available on the market.

### II. SYSTEM DESIGN

It is a well known result that batteries behave as low noise voltage sources provided that the current which they supply is very low [1]. In other words, it is possible to employ a battery as a very low noise voltage reference. In fact, in low frequency noise measurements, a high accuracy in the value of the supplied current, as that which could be obtained by means of a Zener diode, is normally not important. It is much more important to keep the background noise of the system to a minimum. In the circuit reported in Fig.1, already proposed in [2], a battery which does not supply current is employed for biasing a low-noise FET (8 2SK146 by Toshiba in parallel) used as current source.

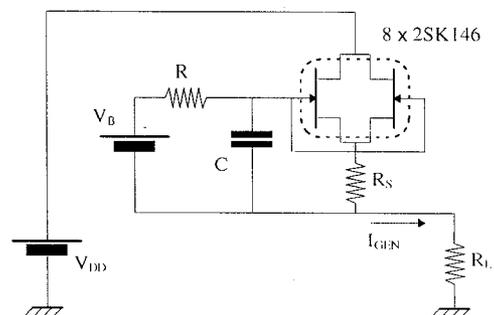


Fig.1. Schematic of the ultra low noise current source.

In Fig. 1  $R_L$  represents the load. By neglecting the gate-to-source voltage (a few hundreds of millivolts for this transistor), the current supplied to the load is given by :

$$I_{GEN} = \frac{V_B}{R_S} \quad (1)$$

The value of  $I_{GEN}$  can be adjusted by selecting an appropriate value for  $R_S$ . The most important source of low frequency noise in the previous circuit is the input equivalent voltage noise source  $e_{nFET}$  of the FET. Therefore, the power spectral density  $S_{i_{nGEN}}$  of the current fluctuations in the load is given by :

$$S_{i_{nGEN}} = S_{e_{nFET}} \left[ \frac{g_m}{1 + g_m R_S} \right]^2 \quad (2)$$

where  $S_{e_{nFET}}$  is the power spectral density of  $e_n$  and  $g_m$  is the transconductance of the FET. In many cases, (2) reduces to :

$$S_{i_{nGEN}} \cong \frac{S_{e_{nFET}}}{R_S^2} = S_{e_{nFET}} \left( \frac{I_{GEN}}{V_B} \right)^2 \quad (3)$$

since, normally,  $g_m R_S \gg 1$ .

This circuit, however, has some drawbacks. First of all, it is not easy to find on the market the active components which we have used, since they are now produced by the manufacturer only upon request and, therefore, only for very large quantities. Moreover, the simple topology shown in Fig.1 suffers from a serious limitation : if the power dissipated by the FET increases (as it happens when a high value of  $I_{GEN}$  has to be delivered to a low resistance load) the effects of the temperature fluctuations of the active devices cause a remarkable degradation of the noise characteristics [1]. However, since the Joule heating depends on the product  $I_{GEN} \cdot V_{DS}$ ,  $V_{DS}$  being the source to drain voltage of the FET, this undesired effect could be reduced by maintaining the voltage  $V_{DS}$  as low as possible, independently of the supplied current.

This result has been obtained in the circuit reported in Fig. 2 in which a different type of active device (two IF3601 by Interfet in parallel), easily available on the market, is employed.

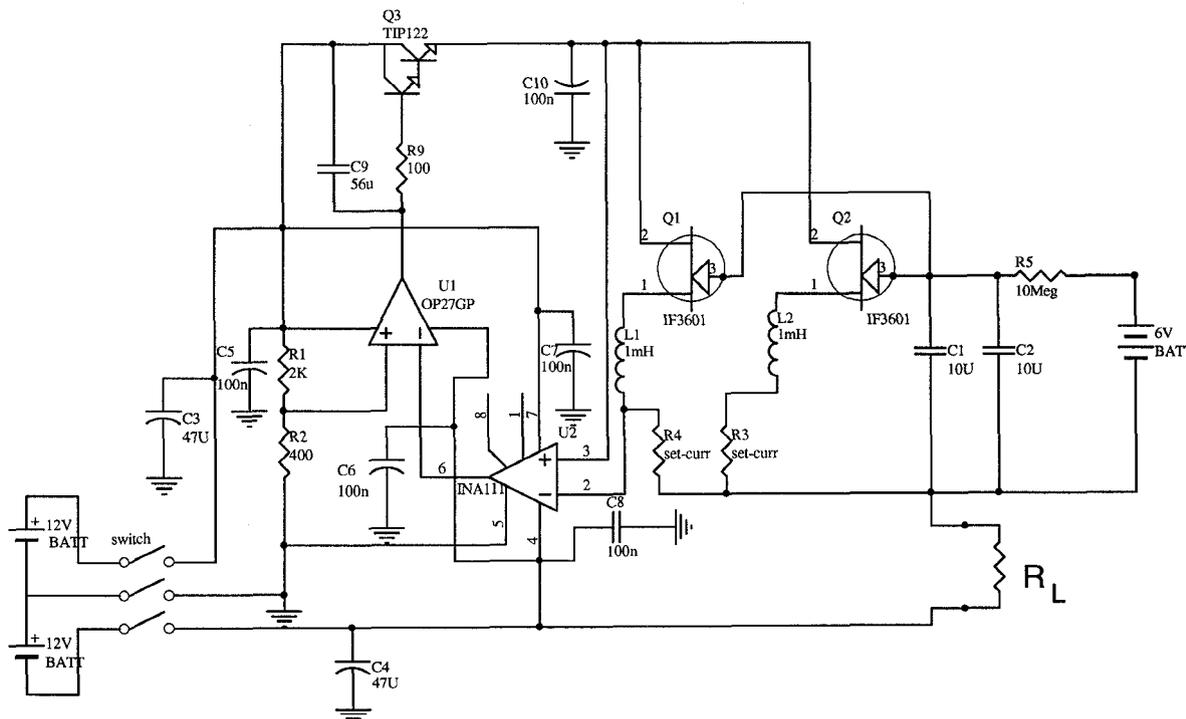


Fig. 2. Schematic of the new ultra low noise current source.

The peculiarity of this circuit lays in the fact that the voltage  $V_{DS}$  is kept constant by means of the feedback loop U2-U1-Q3. The operation of such feedback loop is as follows: the differential amplifier U2 (INA111, gain=1) reads the differential voltage  $V_{DS}$  and provides the inverting input of the high gain operational amplifier U1 (OP-27) with a voltage, referred to ground, equal to  $V_{DS}$ . The voltage which is present at the non-inverting input of U1, obtained by means of the voltage divider  $R_1/R_2$ , is equal to the desired value of  $V_{DS}$ . The operational amplifier U1 acts as an error amplifier and drives the transistor Q3 (a Darlington type TIP122) which sets the value of the voltage at the drain of the FETs.

At equilibrium; the voltage difference between the inverting and non inverting input of U1 is approximately zero, which implies that  $V_{DS}$  is equal to the desired value. Such value is about 2 V, and it is the result of a compromise between the need to reduce the power dissipated by the FETs and the need to maintain them in the saturation region.

In order to reduce the effects of thermal transients or of accidental mechanical shocks, which could cause slow fluctuations of the output current, an RC low pass filter ( $R_5, C_1+C_2$ ) with a corner frequency of 0.8 mHz, has been interposed between the battery and the gates of the FETs. The values of  $R_5$  and of  $C_1+C_2$  (10 M $\Omega$  and 20  $\mu$ F, respectively) have been chosen in such a way as to make the contribution of the thermal noise of the resistor  $R_5$ , in the frequency range above 10 mHz, negligible.

### III. MEASUREMENTS

The measurements have been performed by using metallic film, excess noise free, resistors for  $R_L$ . Different values of the output current have been set by changing the resistors  $R_3, R_4$  ( $R_3=R_4$ ) which have the same function as the resistor  $R_5$  in the circuit in Fig. 1. An ultra low noise preamplifier, described in [3] was employed in order to measure the power spectrum  $Se_{rGEN}$  of the voltage fluctuations across  $R_L$  for any supplied current. The measurement of  $Se_{rGEN}$  provides us with a means for the evaluation of the spectrum  $Si_{rGEN}$  of the current fluctuations through the load. In fact, it results:

$$Si_{rGEN} = \frac{Se_{rGEN}}{R_L^2} \quad (4)$$

However, for a correct evaluation of  $Se_{rGEN}$  we must take into account the noise introduced by the preamplifier and the thermal noise of  $R_L$ .

The power spectrum  $S_{V_i}$  of the voltage fluctuations at the input of the preamplifier is given by the following relationship:

$$S_{V_i} = Se_{rGEN} + Se_{rP} + R_L^2 Si_{rP} + Se_{rTH} \quad (5)$$

where  $Se_{rP}$  and  $Si_{rP}$  are the power spectra of the input equivalent voltage and current noise sources of the preamplifier, while the term  $Se_{rTH}$  accounts for the thermal noise of  $R_L$ .

The total contribution  $S_{BN}$  resulting from  $Se_{rP}$ ,  $Si_{rP}$  and  $Se_{rTH}$  was evaluated by disconnecting the current source and by leaving  $R_L$  alone at the input of the preamplifier. The spectrum  $Se_{rGEN}$  was then evaluated by subtracting  $S_{BN}$  from the measured spectrum  $S_{V_i}$ . The spectra reported in Fig. 3 have been obtained following the procedure outlined before with two different values of the supplied current  $I_{GEN}$  (23 and 46 mA) and with the same value for  $R_L$  (200  $\Omega$ ). The spectra have a typical  $1/f^\gamma$  behavior with a value of  $\gamma$  close to 1.5 in the frequency range from 5 mHz to 1 Hz. A comparison of the spectra in Fig. 3 with the spectrum of the equivalent input voltage noise source  $e_{rFET}$  of the FET, which have been independently measured, allow us to conclude that they are consistent with (3), that is  $Si_{rGEN}$  is essentially due to the noise introduced by the FETs.

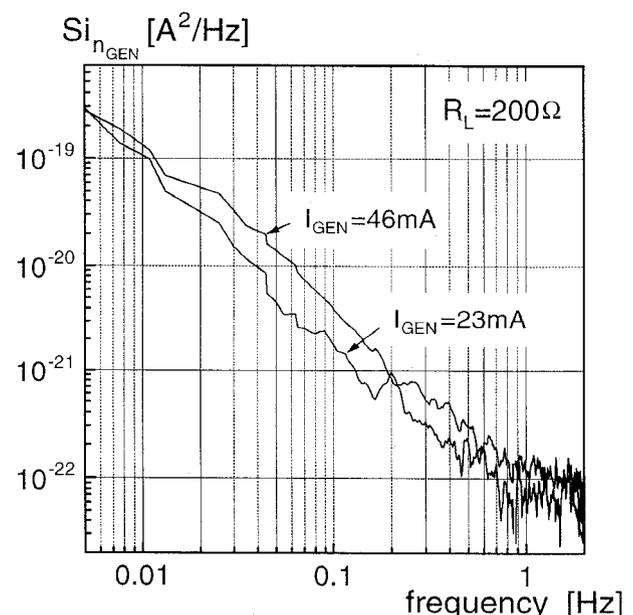


Fig.3. Power spectra of the current fluctuations at the output of the ultra low noise current source.

The difference between the two spectra in Fig. 3 are due to the different values of the resistances ( $R_3, R_4$ ) needed for obtaining the two different values of  $I_{GEN}$ .

In order to ascertain the dependence of  $S_{i_{nGEN}}$  on the DC voltage across  $R_L$ , a set of measurement were performed at the same value of the supplied current (23 mA) but with different values of the load resistance  $R_L$ . The value of  $(S_{i_{nGEN}})^{1/2}$  at the frequency of 50 mHz is reported in Fig. 4 versus  $R_L$ . As it can be seen, for a given value of the supplied current,  $S_{i_{nGEN}}$  is essentially independent of the load resistance and, hence, of the output voltage  $V_{GEN}$ .

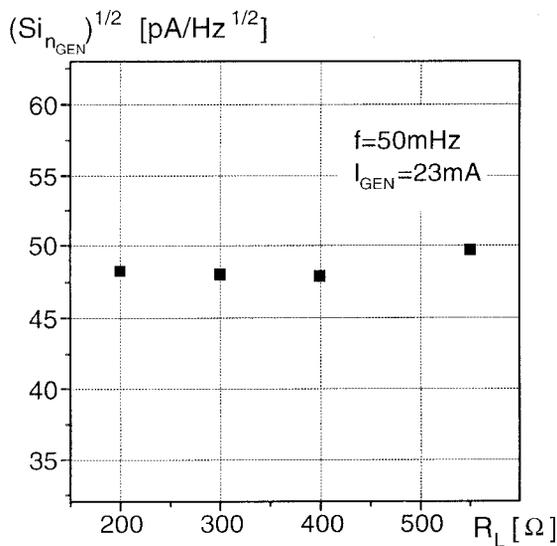


Fig.4. Output current noise spectral density (f=50mHz) as a function of the load resistance. The supplied current is 23 mA.

#### IV. CONCLUSIONS

The design, realization and testing of an ultra low noise current source has been described. The most interesting characteristic of the instrument, at present used for noise measurements in metal stripes for integrated circuits, is the extremely low level of the background noise. The careful design and the accurate selection of active and passive components, have allowed us to obtain noise levels similar to those which were previously possible only by means of low noise batteries. For a supplied current of about 50 mA, some typical values of the output equivalent current noise  $i_{nGEN}$  of the new current source are: 110, 49, 12 pA/(Hz)<sup>1/2</sup> at 0.05, 0.2 and 1 Hz, respectively. The excellent noise performances of the instrument makes it particularly suitable for applications in ultra low noise measurement systems, where a quasi-ideal current source is required.

#### ACKNOWLEDGMENT

The authors would like to thank P. Frega for the valuable support during the realization of the prototypes.

#### REFERENCES

- [1] B. Pellegrini, R. Saletti, B. Neri, P. Terreni, "Minimization of low-frequency noise sources in electronic measurements" in *Noise in Electrical Measurements, Proc. of 1st Int. Symp. on Measurement of Electrical Quantities*, p. 195-200, IMEKO, Budapest, 1987.
- [2] C. Ciolfi, M. De Marinis, B. Neri, "Voltage and current sources for ultra low noise measurement systems", *Alta Frequenza*, vol. 7, pp. 55-58, Luglio - Agosto, 1995.
- [3] C. Ciolfi, M. De Marinis, B. Neri "Ultra low noise, PC-based measurement system for the characterization of the metallizations of integrated circuits", *Proc. of the IMTC96 Conf.*, A. Barel Ed., p.319, Brussels, 1996.