

## A PULSED LOW CURRENT TEST SOURCE

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Instruments used for particle beam measurements often appear as true current sources. As such, the associated electronics can only be properly tested with a source of similar characteristics. While pulsed current sources can be easily designed for milliampere and greater currents, submicroampere sources are difficult to build. This note describes the design of a pulsed current source usable in the range from 100 picoamperes to 2 microamperes.

A true current source appears to be of infinite impedance. As such, a load resistor has no effect upon the current being supplied. In contrast, a voltage source provides the current needed to maintain the required output voltage. Examples of true current sources are the output of a Faraday Cup, a secondary emission detector or an ion chamber. At some point, even these devices can affect the current if the voltage produced in them by the beam signal influences the production mechanism.

In testing the electronics used to observe such signals, care must be taken to simulate the signal source properly. If a voltage source is connected to the input of the circuit, the current is determined by the input resistance and the source impedance. In a circuit designed to work as a current amplifier this can lead to an error. In the open circuit case (normal operation) only the unamplified offset is seen at the output, since no current flows. If the test source impedance is finite then the offset voltage will cause current to flow from the input and appear amplified at

the output. Zeroing the amplifier this will cause an opposite voltage, the amplified offset, to remain when the test voltage source is removed. Thus a generator which approaches a true current source is required for proper testing of certain types of instrumentation electronics.

In the Heavy Ion Transfer Line (HITL) between the Tandem Van de Graaff and the AGS, Faraday cups and beam transformers will be used to measure the beam intensity. The expected currents are in the range from 10 - 200 nA for the dc beam and 1 - 100  $\mu$ A for the pulsed beams, with a risetime of under 20  $\mu$ sec. A current source was required to test the amplifiers. Pulsed current sources using opamps and transistors were not usable in these current ranges. A high quality pulsed low current source has been built using a FET as a switched variable high value resistor with feedback for current control.

By carefully laying out the circuit and shielding input and output leads, switching spikes have been eliminated for currents over a few nanoamperes. For lower currents, they still appear unless the FET is biased slightly "on" (200 picoamperes). Output risetime depends upon the load resistance and capacitance, since the output current is fixed. For short leads a 10 microsecond risetime into 50 k $\Omega$  was obtained.

Operation of the circuit can be understood from Figure 1. The 1 M $\Omega$  resistor (R7) is used to sense the current flowing through the FET (Q1). The difference between this signal and the reference is amplified and applied to the gate of the FET to adjust its resistance to produce the desired current. The value of the current sensing resistor is a compromise between the need for adequate voltage when providing low current, and saturation of the amplifier, or "squeezing" of the FET, when delivering high current. In this condition the FET is at its minimum resistance and the source impedance approaches the 1 M $\Omega$  of the viewing resistor. To obtain the highest source impedance, the voltage for the feedback resistor should be as large as possible.

At the other extreme, the minimum current is set by the noise level of the circuit and the leakage resistance of the FET and circuit components; a practical value for the leakage resistance is  $10^{11} \Omega$ . With the present circuit, a current range of 4 orders of magnitude (100 pA to 2  $\mu$ A) can be obtained by adjusting the input voltage from 0 to 15 volts.

Capacitance of the circuit and FET is an important parameter which can limit the rise and fall times of the pulse. The 2N4416 is well suited to this application with input and output capacitances of 4 and 2 pF. With proper choice of design parameters, careful circuit layout and use of shielded wires for input and output lines, switching spikes can be greatly reduced, while allowing a rise time of less than 10  $\mu$ sec for a 50 k $\Omega$  load (see Figure 2).

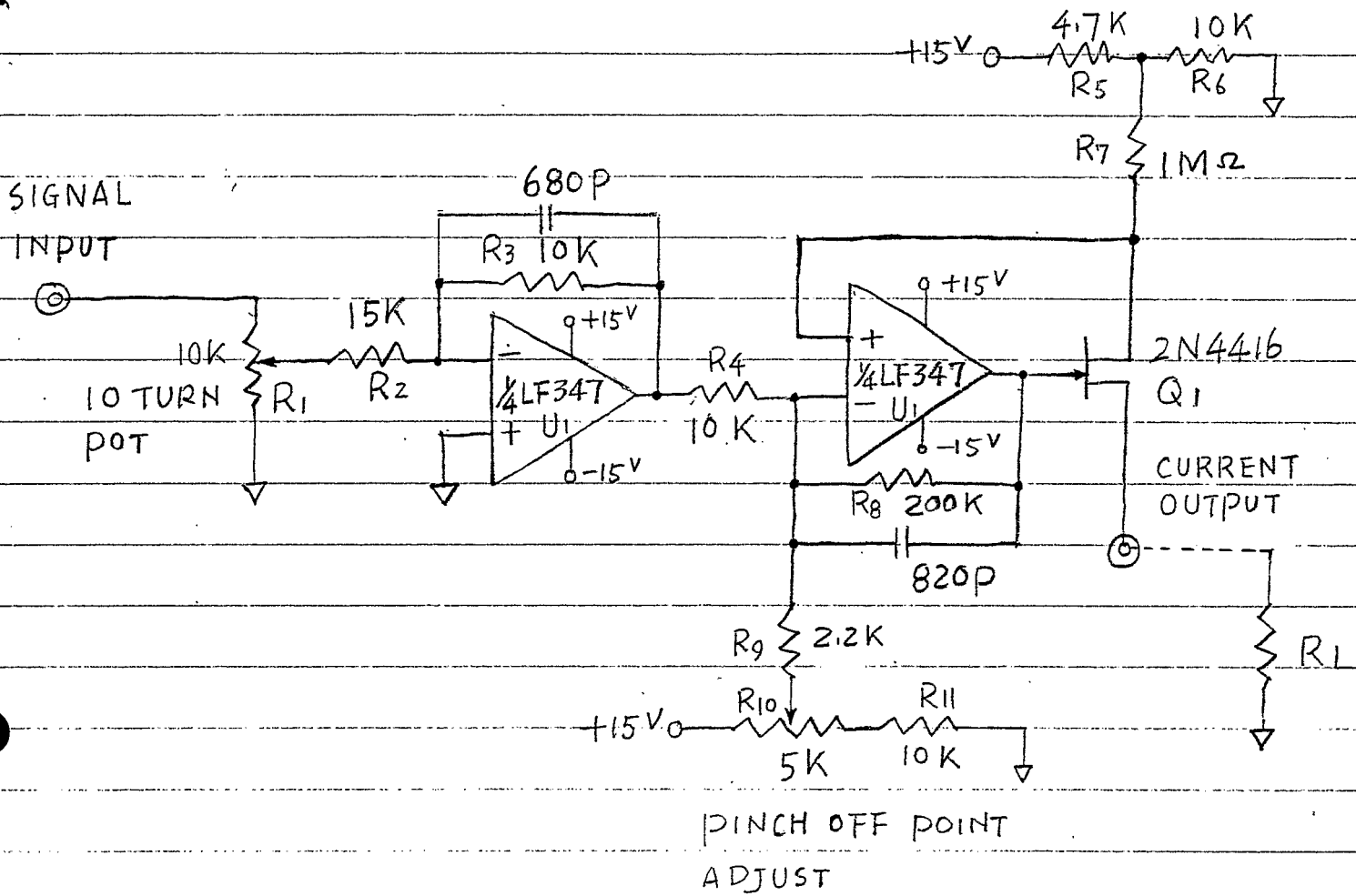
Adjustment of the gate voltage at zero input is critical: if it is too low then there is an input threshold, and switching spikes appear. If the level is set too high then excessive leakage current flows. Best operation was found to be when the gate voltage was adjusted to give a leakage current of 200 pA. Figure 3 shows an 800 pA pulse with this offset.

Performance of the current source versus load impedance is shown in Figure 4 for currents of 10 nA and 1  $\mu$ A. An FET input buffer amplifier was used for the measurements to minimize shunting of the load resistor. The LF356 opamp had an input impedance approaching  $10^{12} \Omega$ . Measurements below 100 k $\Omega$  were difficult for the 10 nA current due to low signal.

At 1  $\mu$ A, performance of the source fell for loads above 1 M $\Omega$ , as the voltage across the FET became too low for effective control. A lower current sensing resistor would have extended the range, but would compromise the lower current performance. For the 10 nA tests the departure from constant current becomes noticeable as the load becomes a significant fraction of the total resistance required for the desired current. Increasing the circuit gain reduces the effect.

### Conclusion

A signal generator has been developed to test circuits requiring a high output impedance, simulating a true current source. While there are a number of ways to producing a dc low current source, this source can also be used in a pulsed mode. By using an FET as a dynamic resistor, a wide current range can be obtained. Active feedback also improves the pulse risetime by overdriving the FET to compensate for circuit capacitance. As a result the source is able to provide current pulses from 100 pA to 2  $\mu$ A while contributing less than 10  $\mu$ sec to the risetime.



- 1) INTENSITY : 100 pA — 2  $\mu$ A
- 2) RISE TIME : 10  $\mu$ s (FOR  $R_L = 56$  K)
- 3) OUTPUT IMPEDENCE :  $> 100$  MΩ — (FOR  $R_L \leq 1$  MΩ)
- 4) PULSE WIDTH : DEPENDS ON INPUT SIGNAL

FIG. 1 PULSED LOW CURRENT SOURCE

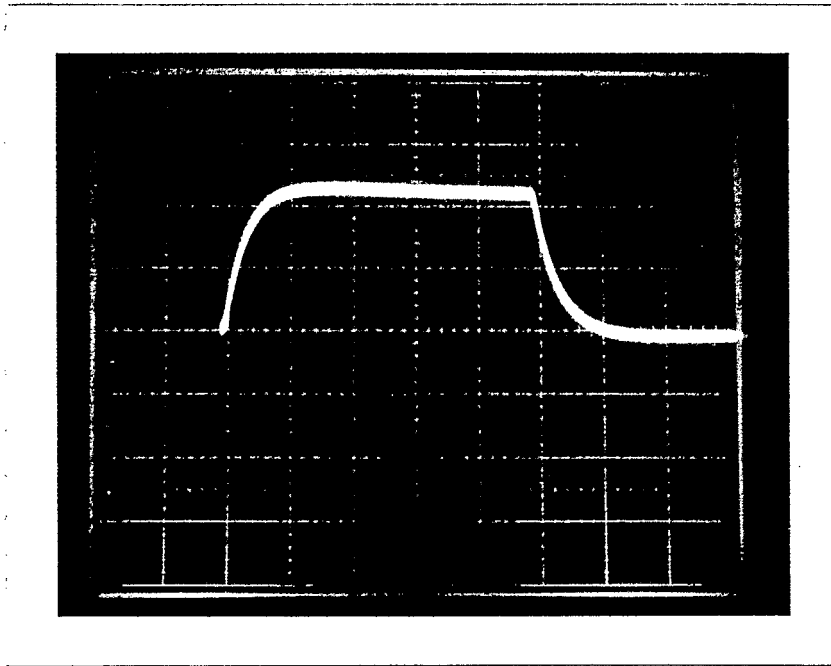


FIG.2 H:  $10\mu\text{s}/\text{DIV}$ . V:  $50\text{mV}/\text{DIV}$   
 $R_L = 56\text{k}\Omega$  (  $1\mu\text{A}/\text{DIV}$  )

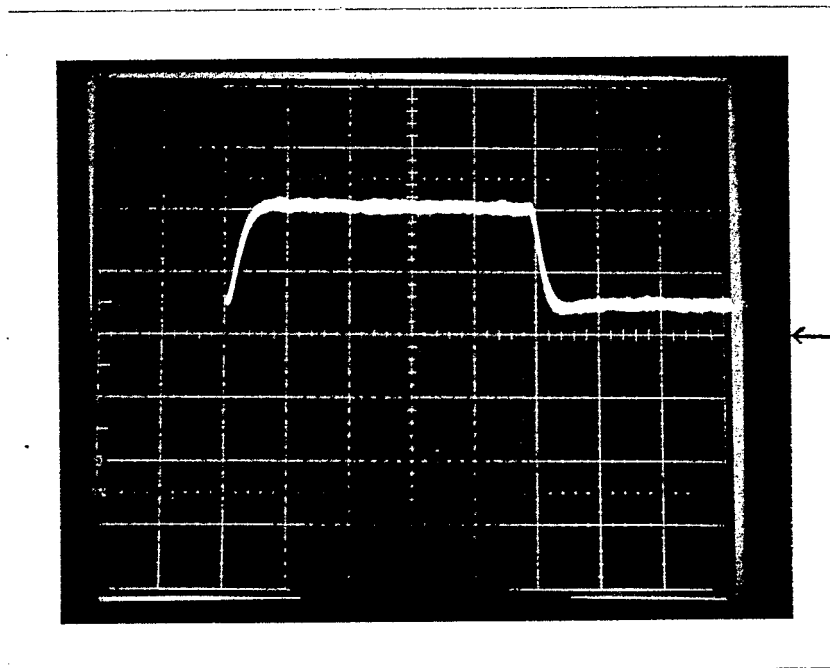


FIG.3 H:  $500\mu\text{s}/\text{DIV}$ . V:  $50\text{mV}/\text{DIV}$ .  
 (  $500\text{pA}/\text{DIV}$ . )



•  $I(100k) = 1 \mu A$

x  $I(100k) = 10 nA$

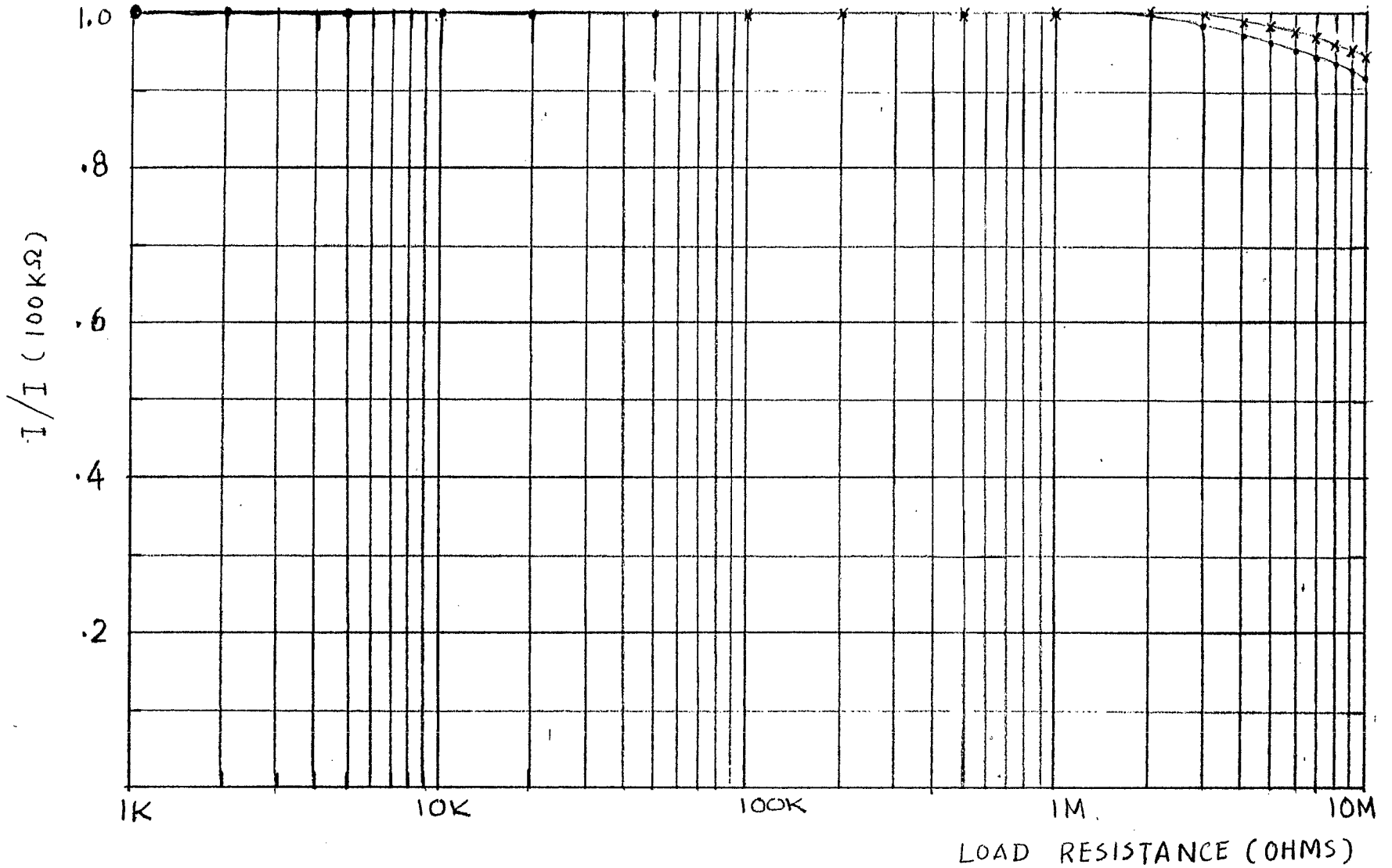


FIG. 4 CONSTANT CURRENT SOURCE PERFORMANCE.