INTRODUCTION TO PRACTICAL ELECTRONICS.
CASE STUDY: NOISE PERFORMANCE IN CMOS DEVICES.

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Abstract

Submicrometer CMOS technologies provide well-established solutions to the implementation of low-noise front-end electronic for a wide range of applications including detector applications.

This paper briefly discusses submicron transistor technologies, the setup necessary for measuring noise in transistors and reason for this measurement.

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Introduction

Fermilab:

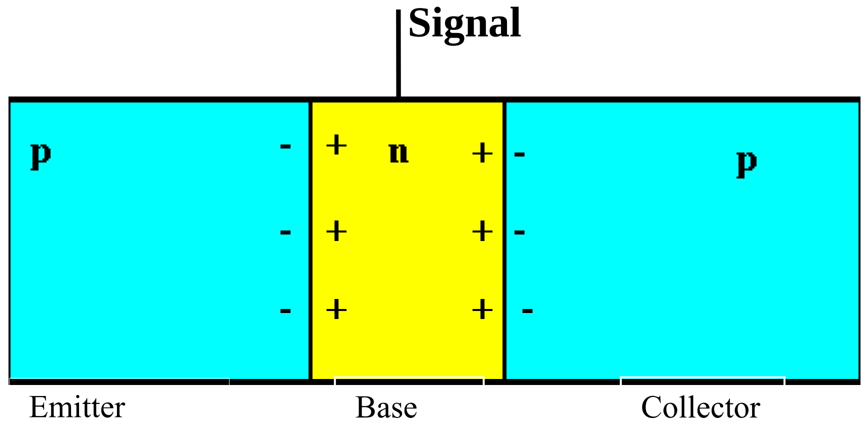
Fermi National Accelerator Laboratory (Fermilab) is a United States Department of Energy Laboratory that specializes in basic research at the frontiers of high energy particle physics. Fermilab can be said to be a laboratory that does its experiments in various forms of ways such as the Mini Booster Neutrino experiment (MiniBooNE) and the SciBar Booster Neutrino experiment (SciBooNE), which are both neutrino experiments, and other various forms of fixed target experiments.

The main experiments carried out at Fermilab are the experiments utlizing the Tevatron, which is one of Fermilab's five accelerators. The Tevatron is a circular particle accelerator that accelerates protons and antiprotons in opposite directions, and this Tevatron accelerates the particles to energies of up to 1 TeV, which is why its name is coined Tevatron. With particles being accelerated in opposite directions in a circular accelerator, these particles get to collide at some point/points, which is basically what is intended. As with collision comes the observation of smaller particles which is what the Fermilab research is all about, the discovery of smaller particles from previously known small particles (in this case, protons and antiprotons). To actually detect these smaller particles, two very large detectors were built at the points of collision of the protons and antiprotons to detect the particles generated as a result of these collisions, and these detectors are called CDF and D0.

In these various detectors, various electrical and electronic devices are present, serving as either measuring instruments, or read out devices. Therefore the field of Electrical and Electronics Engineering is important to the development of high class detectors.

The Transistor.

Image 1: Transistor



Transistors are semiconductor devices that can be used for various purposes, with the two main ones being a switch and an amplifier. Amplifying transistors basically amplifies a relatively weak signal fed into its base, into a much larger current flowing from the emitter to the collector. This kind of system is used in stereo systems where it is used to amplify the weak electrical signal generated from the tape into a strong signal to drive the stereo's speakers, while in transistors used as switches, a certain type of signal into the transistor base will hinder the flow of current from the emitter to the current, and the removal of the base signal, allows the flow of current. Transistors are used as switches in computers, which serves as the backbone of electrical systems in high-energy Physics detectors.

Before the development of transistors, vacuum tubes were already in use as active components in electronic equipments, but the transistor has several advantages over the vacuum tube which includes:

1.) Smaller sized and minimal weight,

2.) Highly automated manufacturing processes, which led to low per unit cost,

3.) Long lasting performance,

4.) Insensitivity to vibration and mechanical shock,

5.) Higher reliability and so on.

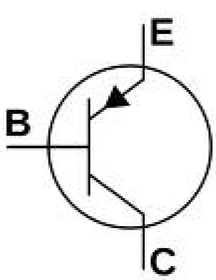
The development of transistors meant lower cost of building electronic devices, as well as smaller sized devices when compared with devices built with a vacuum tube technology.

Transistors can be categorized in different ways, such as the material used, its structure, polarity, amplification level and so on, with the polarity depicted above been an n-p-n transistor With these various categories, various transistor symbols exist, as well as various names for the three terminals of the transistor exist in the engineering world,

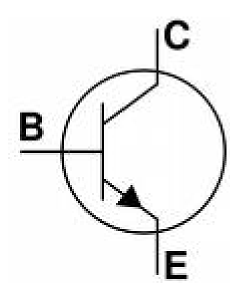
Transistor Types (Structural) :

1.) Bipolar Junction Transistor (BJT): This is mostly used as an amplifier, because the currents at the emitter and collector are controlled by a relatively small base current. The BJT conducts using both the majority and minority carriers.

Image 2: Bipolar Junction Transistor Symbol (BJT)



PNP

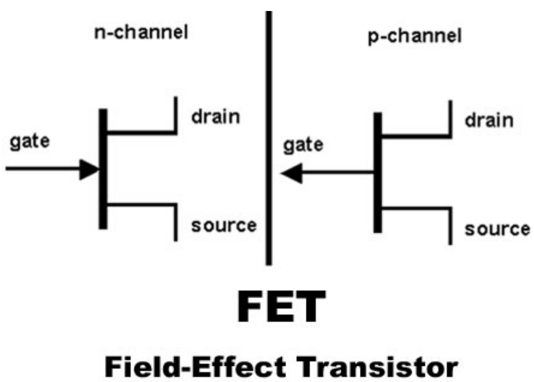


NPN

2.) Field-effect Transistor: Is a unipolar transistor. Unlike the BJT, it uses either electrons or holes for conduction. With this transistor, however comes an additional terminal, called the body, and on most FET's, the body is connected to the source, which makes it look like a 3 terminal device. In FETs, the current flowing between the drain and source is controlled by the voltage applied between the gate and the source. FETs are further divided into two classes, the junction FET(JFET) and the insulated gate FET(IGFET), which is also commonly referred to as the metal-oxide semiconductor FET (MOSFET).

Image 3: Field-Effect Transistor (FET)

3.)



ZVP2106 P-Channel Transistor

Other transistor types such as the point contact transistor, the Drift-field transistor and other exist but will not be discussed in details.

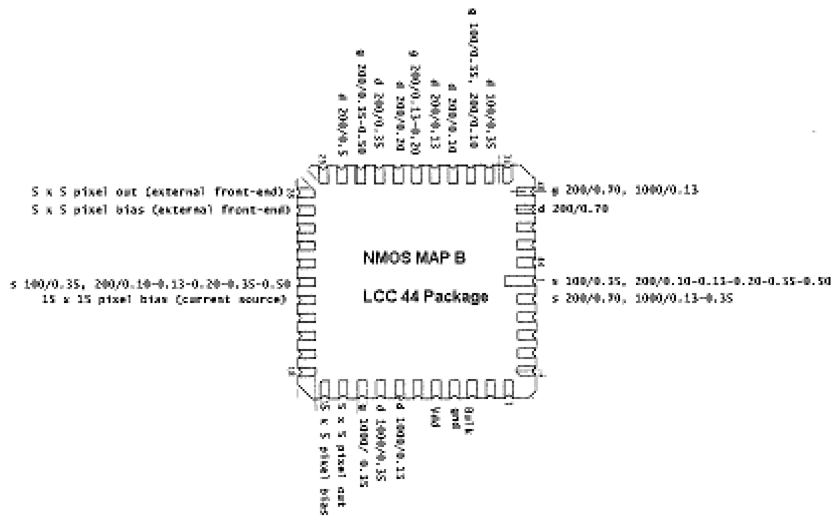
BACKGROUND INFORMATION.

Transistors are present in electronic devices serving as various forms of switches to achieve various goals in the electronic device. Like every other electronic device, practical transistors do not perform as described theoretically, due to heat produced while current flows through them, and also due to the noise they generate internally, therefore producing an imperfect result when used for measurement. However a reduction in the noise generated by transistors leads to better results being obtained.

Technological advancement known as device scaling over the past decade has enabled the use of CMOS processes in the fabrication of mixed signal circuits for radiation detectors (such as the D0 and CDF at Fermilab and the LHC at CERN), with very good performances. The radiation tolerance of CMOS technology which is due to the reduction in transistor dimensions, particularly the reduction in the gate oxide thickness being one of the strong motivations for this advancement. Another attractive aspect is the large scale of integration provided by deep submicron CMOS processes, which makes it possible for several functions to be packed inside a relatively small silicon area.

This project focuses on transistor gate lengths of 0.10 µm, 0.13 µm, 0.20 µm, 0.35 µm, 0.50 µm and 0.70 µm technologies in PMOS and NMOS transistors on chips built in different foundries. An example of such chip is shown below.

Image 4: Various NMOS Transistor Gate Technologies on an LCC 44 chip



Project.

A low-noise RF stand was designed as shown below (Image 4), with the first part of the project being placing the components on an already printed circuit board (PCB). While this served as an introduction to practical electrical and electronics engineering, it also introduced me to the art of soldering.

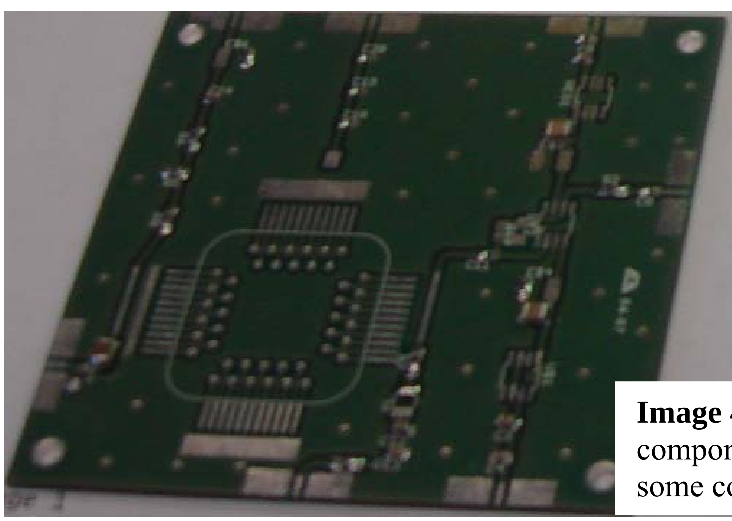


Image 4: Board on which components were soldered, with some components been shown

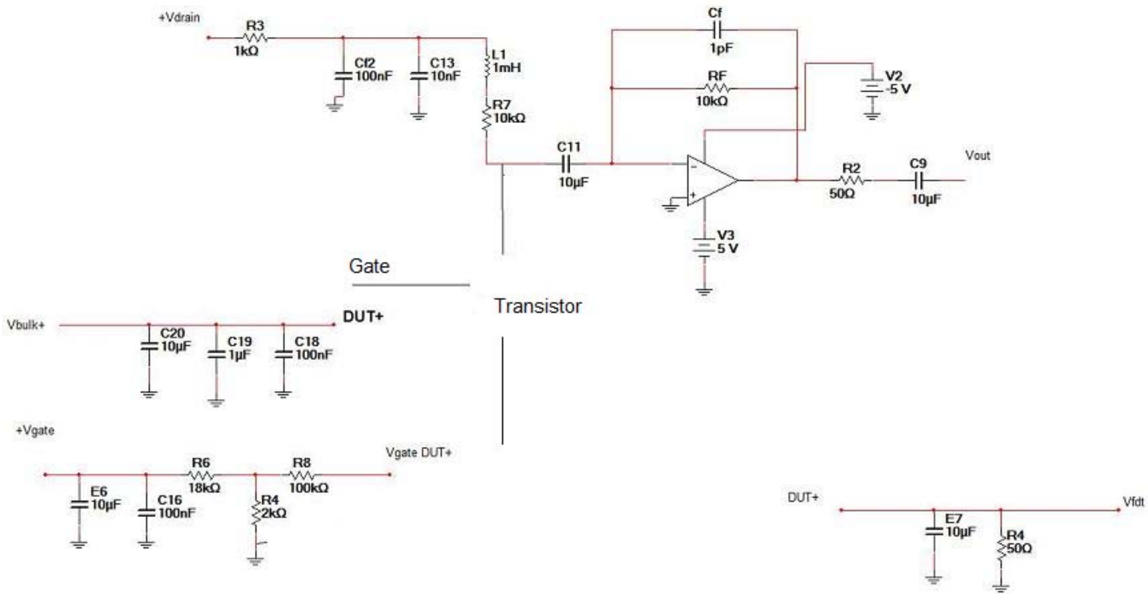
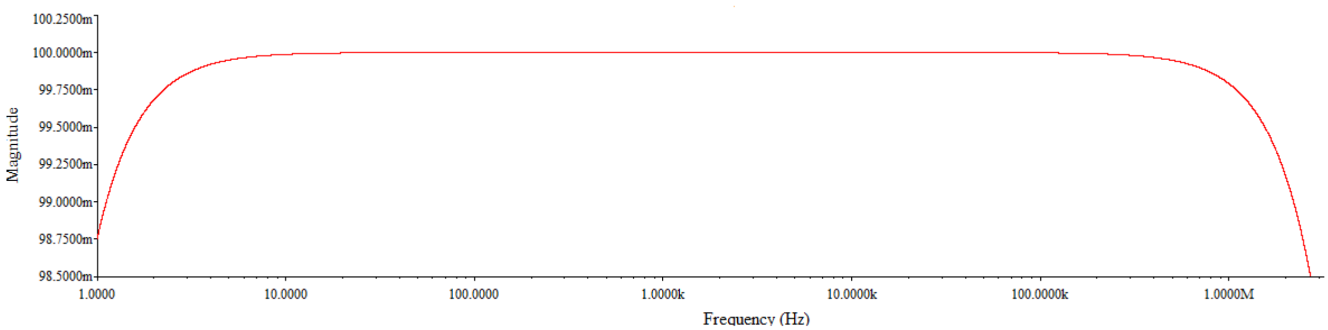


Image 5: Schematic showing the layout of circuit components

After soldering individual components unto the board, the circuit was debugged (without the transistor), to verify if the output obtained matched what was intended; therefore voltage was applied at the C11 junction. With this configuration, the operational amplifier worked with an open loop gain, as the capacitor acted as a current source to the 10kΩ resistor RF, which therefore gave a very high gain. To correct this, a 1MΩ resistor was placed in series with the voltage source and C11, thereby acting as a current source to the circuit, but with a lower current being supplied. In the test done, a $5V_{pk\text{-}pk}$ sinusoidal wave was applied to the 1MΩ resistor, therefore theoretically becoming a current source supplying $5\mu A_{pk\text{-}pk}$ (obtained from Ohm's law: V=IR) of current to the capacitor. The magnitude of the output voltage can algebraically be evaluated using $(Rf \div Rf1) * Vin$, and the bandwidth of the system given by $1/(2 * \pi * Rf * Cf)$. A low pass filter is meant to be obtained with C11 filtering off DC input, however the transfer function obtained was narrower than expected, which signified an error in circuit build or measurement.

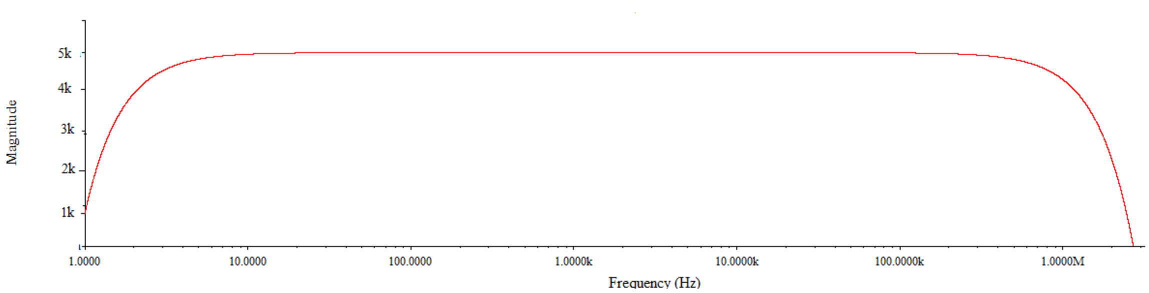
With no marking of input bias current for the operational amplifier, it was considered that there was a form of bias current (in the mirco-amp range)needed to drive the op-amp; therefore the percentage loss of current from C11 to the feedback network is great for a low output current source. Therefore, the series resistor value was reduced from 1M to 100K to produce a higher current, which reduces the percentage of the current being lost to the amplifier. With this replacement, the transfer function was obtained as shown below.



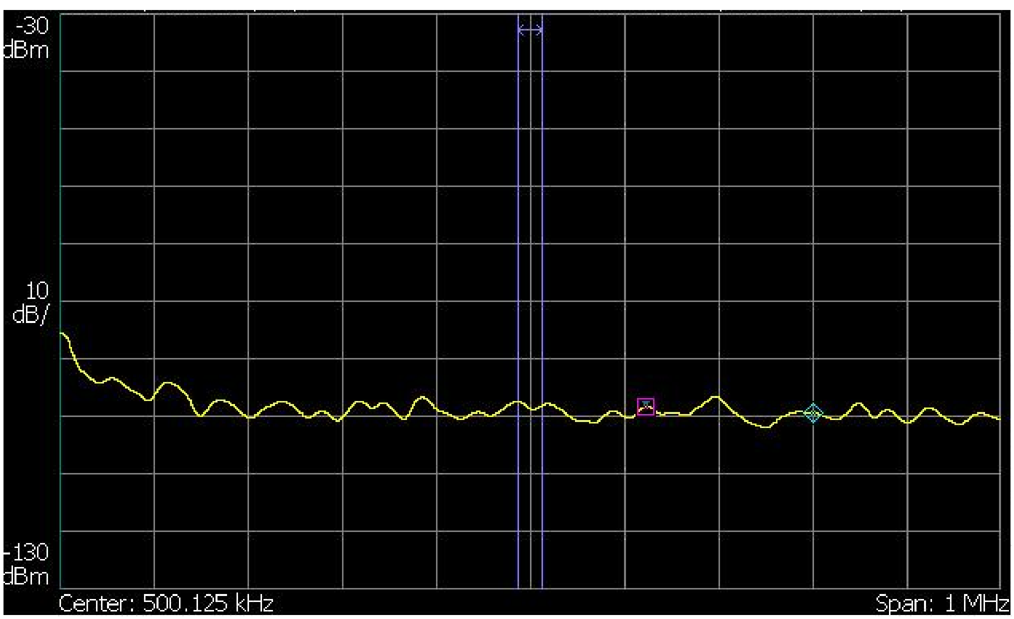
With the transfer function, $H(s) = \frac{Vout}{Vin}$, taking input as the voltage into the resistor and not the current into C11.

The plot above is a theoretical representation of the transfer function, however the results obtained in the laboratory were greatly similar to that above, with the exception of some ripples on the top flat side of the plot.

However, to measure the transfer function in the transistor, the input reference would be the drain current; therefore the current into C11 is needed to calculate the transfer function, which gives the plot below.



The plot is similar to that previously obtained, except for the magnitude difference. With this transfer function, noise produced by the transistor would be amplified when the drain current is significantly greater than the input bias current of the operation amplifier. With the amplification and the bandwidth of the circuit already measured, the noise power produced by the circuit elements and the operational amplifier is obtained by connecting the output of the output of the operational amplifier to a spectrum analyzer and the plot is obtained as shown below. With the needed circuit information known, the transistor noise can easily be obtained, and extensive analysis and results will lead to the realization and formulation of various equations leading to the noise levels in these transistors.



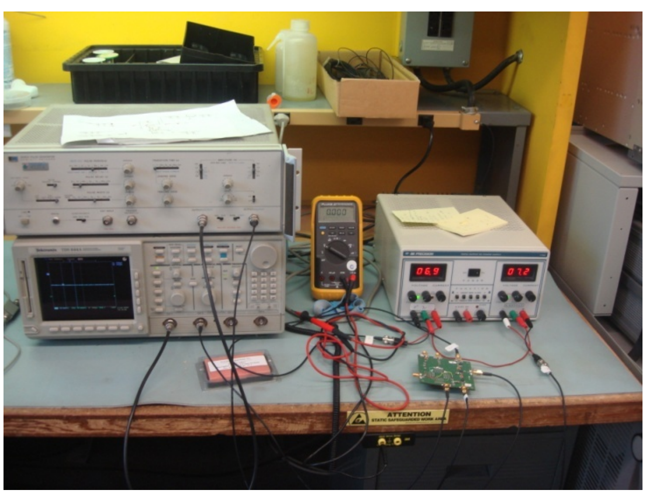
Noise Power Spectrum for circuit components without transistor

From the plot above, it is evident that the noise power is great at lower frequency which is due to the flicker noise component being greater than the white noise components, however the flicker noise components steadily degenerates therefore showing a white noise region which is expected in the circuit.

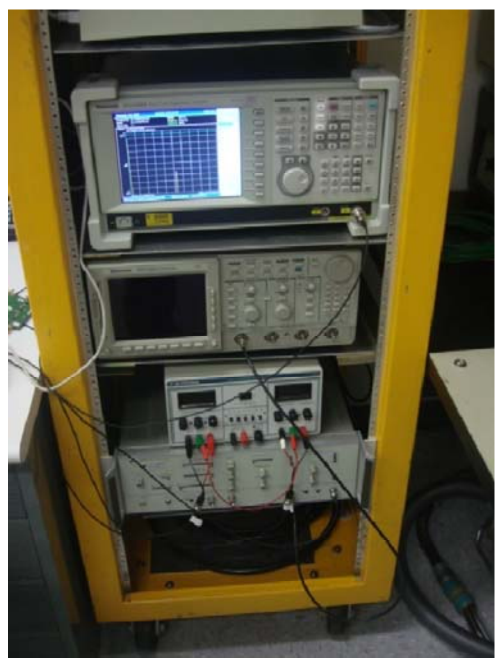
Conclusion.

The RF stand needed for noise measurement was successfully built and debugged, however noise measurement in the transistors are yet to begin due to circuit modifications and delayed product arrivals. It should be noted that to improve the function of this circuit, an operational amplifier with a lower input bias current or a amplifier transistor should be used to reduce the effect of the current being used by the operational amplifier.

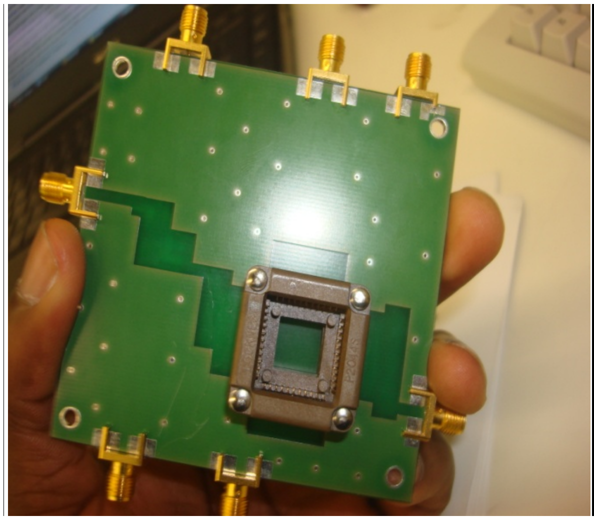
Additional Images from Laboratory



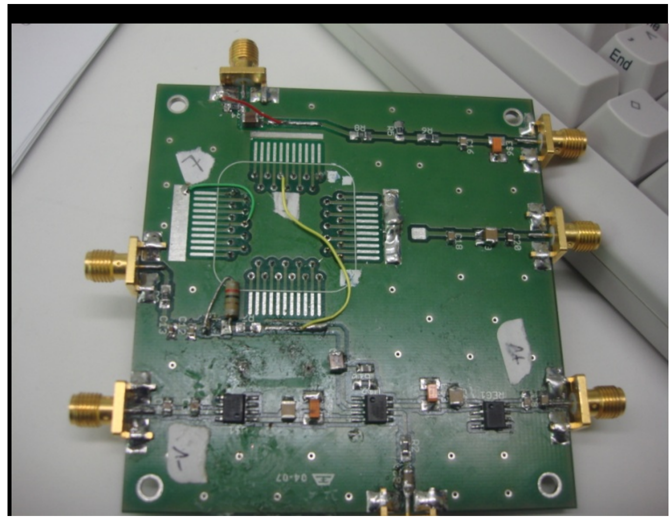
Instruments used for measurement



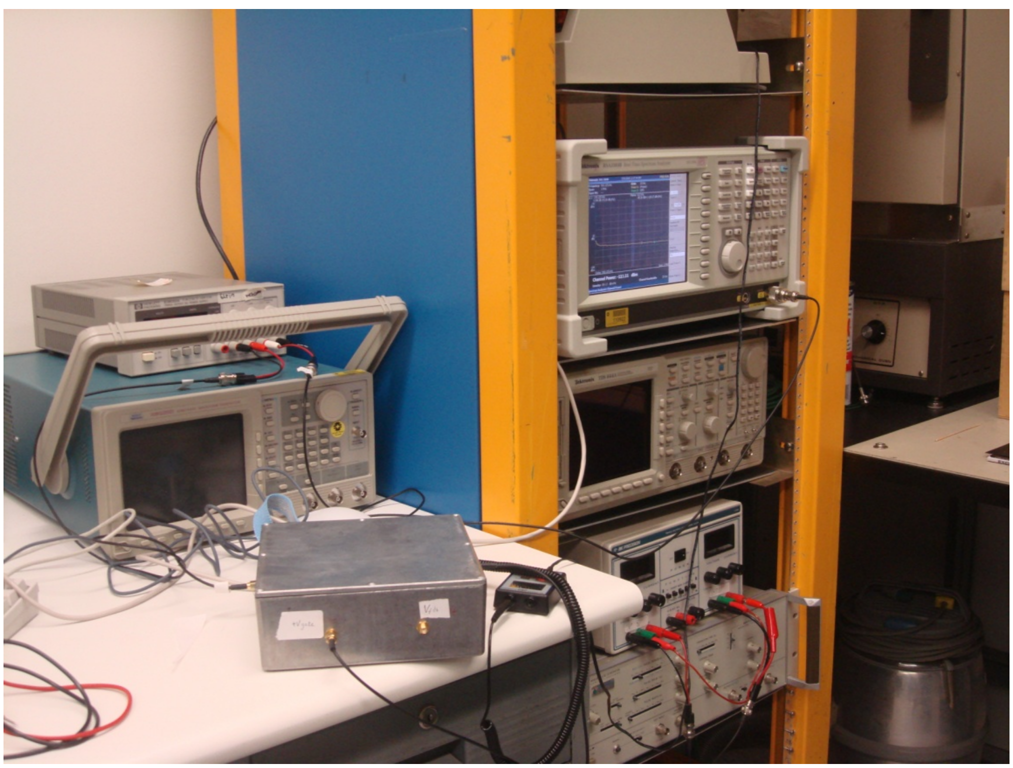
Instrument Stand T-B: Spectrum Analyzer, Oscilloscope, DC Power Supply and Pulse Generator



Printed Circuit Board showing socket for mounting transistor chip



Printed Circuit Board showing top side of board with components soldered.



Circuit Board In an aluminum RF enclosure to reduce effect of external noise in the system with measuring instruments and power supplies in background.

References

[1] M. Manghidoni, L.Ratti, V.Re and V.Speziali "Submircron CMOS Technologies for Low-Nosie Analog Front-End Circuits" IEEE Transactions on Nuclear Science, Vol 49. No4. August 2002.

[2] http://www.allaboutcircuits.com

[3] http://www.solarbotics.com

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