PRACTICAL TEST SET-UP AND METHOD FOR DETERMINING THE RESPONSE CHARACTERISTICS OF A LOG RATE CHANNEL OVER 6 DECADES

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ABSTRACT

A test method was developed using modern, readily available instrumentation to produce an exponentially rising signal over 6½ decades. The method includes validation and calibration tests. It was used to simulate the current signal that would be produced from an ion chamber during a hypothetical loss of Regulation event for a reactor from a shutdown state. This simulation scenario was then used to test the log rate channel of the new ion chamber amplifiers for the NRU research reactor second trip system upgrade.

METHOD 1 - Set-up & Validation

A Personal Computer (PC) equipped with an IEEE-488 port and running Lotus-123* with Lotus Measure* was connected to both a Keithley Model 220 Programmable Current Source (PCS) and to a Fluke Model 8840A Digital Multimeter (DMM) via their IEEE-488 ports. Both the output of the PCS and the input to the DMM were connected across a common resistor. The DMM was set to monitor voltage in auto-ranging mode.

A set of electric current values was generated in the spread sheet starting at 80pA (equivalent to 10^{-4}% reactor power) and ranging up to 120uA (equivalent to 150% reactor power). Each point was approximately 1.0% greater than the previous one in anticipation of a 10 point per second throughput.

Paired Lotus Measure instructions were programmed into the spread sheet such that after each data point (current) was sent to the PCS a corresponding value (of voltage) was read back into the same spread sheet immediately from the DMM. The source data was then adjusted to accommodate the timing of the set-up to achieve a current increase of 23.0 seconds per decade. This is based on the conversion of natural logs to base ten logs and a required acceleration of 10%. Given this arrangement, each simulation pass scanned 1430 data points and took approximately 2.5 minutes to run.

The DMM measured voltages were subsequently converted to output current ($I_{out} = V_{out}/R$) and graphically analyzed along with their corresponding spread sheet created input current (I_{in}) for log conformity and temporal fidelity. Figures 1 through 4 show I_{in} versus Log (I_{out}) and 100 x Log (I_{out}/I_{in}) to emphasis log non-conformances in the measurement system.

OBSERVATIONS

The Figures 1 and 2 indicate clearly the range changes of the DMM. Each range is slightly offset from the previous one indicating minor (and acceptable) calibration differences between ranges. The initial portion of the curve (Figures 1 and 2) where the current is in the picoamp range - is slightly offset from that which is expected under ideal conditions. The small current offset was presumed to be due to input offset current (or bias current) of the DMM. This area was investigated further using a 10 M Ω resistor instead of a 1 M. The input offset error current from the DMM had produced 0.25 millivolts across the 10 M Ω resistor and 0.025 millivolts across the 1 M Ω resistor. By using the offset feature of the DMM, with the current source off line, this error current could be temporarily nulled. (It was found to drift so the offset nulling had to be done just prior to running the curve).

*** Lotus 123 and Lotus Measure are Registered Trade Names of Lotus Development Corporation.**

The latest portion of the curve, where the current is high and the voltage is in the 100 volt range is significantly offset. At the high end, in the 20 to 100 volt range, the input resistance of the DMM is $10^7\ \Omega$ versus 10^{10} on all other ranges. There should therefore be a 10% error in the magnitude over this portion of the curve.

Noise is significant and shows in Figures 1 and 2. The noise signal will become smaller as the current increases due to the nature of the graph construction. Conducted and radiated susceptibility were both noted. The predominant noise was a random large spike - seen in Figure 2. It was treated as a minor inconvenience resulting in an occasional requirement to repeat a test.

The method was then modified slightly to include multiple measurements after each current value was output. The results are plotted in Figures 3 and 4. This emphasises the temporal response of the output signal with respect to the desired staircase wave. Figure 3 emphasises the staircase input and shows the random errors in reading the signal at these low levels. There is no evidence of 'staircase' shape in the measured response.

Figure 4 is a decade step with a long dwell to investigate the response time delay. The difference in settling time for the two output current values is obvious.

Figure 5 shows a larger step of input current and into a lower resistance load. Note the improved response time. This load resistance is the same as that provided by the amplifier.

METHOD 2 - Testing

Once the above set-up had been proven the output of the PCS was connected to the amplifier to be calibrated and the electrometer connected to the amplifiers Log Rate or Log output for calibration. The in-situ test of an amplifier is shown in Figure 7, 8 and 9.

DISCUSSION

The slow response times in the small current portion of the tests are a result of the small current charging the circuit capacitance. The capacitance is the sum of the coaxial cables, the input of the meter and output of the current source.

For a signal of 100pA and a total capacitance of 1nF.

$$\frac{dv}{dt} = \frac{i}{C} = \frac{100 \times 10^{12}}{1.000 \times 10^{9}} = 0.1 \text{v/sec}$$

If the circuit resistance is high, as in Figures 1 through 4 then this slew rate appears as a long time constant. If the circuit resistance is low, as in Figure 5 through 9 then the slew rate can be easily identified. This small signal error is not specific to this test but will be experienced for any current source and is dependant on the capacitance in the input circuit.

In the case of the exponential signal covering the range of 10^{-4}% RP to 100% RP (Figures 1 and 2), the slew rate will change with the current magnitude over the six decades. This has the affect of providing an improvement in temporal tracking as the signal increases: or stated conversely - an error exists in this value at small signals.

At higher current values ie 10μA (and 1nF) the slew rate would be 10000v/sec.

Figure 6 is the output of an analog circuit simulation session showing the linear signal output, the log signal output and the log rate output for a similar exponentially rising input. Note that the log rate signal reaches 99% of final value at about the 100 second point.

The result of this temporal distortion at the input will show at the output of the log rate stage most profoundly as a reduction of expected rate for the small signal inputs and less obviously in a delay in the rising edge of the Log Rate signal.

Figure 7, 8 and 9 show the effect of bias or nulling errors on the Log Rate output.

CONCLUSIONS

This test is more informative than the common single measurement of the derivative time constant component values, and may be performed in-situ without decommissioning the amplifier. Non-conformances to the Log function, input bias errors, and log rate performance can all be investigated.

The temporal distortion inherent in the staircase signal is small and acceptable for this testing.

Adaptation to different starting or ending values is convenient due to the inherent nature of the spreadsheet as a test platform.

REFERENCES

1 Lotus Development Corporation, "Lotus Measure Reference Manual"

2 Keithley Instrument Ltd, " Programmable Current Source Model 220 Instruction Manual"

3 Fluke Instruments Ltd, "8840A Multimeter Instruction Manual"

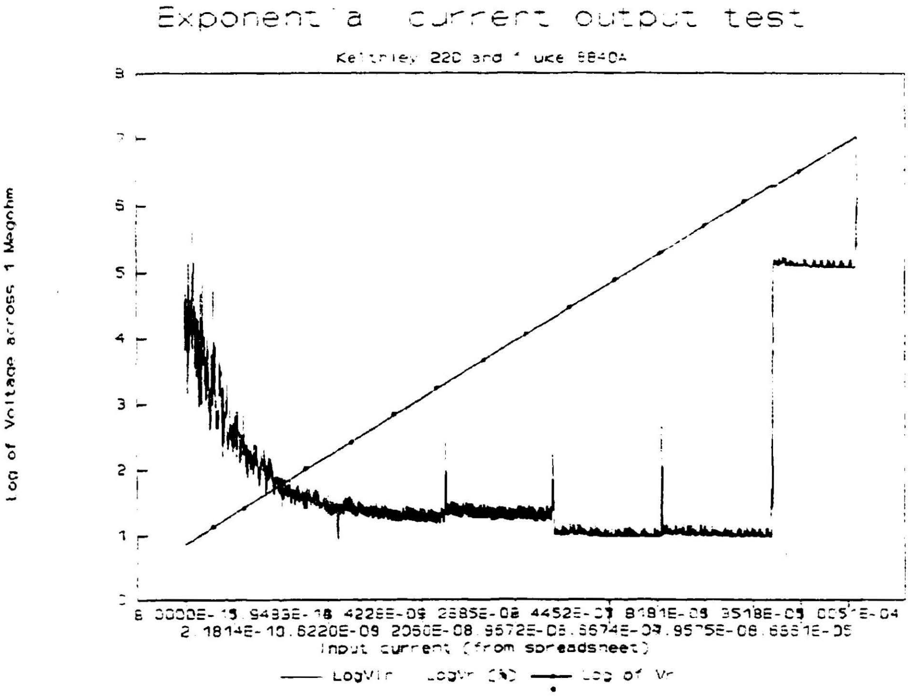

Figure 1

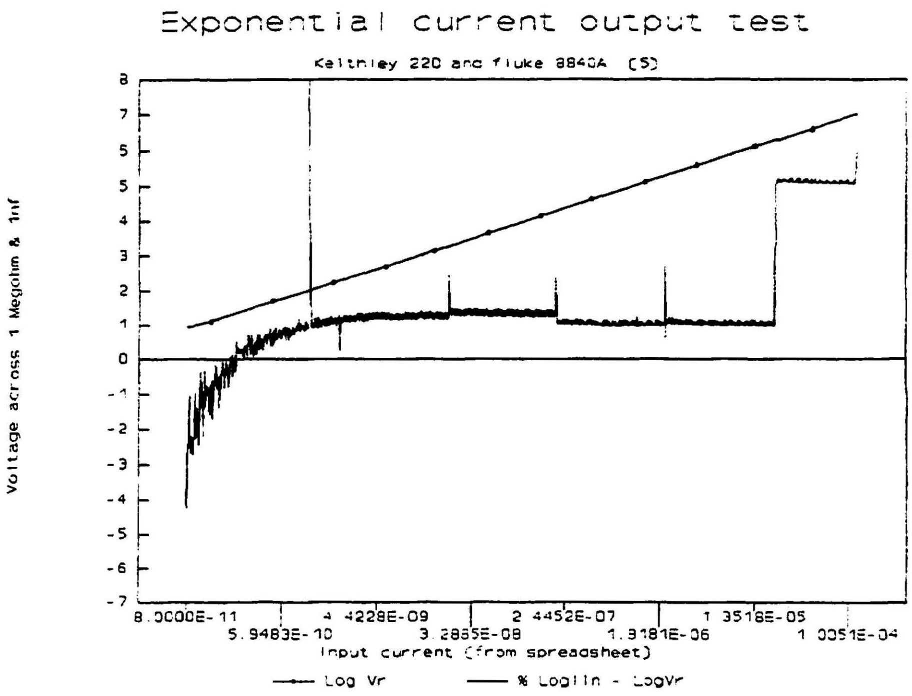

Figure 2

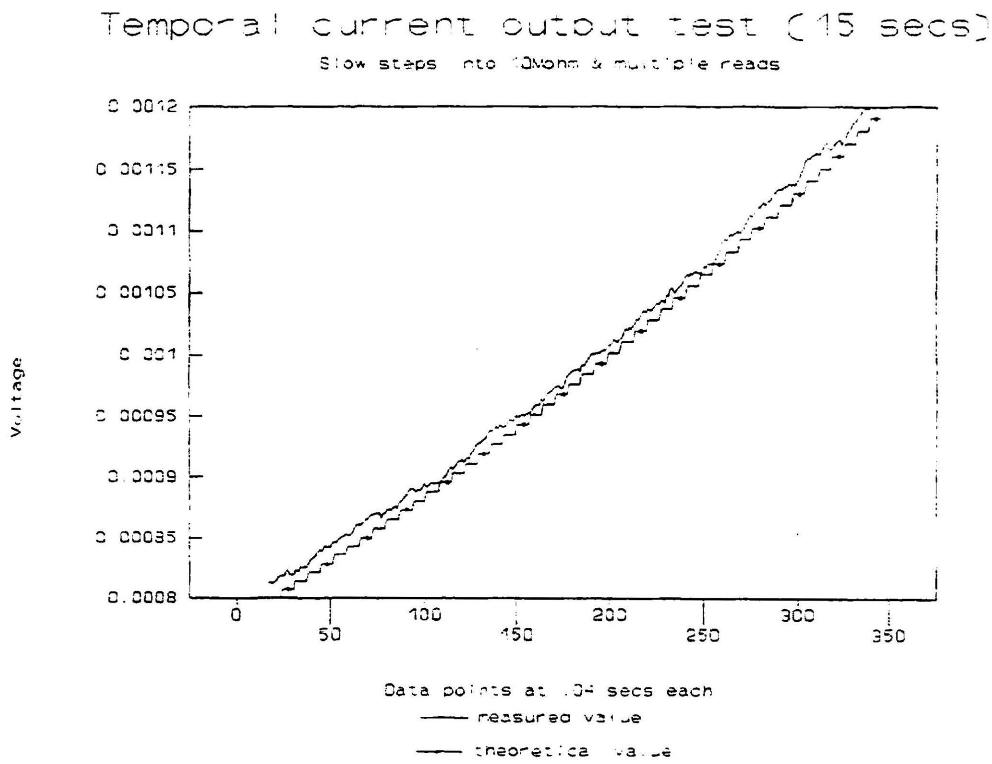

Figure 3

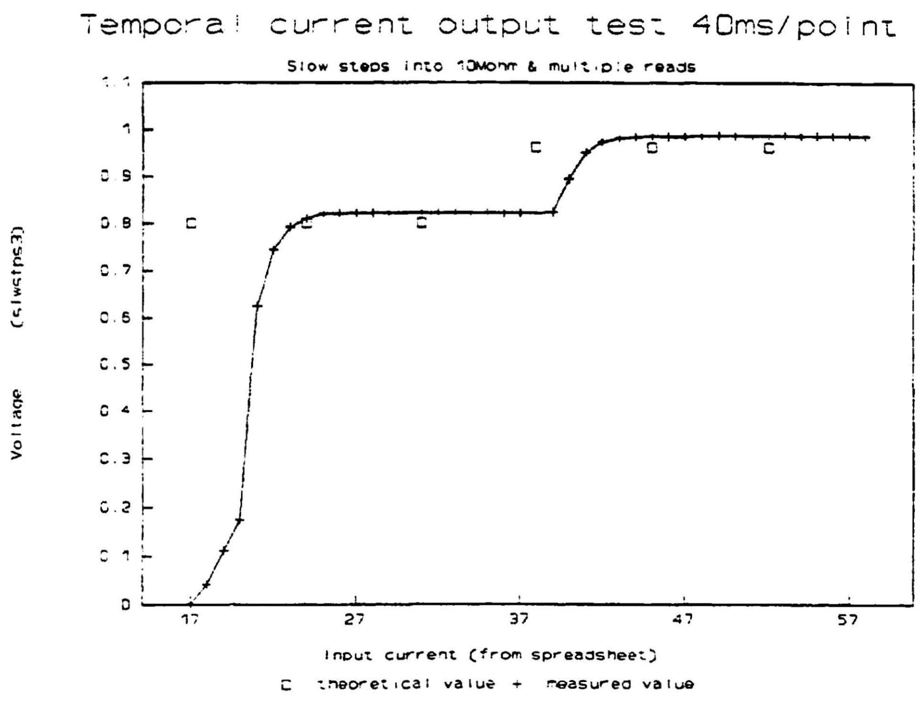

Figure 4

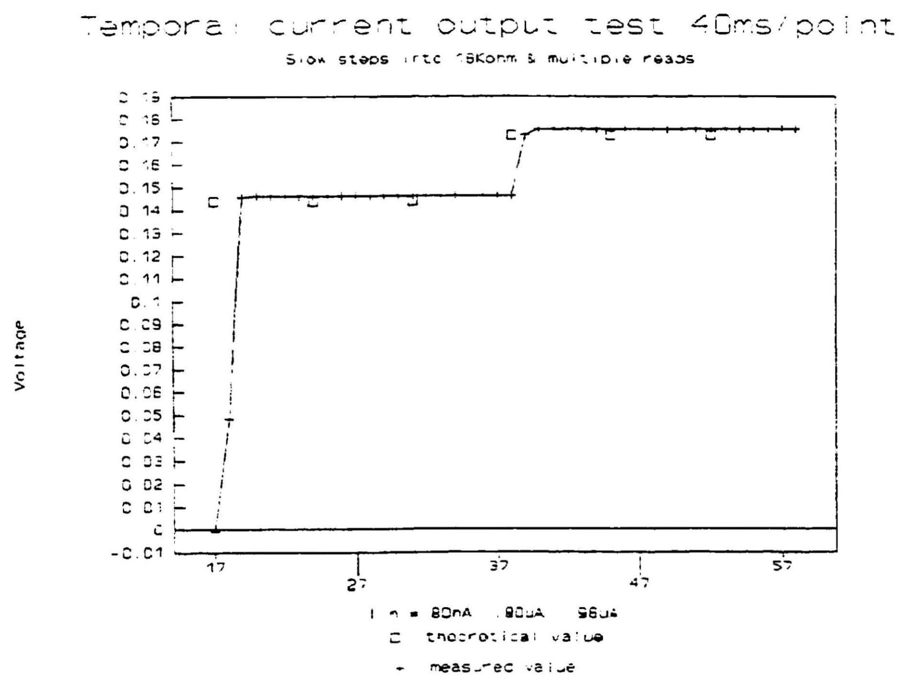

Figure 5

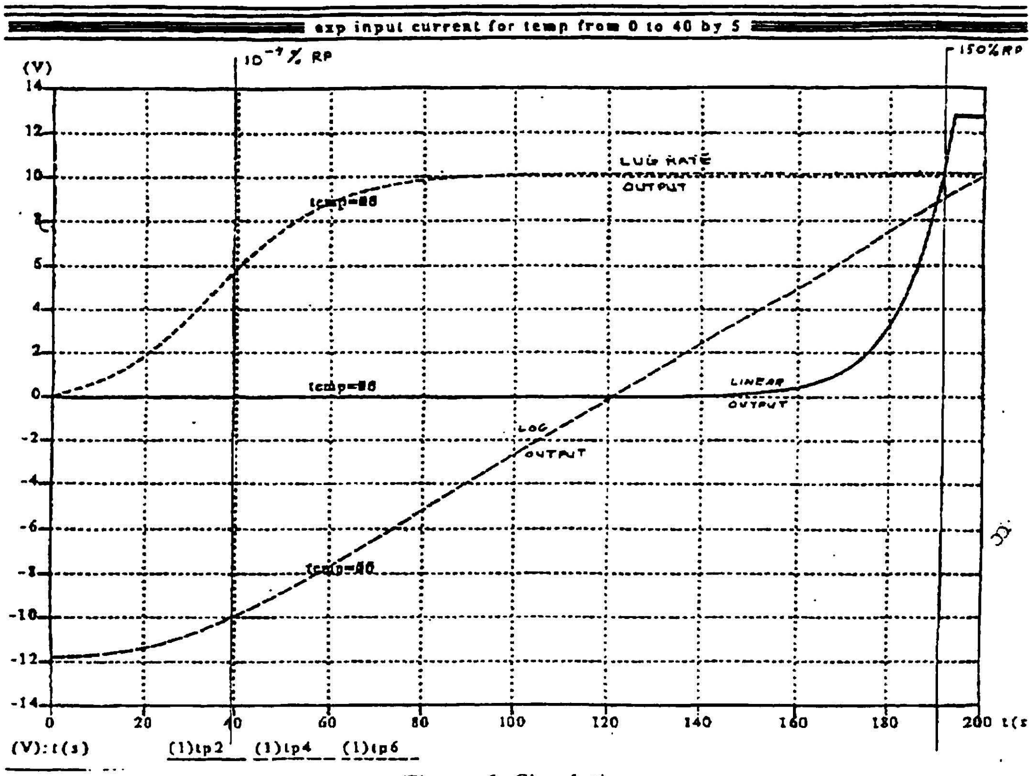

Figure 6 Simulation

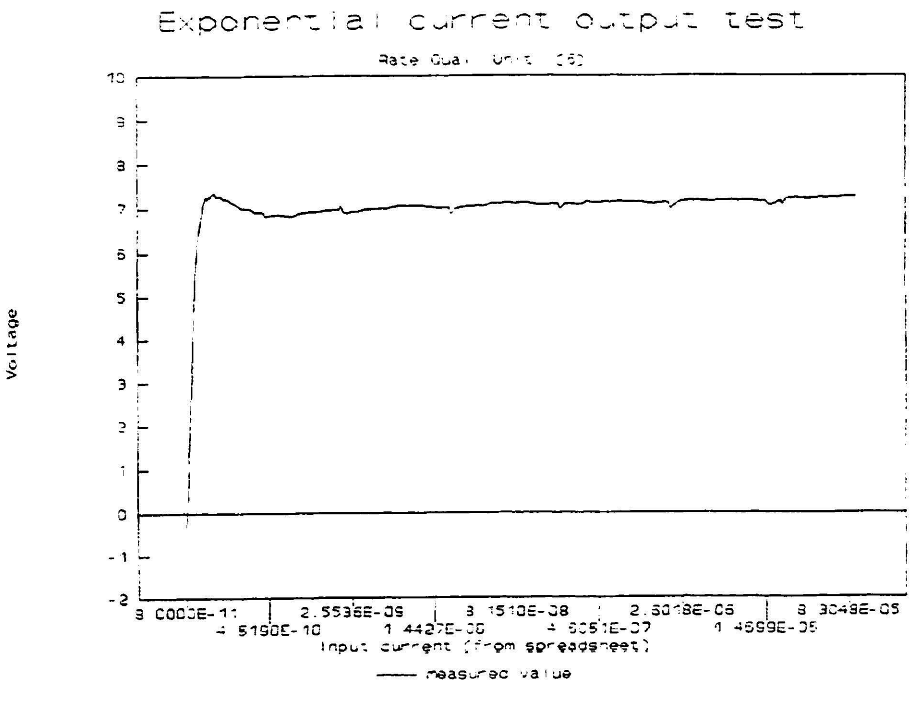

Figure 7

TESTS OF ARC-WELDING-RELATED EMI EFFECTS ON STARTUP INSTRUMENTATION

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ABSTRACT

The tests described in this paper were conducted to characterize the effects that electromagnetic interference (EMI), from arc welding, has on startup instrumentation (SUI). This paper reviews the results of a literature search on EMI resulting from arc welding and gives the objective and scope of the tests conducted and describes the test equipment and setting, and test procedure and results. Arc-welding-related EMI levels in an SUI system were measured to determine the dominant source of interference, the coupling path and the susceptible part of the SUI system. The effectiveness of easily implemented improvements in reducing the level of EMI in the SUI system were also tested. Recommendations are provided on how to eliminate or reduce the EMI effects on sensitive nuclear instruments.

1. INTRODUCTION

An investigation into electromagnetic interference (EMI) with CANDU®[1] plant startup instrumentation (SUI) from arc welding has been initiated in response to a request from a CANDU station. Startup instrumentation is used for monitoring neutron flux during reactor shutdown and startup periods when the neutron flux is below the measurement range of the normal neutronic instrumentation. The problem of EMI with SUI has resulted in spurious trips of safety systems on several occasions at a number of CANDU units [1].

A recent survey on SUI in domestic CANDU stations [1] has revealed that arc welding activities have caused a number of spurious reactor trips and a number of significant event reports have been filed on these events. The general practice in CANDU stations is to avoid arc welding near the SUI and other sensitive equipment and cabling, and to use direct current where welding near sensitive equipment cannot be avoided. Use of high-frequency alternating current to generate or stabilize the arc is generally avoided because arc welding is thought to be more likely to cause EMI when operating in this mode.

A literature search and communication with station personnel and EMI consultants have shown that, as in Canada, the general approach to problems of EMI caused by arc welding, adopted by US nuclear utilities, is to avoid arc welding near potentially sensitive equipment [2-5] and (Meininger, R., CHAR SERVICE, INC., personal communication, 1995 June 12; Shankar, R., EPRI NDE Center, personal communication, 1995 August 10; Chiarella, J., Connecticut Yankee Atomic Power Co., personal communication, 1995 September 13). The Electric Power Research Institute (EPRI) advises that the administrative and procedural controls on arc welding be used. EPRI also advises that where arc welding is necessary in rooms containing in-service EMI sensitive safety equipment, the welding must be contained in shielded enclosures [2, 5]. However, the authors of the EPRI reports could not identify any plants that have applied shielding to arc welding operations, nor any work to identify the welding interference coupling path.

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1 CANDU® is a registered trademark of Atomic Energy of Canada Limited (AECL).

A search for information on EMI resulting from arc welding in other industries has revealed that, as in the nuclear industry, arc welding near sensitive equipment is avoided where practical. However, researchers at the NASA Lewis Research Center, who were faced with the problem of welding near sensitive electronic equipment (qualified for EMI immunity to MIL-STD-461A requirements), have applied standard EMI control techniques to reduce welder emissions to a level compatible with the equipment. The NASA researchers found that EMI emissions were mainly from cables and that major benefits in reducing emission were obtained by (i) providing a good ground return connection close to the weld site, (ii) using short ground and electrode cables, and (iii) twisting the ground and electrode cables together [6]. The welding equipment used was an orbital arc welder, which is a robotic welder designed for making circumferential welds on tubing. The unit includes a shield around the arc that is provided primarily as vision protection for nearby personnel, but may also have provided electromagnetic shielding for radiated emissions from the arc (Sargent, N., NASA Lewis Research Center, personal communication, 1995 Oct. 16). Although the welder used is different from those used in CANDU stations so that the NASA experience may not be directly applicable to CANDU stations, the NASA work is a useful reference for the general problem of reducing arc-welding-related EMI.

The paper is arranged as follows. Section 2 gives the objectives and the scope of the tests, Section 3 describes the test equipment and test setups, and Section 4 provides test results. Section 5 provides conclusions and recommendations on eliminating or reducing EMI from arc welding on the basis of the test results obtained.

2 OBJECTIVES AND SCOPE

The objectives of the investigation are to characterize the EMI effects on SUI from arc welding and to develop recommendations for eliminating or reducing EMI from arc welding.

In the investigation, an SUI instrumentation channel was exposed to arc welder emissions, and the EMI effects were carefully observed using an oscilloscope. Electromagnetic interference effects were characterized for the following variables:

- type of welding:
  - Tungsten Inert Gas (TIG) welding or Shielded Metal Arc Welding (SMAW), also known as stick welding,
- welder setup:
  - High Frequency switch ON or OFF,
  - ac or dc current mode,
  - straight or reverse polarity,
- configuration of the ground and electrode cables, i.e..
  - location and quality of the connection of the ground cable to the work,
  - ground and electrode cables laid loose on the floor or twisted together,
- location of the SUI detector and cable with respect to the weld site, and
- degree of electromagnetic shielding provided for the SUI detector and cable and the processing electronics.

Arc welder emissions were not measured in this investigation. Arc welder emissions have been measured in a related investigation and will be reported separately [7].

3. TEST EQUIPMENT AND SETUP

The following equipment was used (see Figures 1 and 2):

Arc welding machine:

Miller Electric Manufacturing Co. Model Syncrowave 300.

SUI and pulse generator:

The SUI includes a Boron Trifluoride (BF3) neutron detector, a pre-amplifier, a high voltage (HV) dc supply, a shaping amplifier, a single channel analyzer (SCA), a dual counter/timer, and a linear/log rate meter. A pulse generator is included to aid in setup of the SUI. With the exception of the detector and pre-amplifier, the above are nuclear instrumentation modules (NIM) mounted in a NIM Bin complete with power supply. For the tests, the NIM Bin was housed in a small steel cabinet (0.5 m high). The model of the above equipment are listed in Table 1. A schematic block diagram showing the signal flow in the SUI is presented in Figure 1.

Measuring instruments for monitoring EMI levels:

Measuring instruments included a digital storage oscilloscope (200 MHz bandwidth), a plotter and a power line monitor. The measuring instruments are listed in Table 2.

EMI suppression equipment:

Electromagnetic shielding and noise filtering were applied to prevent coupling arc-welding emissions to the SUI detector, detector cable and NIM Bin.

Improved shielding was provided by mounting aluminum shielding panels securely bonded to the SUI cabinet to cover the open front and back of the cabinet.

Cables penetrating the cabinet provide a possible path for conducting interference into the cabinet. To break this coupling path, noise coupling to the SUI cabinet was suppressed by wiring low-pass filters into the power line for the SUI NIM Bin and the cable connecting the rate meter output to the oscilloscope. The filters were of the feed through type and were installed in one of the shielding panels.

Noise filtering was not applied to the detector cable because of the large bandwidth of the detector signal. However, noise pick-up on this cable could be reduced by placing the detector and cable inside the SUI cabinet.

In addition, isolation transformers were available for powering the NIM Bin and measuring instruments. Except where noted otherwise, the shielding panels were not mounted on the cabinet, the power line and signal line filters were bypassed, the detector and cable were not placed inside the cabinet and the isolation transformers were not used. The available EMI suppression equipment is listed in Table 3.

The SUI was setup using a pulse generator in place of the neutron source. The SUI setup was typical of that at CANDU stations. Readers may refer to [8] for details of the test procedure. The SUI settings and measured signals were as listed in Table 4 and Table 5, respectively.

The setup used in measurements of EMI levels in the SUI resulting from arc welder operation is as shown in Figure 2, which shows the relative locations of the arc welder, the steel welding table, the carbon steel pipe that served as the work piece, the weld site, the SUI detector and the SUI cabinet.

The arc welder used as the EMI source is the model Syncrowave 300 from Miller Electric Mfg. The machine was connected to a dedicated single phase 550 V 60 Hz supply. The arc welder was initially configured for TIG welding, but the SMAW process, also known as stick welding, was also used. These welding processes differ in the electrode and electrode cable used and in requirements for gas flow and cooling water.

The welder setup was changed during testing to study the effect of various welder operating modes. The welder setups are summarized in Table 6. For each aspect of the welder setup, the table lists both the options used and the initial setup. In the discussion of test results, the welder setup is described in terms of differences from the initial setup listed in Table 6.

Several configurations of the welder ground connection were used. In the initial configuration, the welder ground cable was clamped at the far end of the pipe, about 3 m from the weld site, as shown in Figure 2. To study the effect of poorer ground connections, the welder ground cable was later clamped to a nearby leg of the steel welding table and changes were made in the electrical contact between the pipe and welding table. For some tests, the pipe was laid directly on the table, so there was electrical contact along the entire length of the table. For some other tests, electrical contact between the pipe and the welding table was severely restricted by laying the pipe on an insulating support placed near the weld site, and across an aluminum block, about 1-cm square and 10-cm long, near the other end of the table. This forced the welding current to flow the length of the pipe and through a small contact area between the pipe and aluminum block. The contact pressure applied was just that resulting from the weight of the pipe.

In most of the tests, the configuration of the ground cable and electrode cable was uncontrolled. Some length of the electrode cable was coiled and hung near the welder. The remaining length of the electrode cable and entire length of the ground cable, which was shorter, was laid on the floor in random fashion. For some of the tests, the electrode and ground cables were twisted together as this may be expected to reduce magnetic field emissions.

4. TEST PROCEDURE AND RESULTS

Electromagnetic interference measurements were conducted as consecutively numbered tests for various welder operating conditions and configurations of EMI suppression equipment. A summary of the tests is provided in Table 7 of this paper. A more detailed description of the results is provided in [8].

The setup used for the tests is as shown in Figure 2. During testing, the configuration of the SUI was as listed in Table 4. The setup of the arc welder is described for each test in terms of the difference from the initial setup, as listed in Table 6, or the setup for a previous test.

The SUI detector was initially placed on the welding table, about 0.5 m from the carbon steel pipe and about 1 m from the location of the arc. An arc was struck briefly during each test, at the location indicated in Figure 2. Unless otherwise indicated, the detector and cable were placed as above, and an arc was present during testing.

The oscilloscope was used in analog mode to carefully inspect signals in the SUI. The normal preamplifier and amplifier output signals were series of pulses (due to the signal generator) having amplitude and repetition rate as listed in Table 5. The presence of other pulses in the preamplifier or amplifier output, or a significant deviation in the rate meter indication or output from that listed in Table 5, was interpreted as evidence of EMI.

Electromagnetic interference was observed at the preamplifier and amplifier outputs as randomly occurring, short pulses having a duration similar to that of pulses from the pulse generator, but a lower amplitude. Sweep speeds near 1 µs/division were used to inspect the pulse shape as the pulses were several microseconds wide. Because of the low pulse rate, much slower sweep speeds, up to 5 ms/division, were used to estimate the average pulse rate. The characteristics of the measured wave forms were recorded in the test log and form the basis for the description of the test results.

To obtain plots of the SUI wave forms, the oscilloscope was used in its digital storage mode with its RS-232 serial port connected to the plotter. Sample plots obtained in the tests are shown in Figures 3 and 4. The vertical sensitivity (volts/division) and time base (seconds/division) are shown at the bottom of each plot. A complete set of plots is provided in [8].

The power line monitor recorded some line-to-neutral and neutral-to-ground high frequency noise and also some neutral-to-ground RMS bursts. However, the above power disturbances produced no spurious pulses at the preamplifier or amplifier output, and no disturbance in the rate-meter output.

5. CONCLUSIONS AND RECOMMENDATIONS

A survey of the general approaches adopted by nuclear utilities and other industries in dealing with EMI resulting from arc welding has been conducted. The survey has revealed that EMI resulting from arc welding is a recurring problem, but that no satisfactory solution has been developed within the nuclear power industry to protect sensitive equipment from EMI resulting from arc welder emissions. Administrative controls on arc welding have been used in the nuclear industry to avoid exposure of sensitive equipment to arc welder emissions. Techniques have been developed by NASA to minimize emissions from arc welding, thus avoiding possible damage to sensitive electronic equipment that cannot be removed from proximity to the weld site. The key elements of the NASA technique are to provide a low resistance ground connection, keep cables short and to twist the ground and electrode cables together. These precautions are intended to avoid return current flowing in or near the possible victim equipment and to minimize magnetic field emissions from the cables.

A series of tests aimed at achieving a better understanding of EMI resulting from arc welding in the SUI has been conducted. The tests made use of quantitative measurements of EMI levels in the SUI system to evaluate various welder operating modes and several noise reduction measures applied to the welder and SUI system. The SUI system was monitored for interference effects at the preamplifier, amplifier and rate-meter outputs.

Conclusions regarding the characteristics of spurious signals present in the SUI system because of arc welding and the method of interference coupling are as follows (see also summary of recommendations in Table 8):

- Spurious signals due to arc welding appear as impulsive noise at the preamplifier and amplifier outputs. An exception is the short (5 - 7 µs) bursts of decaying oscillations that appear at the preamplifier output when high-frequency stabilization is switched on.
- The SUI detector and the cable to the preamplifier are the parts of the SUI system that are most susceptible to interference from arc welding. As interference is reduced by increasing the separation from the welding apparatus and/or providing additional shielding, it is concluded that interference is radiatively coupled.

  No evidence of pick-up on SUI system cables other than the detector cable was noted in the tests. No evidence of interference conducted via the power line was noted.
- Spurious pulses can appear at the preamplifier and amplifier outputs under all welder operating modes, but the pulse amplitude and frequency of occurrence depend strongly on the welder operating mode and distance from the SUI.
- For certain welder operating modes, there is no evidence of EMI at the rate-meter output. This is because the amplitude of spurious pulses at the SCA input falls below the lower level discriminator setting (3.0 V), so that spurious pulses do not contribute to the count rate.

Note that interference effects, i.e., the presence of spurious signals at the preamplifier and amplifier outputs, are not considered significant unless the rate-meter output is also affected. Conclusions regarding the severity of interference effects arising from various welder operating modes are as follows:

1. Tungsten-inert-gas welding in dc mode without high-frequency stabilization produces no significant interference effect on the SUI, even when the SUI detector and detector cable are in very close proximity (<1 m) to the welding arc, welding electrode and ground cables, and structures carrying the return current.

   Although TIG welding may result in some spurious pulses induced in the detector and/or detector cable, the rate-meter output is unaffected.

   Where arc welding near SUI or other sensitive equipment cannot be avoided, TIG welding is the recommended welding process.
2. Shielded Metal Arc Welding produces greater interference effects than TIG welding. The rate-meter output is affected by SMAW welding, except where a separation of several metres is maintained between the weld site and the detector and detector cable.

   Shielded Metal Arc Welding near sensitive equipment, such as SUI, should be avoided.

3. Use of high-frequency stabilization can result in very strong interference effects. The interference source is the welding machine itself and emissions are present even if there is no welding current drawn.

   The interference caused by high-frequency stabilization is reduced substantially when the SUI detector is removed more than 7 m away from the welding machine. The interference may be reduced below a significant level by addition of shielding for the detector and cable. It is not necessary that the shield entirely surround the detector and cable to provide a substantial benefit.

   High-frequency stabilization should be disabled whenever possible. If it is necessary to use high-frequency stabilization, there should be at least 5-m separation between the SUI detector/cabling and the welding machine.

4. Welding in dc mode generates less interference than welding in ac mode. Welding in ac mode produced significant interference effects in the tests.

   Direct current welding is recommended for maintenance and repair work near sensitive equipment. The polarity should be set to STRAIGHT polarity for TIG welding and REVERSE polarity for SMAW welding as the above settings produce superior welds and less interference.

   The welding electrode is at a negative potential with respect to the welder ground under STRAIGHT polarity, and at a positive potential under REVERSE polarity. It is normal practice to use REVERSE polarity for SMAW welding, as this yields a better quality weld. (TIG welding is always performed in STRAIGHT polarity.)

5. Transient interference may result when welder switch settings are changed, even in the absence of an arc. Transient interference was noted several times during the tests and appeared to coincide with changing switch settings. Transient interference appeared to be caused by toggling the polarity switch from STRAIGHT to REVERSE, but the effect did not occur consistently and could not be confirmed.

   Changing welder settings should be avoided when working near sensitive equipment. The welder setup should be completed before the welder is brought into proximity to SUI or other sensitive equipment.

6. A good ground connection is important in minimizing welder emissions. The ground connection should be made close to the weld site, good electrical contact should be provided between the work piece and welder ground cable and the welder ground cable should be kept short.

Conclusions regarding noise reduction measures applied to the welder and SUI system are as follows:

7. Additional shielding for the SUI detector and detector cable is effective in reducing EMI resulting from arc welding. The shielding does not need to completely enclose the detector and cable to provide a significant benefit.

   A number of approaches may be used to improve shielding for the detector cable, including dedicated conduit, triaxial cable or Zippertubing. Zippertubing is potentially of great benefit as it may be applied quickly in existing installations. An evaluation of Zippertubing is recommended.

8. No reduction in arc welder interference was observed as a result of twisting the welder electrode and ground cables together. In fact, interference effects were observed to become greater as a result of twisting the cables together.

   This finding contradicts findings of NASA researchers, who found emissions to be reduced as a result of twisting ground and electrode cables together. Additional investigation is recommended.

9. It was observed in the tests that disturbing the detector cable could result in generation of significant noise in the SUI system. Care should therefore be taken to avoid mechanical disturbance of in-service SUI detector cabling.

10. The SUI shaping amplifier acts as a band pass filter for the preamplifier signal. The shaping time constant should be properly adjusted to accommodate the count rate and achieve best noise reduction results.

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TABLE 1. SUI EQUIPMENT MODULES

SUI Equipment	Manufacturer	Model
BF3 Detector	N. Wood Counters	G-10-8
Preamplifier	Canberra	2006
High Voltage	Canberra	3102
Amplifier	Ortec	485
SCA	Canberra	2031
Dual Counter/Timer	Canberra	2071A
Lin/Log Rate Meter	Ortec	449
NIM BIN	Ortec	401A
NIM BIN Power	Power Design Inc.	AEC-320-3
Precision Pulse Generator	Ortec	419

TABLE 2. MEASURING INSTRUMENTS

Measuring Instrument	Manufacturer	Model
Power line monitor	BMI	4800 PowerScope
Oscilloscope	John Fluke Mfg. Co. Inc	PM3392A, 200 MHz
Plotter	Hewlett Packard	7475A
Spectrum Analyzer	Hewlett Packard	4195A
EMI Probe Set	Electro-Metrics	EHFP-30
Current Probe	Solar Electronics	9215-1N

TABLE 3. EMI SUPPRESSION EQUIPMENT

EMI Suppression Equipment	Manufacturer	Model
Shielding Cabinet	CRL (retrofitted)	
Signal Line Filter	Spectrum Control	SCI-2330-004, DC9402
Power Line Filter	Spectrum Control	SCI-6340-007, DC9440
Isolation Transformer	Solar Electronics	7032-1

TABLE 4. SUI EQUIPMENT SETTINGS

SUI Equipment	Switch/Knob	Setting Options	Setting
High Voltage	Coarse Selection Switch	0 KV, 0.5 KV , 1.0 KV	1.0 KV
	Fine Selection Knob	10 Turn Pot	8.0
Preamplifier			Default setting
Amplifier	Coarse Gain	2^1 to 2^6	4
	Fine Gain	3.0 to 10.0	4.5
	PZ Trim		Properly adjusted
	Polarity	POS or NEG	POS
	Pulse Shape	Uni- or Bi-polar	Unipolar
SCA	Lower Level	10 turn pot	3.0 V
	Window	10 turn pot	10.0 V
Dual Counter/Timer	Display Select	A or B	A
	Counter B Preset	0.01 Sec or 0.01 Min	0.01 Sec
	Thumbwheel	N, M, P	1, 0, 2
	Counting Mode	Single or Recycle	Single
Rate Meter	Range	10 to 10^6 in 1-3-10 steps	10^2 Hz
	Time Constant	0.03 to 30 in 1-3-10 steps	1 or 3 sec.
	Zero Suppression	10 turn pot	properly adjusted
Pulse Generator	Pulse Repetition Rate	60 Hz, 70 Hz	60 Hz
	Normalize	10 turn pot	7.55
	Pulse Height	10 turn pot	1.09
	Relay	AC Freq, Off, Int Osc	AC Freq
	Ref Voltage	Int, Ext	Int
	Polarity	POS, NEG	NEG
	Rise Time	Min, 20, 50, 100, 250	Min
	Output	Direct, Attenuated	Direct

TABLE 5. SIGNALS MEASURED IN VERIFICATION OF SUI SETUP

Signal/ Indication	Level
Pulse amplitude at the output of the pulse generator	-0.22 V
Pulse amplitude at the output of the preamplifier	0.43 V
Pulse amplitude at the output of the amplifier	8.5 V
Pulse rate at the pulse generator output	60 Hz
Rate-meter reading (dial)	58 Hz *
Rate-meter output voltage	6.0 V (indicates 60 Hz)

* The observed discrepancy between the pulse repetition rate setting and the rate-meter dial reading is acceptable.

TABLE 6. SETUP OF THE ARC WELDER

Item	Options	Initial Setup
Welding process	• TIG welding • SMAW (stick welding)	TIG welding
Welding work piece	• Carbon steel pipe • Aluminum plate	Carbon steel pipe (laid on steel welding table)
Welder high-frequency (HF) stabilization	• Off • Start • Continuous	Off
Welder current mode	• ac • dc	dc
Welder polarity	• Straight (-) • Reverse (+)	Straight
Start current	• Dial setting: 0 to 10	Dial set at 2 for all tests
Current setting	• 0 A to 375 A in two ranges	100 A (high range)
Welding ground connection	• Far end of pipe • Ground cable clamped to table leg, pipe laid directly on table • Ground cable clamped to table leg, pipe in restricted electrical contact with table	Far end of pipe
Electrode and ground cable configuration	• Untwisted (normal) • Twisted together	Untwisted

TABLE 7. SUMMARY OF TEST RESULTS

Test No.	Welder Configuration	Results
1	- Settings per Table 6, except high-frequency (HF) stabilization set to CONTINUOUS.	- EMI effects apparent with and without arc struck. - Rate-meter reading: 2500 to 3000 Hz.
2	- Settings per Table 6.	No evidence of EMI.
3	- Current setting at 375 A.	No evidence of EMI.
4	- Two full turns of detector cable wound around the pipe. - Ground cable clamped to table leg about 3 m from the weld site. - Conducting support (aluminum block) placed under the pipe 3m from the weld site (near the ground connection). - Non-conducting support placed under the pipe near the weld site.	- Low-amplitude spurious pulses observed at the amplifier output. - Rate-meter reading normal, i.e., 60 Hz.
5	Same as Test 4, except: - Extra length of coaxial cable added between the amplifier and the SCA. - A longer HV cable used.	- Sparking observed occasionally at aluminum pipe support block was correlated with momentary increases in rate-meter reading.
6	Same as Test 4, except: - Longer cables used as in Test 5 - Polarity set to REVERSE.	- Low-amplitude spurious pulses observed at the amplifier output. - Rate-meter reading normal, i.e., 60 Hz.
7	Same as Test 4, except: - Welder set up for SMAW welding. - Longer cables used as in Test 5 - Polarity set to REVERSE.	- A number of spurious pulses observed at the amplifier output. - Rate-meter reading: 240 Hz.
8	Same as Test 4, except: - Welder set up for SMAW welding. (Same as Test 7, except: straight polarity).	- More spurious pulses observed at the amplifier output, compared with Test 7. Bipolar pulses 2-5 V_p. - Rate-meter reading: >1100 Hz.
9	Same as Test 4, except: - Welder set up for SMAW welding. - Arc not struck. - Polarity set to REVERSE. - NIM Bin temporarily powered through isolation transformer.	- Transient increase in rate-meter reading, coincident with change in polarity setting. - Spurious, repetitive (120 Hz) wave form in preamplifier output. - Amplifier and rate-meter output not affected.
10	- Welder set up for SMAW welding. - Ground cable clamped to table leg about 3 m from the weld site. (All other settings as in Table 6).	- Low-amplitude spurious pulses observed at the amplifier output. - Rate-meter reading affected slightly. Slight variation in reading observed.
11	- Welder set up for SMAW welding. - Ground cable clamped to table leg about 3 m from the weld site. - Polarity set to REVERSE. (All other settings as in Table 6).	- Low-amplitude spurious pulses observed at the amplifier output. Lower interference than in 10. - Rate-meter reading was stable at 60 Hz.

TABLE 7. SUMMARY OF TEST RESULTS, CONT'D

Test No.	Welder Configuration	Results
12	- Polarity set to REVERSE. - Ground cable clamped to table leg about 3 m from the weld site. (All other settings as in Table 6).	No evidence of EMI.
13	- HF stabilization set to CONTINUOUS and used with foot pedal control - Polarity set to REVERSE. (All other settings as in Table 6).	Spurious pulses observed as in Test 1.
14	- Welder set up for SMAW welding. - Polarity set to REVERSE. (All other settings as in Table 6). Position of detector and cable was varied.	- Detector and cable placed inside the SUI cabinet: no evidence of EMI - Detector beside the pipe: spurious pulses observed in amplifier and rate meter outputs, rate-meter reading was 70 Hz. - Detector cable wrapped around the pipe: more interference observed, rate meter reading was 110 Hz.
15	- Welder set up for SMAW welding. - Welding ground connected to table. - Pipe laid directly on table. - Detector placed on top of oscilloscope, 2 m from the end of the pipe and ground connection, and 4 m from the weld site. (All other settings as in Table 6).	No evidence of EMI.
16	- HF stabilization set to CONTINUOUS - Detector and cable locations varied. - No welding arc. (All other settings as in Table 6).	- Detector and cable placed on aluminum panel that was electrically connected to the cabinet by short bonding straps, but not mounted: no evidence of EMI. - Detector and cable moved toward the welder machine (from 2 m to 1.5 m separation): lots of spurious pulses observed. Rate meter reading increased to 700 to 1000 Hz.
17	- HF stabilization set to CONTINUOUS. - SUI detector and cable placed on the welding table. - Aluminum shielding panels mounted on SUI cabinet, but penetrated by the detector cable. - No welding arc. (All other settings as in Table 6).	- Spurious pulses present at the amplifier output. EMI radiated by welder appears to be coupled to the detector and/or its cable.
18	- HF stabilization set to CONTINUOUS - Detector and cable inside the cabinet. - Shielding panels electrically connected, but not mounted on the SUI cabinet. - No welding arc. (All other settings as in Table 6).	No evidence of EMI was observed as the cabinet was turned so that the open front of the cabinet faced the welding machine.
19	- Welder set up for SMAW welding. - Ground cable clamped to table leg about 3 m from the weld site, as in Test 4. - Detector and cable laid on table parallel to the pipe (distance about 30 cm). (All other settings as in Table 6).	- Noise observed in amplifier output. - Rate-meter reading was about 800 Hz.

TABLE 7. SUMMARY OF TEST RESULTS, CONT'D

Test No.	Welder Configuration	Results
20	- Same as Test 19, but with the ground and electrode cables twisted together. The excess length of electrode cable was twisted backwards with the twisted cable assembly so that the two parts of the electrode cable were half a turn apart. (All other settings as in Table 6).	- No reduction in EMI. In fact, the rate-meter reading increased to about 2000 Hz.
21	- Same as Test 19, but with the ground and electrode cables twisted together. The excess length of electrode cable was twisted backwards with the twisted cable assembly so that the two parts of the electrode cable were adjacent. (All other settings as in Table 6).	- EMI level similar to that in Test 21. Rate-meter reading was at 2000 Hz. - Changing the location of the welder ground cable connection from the table leg of the welding table to the pipe produced no change in the spurious count rate. Rate-meter reading was still at 2000 Hz.
22	Same as Test 19, except that: - The excess length of the electrode cable was unwound and laid on the welding table. - The ground cable was clamped to table leg about 3 m from the weld site, as in Test 4.	- Some reduction in EMI observed compared with Tests 20 and 21. No reduction in EMI compared with Test 19. - Rate-meter reading was at 1200 Hz. Spiking toward 2000 Hz was observed briefly once.
23	Same as Test 22, except that: - Polarity set to REVERSE.	- Reduced level of EMI observed, compared with Tests 20, 21, and 22. - Rate-meter reading was at about 200 Hz.
24	Settings per Table 6, except that: - Welder set up for SMAW welding. - Current mode set to ac welding.	- A significant level of EMI was observed on the amplifier output. - Rate-meter reading was around 600 Hz.

TABLE 8. RECOMMENDATIONS

No.	Recommendation
1.	Tungsten-inert-gas welding is recommended for maintenance and repair work near sensitive SUI equipment.
2.	Shielded Metal Arc (stick) welding should be avoided.
3.	High-frequency stabilization should be disabled whenever possible. (If it is necessary to use high-frequency stabilization, there should be at least 5-m separation between the SUI detector/cabling and the welding machine.)
4.	Direct current mode welding is recommended for maintenance and repair work near sensitive equipment.
5.	Changing welder settings should be avoided when working near sensitive equipment. The welder setup should be completed before the welder is brought into proximity of SUI or other sensitive equipment.
6.	The ground connection should be made close to the weld site. Good electrical contact should be provided between the work piece and welder ground cable and the welder ground cable should be kept short.
7.	Provide additional shielding for the detector cable: conduit, triaxial cable or Zippertubing. Zippertubing is potentially of great benefit as it may be applied quickly in existing installations. An evaluation of Zippertubing is recommended.
8.	Additional investigation is recommended to determine if twisting welder electrode and ground cables together is useful in reducing welder emissions.
9.	Care should be taken to avoid mechanical disturbance of in-service SUI detector cabling.
10.	The SUI shaping amplifier acts as a band pass filter for the preamplifier signal. The shaping time constant should be properly adjusted to accommodate the count rate and achieve best noise reduction results.

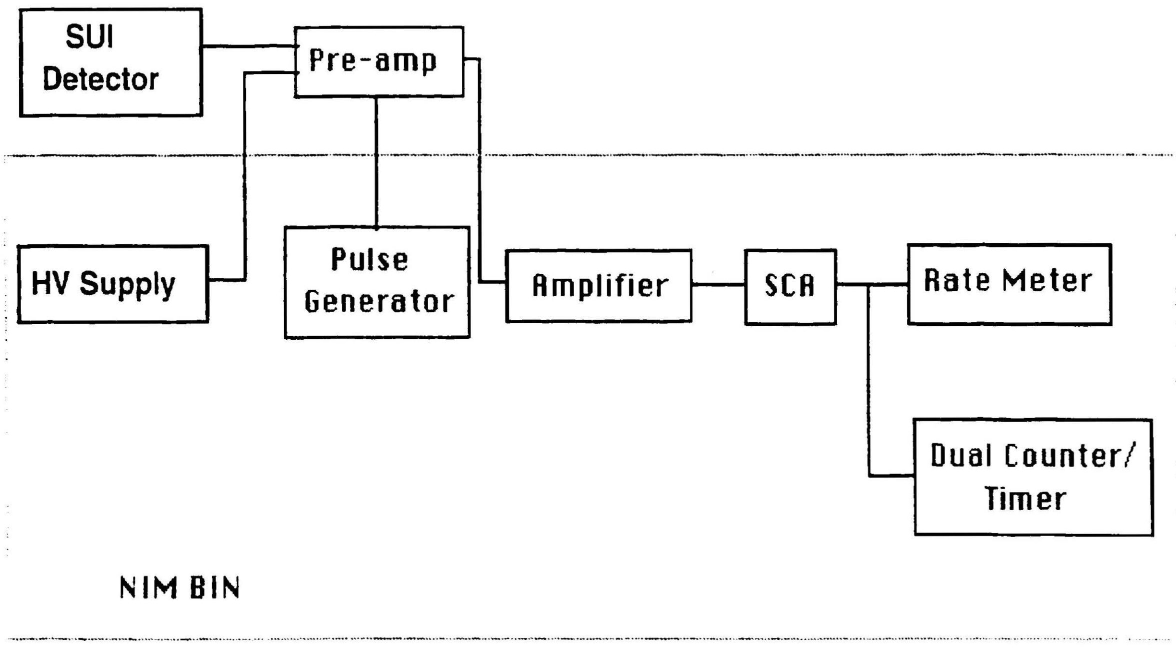

FIGURE 1. BLOCK DIAGRAM OF SUI SYSTEM SETUP

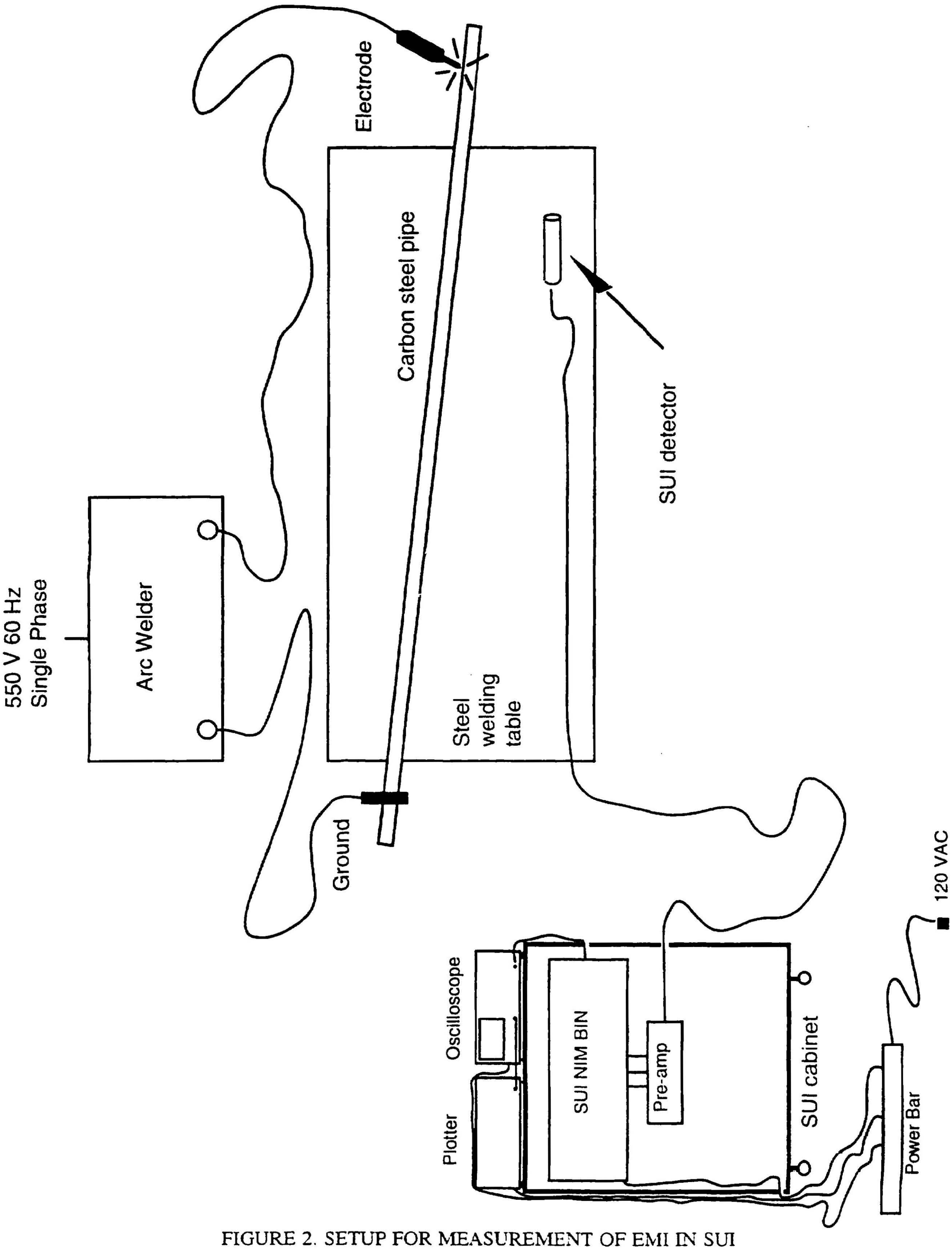

FIGURE 2. SETUP FOR MEASUREMENT OF EMI IN SUI

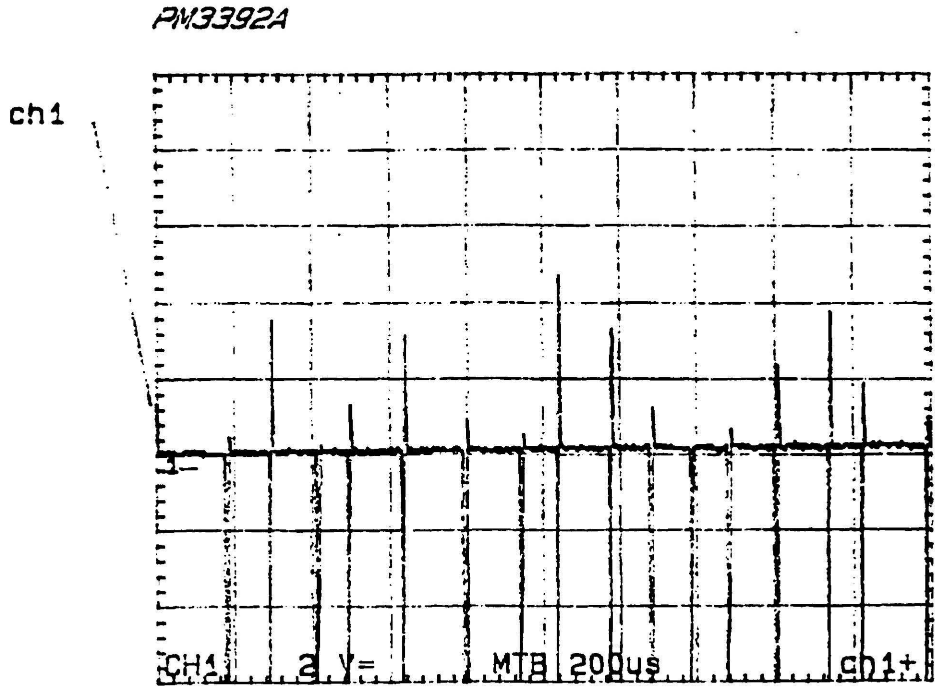

FIGURE 3. AMPLIFIER OUTPUT IN TEST 1

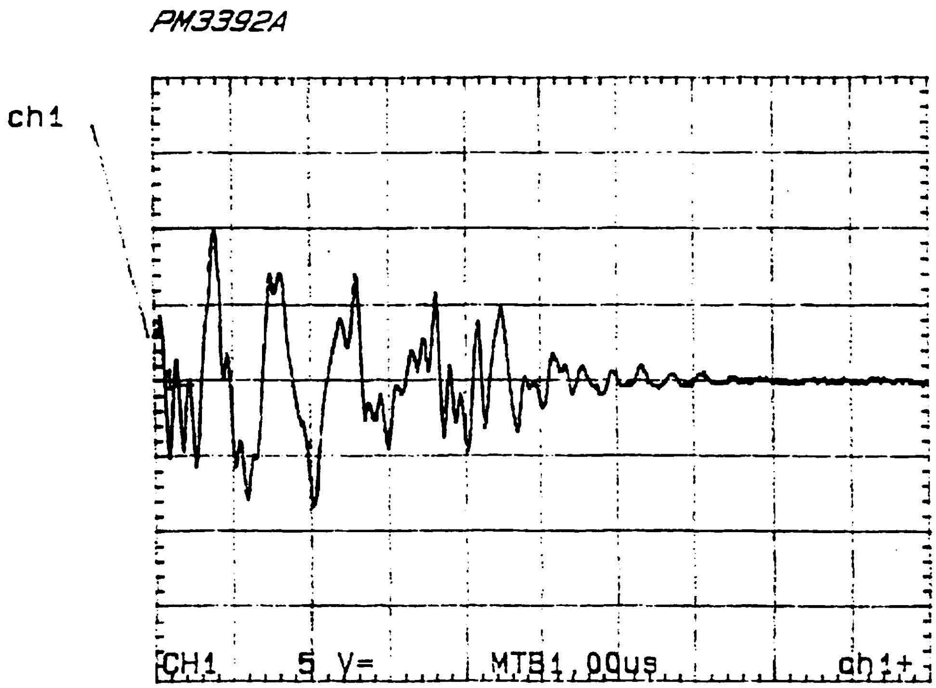

FIGURE 4. PREAMPLIFIER OUTPUT IN TEST 1

PRACTICAL TEST SET-UP AND METHOD FOR DETERMINING THE RESPONSE CHARACTERISTICS OF A LOG RATE CHANNEL OVER 6 DECADES

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IST Canada Inc.

ABSTRACT
A test method was developed using modern, readily available instrumentation to produce an exponentially rising signal over 6½ decades. The method includes validation and calibration tests. It was used to simulate the current signal that would be produced from an ion chamber during a hypothetical loss of Regulation event for a reactor from a shutdown state. This simulation scenario was then used to test the log rate channel of the new ion chamber amplifiers for the NRU research reactor second trip system upgrade.

METHOD 1 - Set-up & Validation
A Personal Computer (PC) equipped with an IEEE-488 port and running Lotus-123* with Lotus Measure* was connected to both a Keithley Model 220 Programmable Current Source (PCS) and to a Fluke Model 8840A Digital Multimeter (DMM) via their IEEE-488 ports. Both the output of the PCS and the input to the DMM were connected across a common resistor. The DMM was set to monitor voltage in auto-ranging mode.

A set of electric current values was generated in the spread sheet starting at 80pA (equivalent to 10^{-4}% reactor power) and ranging up to 120uA (equivalent to 150% reactor power). Each point was approximately 1.0% greater than the previous one in anticipation of a 10 point per second throughput.

Paired Lotus Measure instructions were programmed into the spread sheet such that after each data point (current) was sent to the PCS a corresponding value (of voltage) was read back into the same spread sheet immediately from the DMM. The source data was then adjusted to accommodate the timing of the set-up to achieve a current increase of 23.0 seconds per decade. This is based on the conversion of natural logs to base ten logs and a required acceleration of 10%. Given this arrangement, each simulation pass scanned 1430 data points and took approximately 2.5 minutes to run.

The DMM measured voltages were subsequently converted to output current ($I_{out} = V_{out}/R$) and graphically analyzed along with their corresponding spread sheet created input current (I_{in}) for log conformity and temporal fidelity. Figures 1 through 4 show I_{in} versus Log (I_{out}) and 100 x Log (I_{out}/I_{in}) to emphasis log non-conformances in the measurement system.

OBSERVATIONS
The Figures 1 and 2 indicate clearly the range changes of the DMM. Each range is slightly offset from the previous one indicating minor (and acceptable) calibration differences between ranges. The initial portion of the curve (Figures 1 and 2) where the current is in the picoamp range - is slightly offset from that which is expected under ideal conditions. The small current offset was presumed to be due to input offset current (or bias current) of the DMM. This area was investigated further using a 10 M Ω resistor instead of a 1 M. The input offset error current from the DMM had produced 0.25 millivolts across the 10 M Ω resistor and 0.025 millivolts across the 1 M Ω resistor. By using the offset feature of the DMM, with the current source off line, this error current could be temporarily nulled. (It was found to drift so the offset nulling had to be done just prior to running the curve).

*** Lotus 123 and Lotus Measure are Registered Trade Names of Lotus Development Corporation.**

The latest portion of the curve, where the current is high and the voltage is in the 100 volt range is significantly offset. At the high end, in the 20 to 100 volt range, the input resistance of the DMM is $10^7\ \Omega$ versus 10^{10} on all other ranges. There should therefore be a 10% error in the magnitude over this portion of the curve.

Noise is significant and shows in Figures 1 and 2. The noise signal will become smaller as the current increases due to the nature of the graph construction. Conducted and radiated susceptibility were both noted. The predominant noise was a random large spike - seen in Figure 2. It was treated as a minor inconvenience resulting in an occasional requirement to repeat a test.

The method was then modified slightly to include multiple measurements after each current value was output. The results are plotted in Figures 3 and 4. This emphasises the temporal response of the output signal with respect to the desired staircase wave. Figure 3 emphasises the staircase input and shows the random errors in reading the signal at these low levels. There is no evidence of 'staircase' shape in the measured response.

Figure 4 is a decade step with a long dwell to investigate the response time delay. The difference in settling time for the two output current values is obvious.

Figure 5 shows a larger step of input current and into a lower resistance load. Note the improved response time. This load resistance is the same as that provided by the amplifier.

METHOD 2 - Testing

Once the above set-up had been proven the output of the PCS was connected to the amplifier to be calibrated and the electrometer connected to the amplifiers Log Rate or Log output for calibration. The in-situ test of an amplifier is shown in Figure 7, 8 and 9.

DISCUSSION

The slow response times in the small current portion of the tests are a result of the small current charging the circuit capacitance. The capacitance is the sum of the coaxial cables, the input of the meter and output of the current source.

For a signal of 100pA and a total capacitance of 1nF.

$$\frac{dv}{dt} = \frac{i}{C} = \frac{100 \times 10^{12}}{1.000 \times 10^{9}} = 0.1\text{v/sec}$$

If the circuit resistance is high, as in Figures 1 through 4 then this slew rate appears as a long time constant. If the circuit resistance is low, as in Figure 5 through 9 then the slew rate can be easily identified. This small signal error is not specific to this test but will be experienced for any current source and is dependant on the capacitance in the input circuit.

In the case of the exponential signal covering the range of 10^{-4}% RP to 100% RP (Figures 1 and 2), the slew rate will change with the current magnitude over the six decades. This has the affect of providing an improvement in temporal tracking as the signal increases: or stated conversely - an error exists in this value at small signals.

At higher current values ie 10μA (and 1nF) the slew rate would be 10000v/sec.

Figure 6 is the output of an analog circuit simulation session showing the linear signal output, the log signal output and the log rate output for a similar exponentially rising input. Note that the log rate signal reaches 99% of final value at about the 100 second point.

The result of this temporal distortion at the input will show at the output of the log rate stage most profoundly as a reduction of expected rate for the small signal inputs and less obviously in a delay in the rising edge of the Log Rate signal.

Figure 7, 8 and 9 show the effect of bias or nulling errors on the Log Rate output.

CONCLUSIONS

This test is more informative than the common single measurement of the derivative time constant component values, and may be performed in-situ without decommissioning the amplifier. Non-conformances to the Log function, input bias errors, and log rate performance can all be investigated.

The temporal distortion inherent in the staircase signal is small and acceptable for this testing.

Adaptation to different starting or ending values is convenient due to the inherent nature of the spreadsheet as a test platform.

REFERENCES

1 Lotus Development Corporation, "Lotus Measure Reference Manual"

2 Keithley Instrument Ltd, " Programmable Current Source Model 220 Instruction Manual"

3 Fluke Instruments Ltd, "8840A Multimeter Instruction Manual"

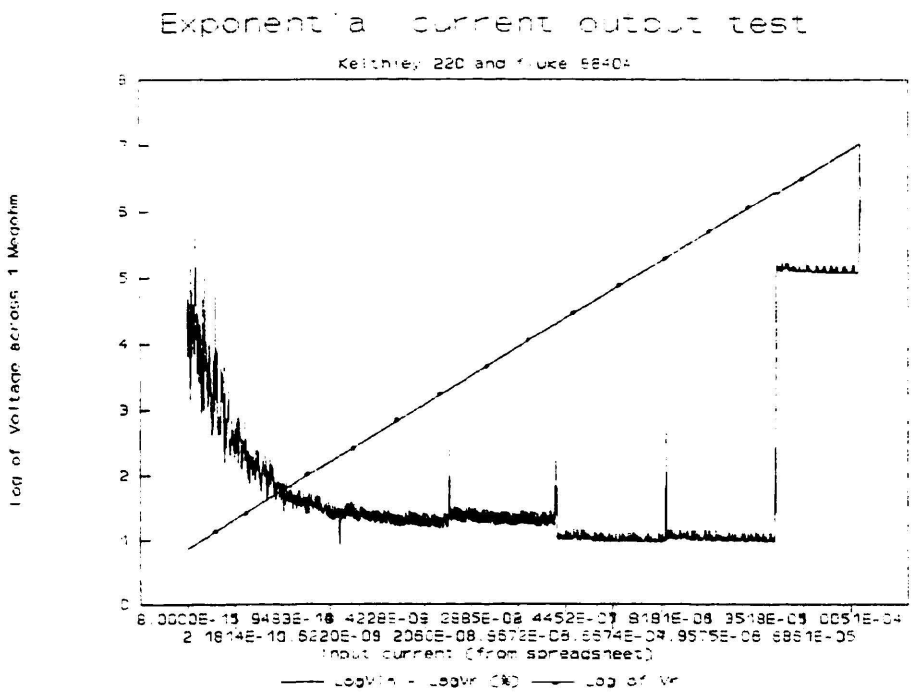

Figure 1

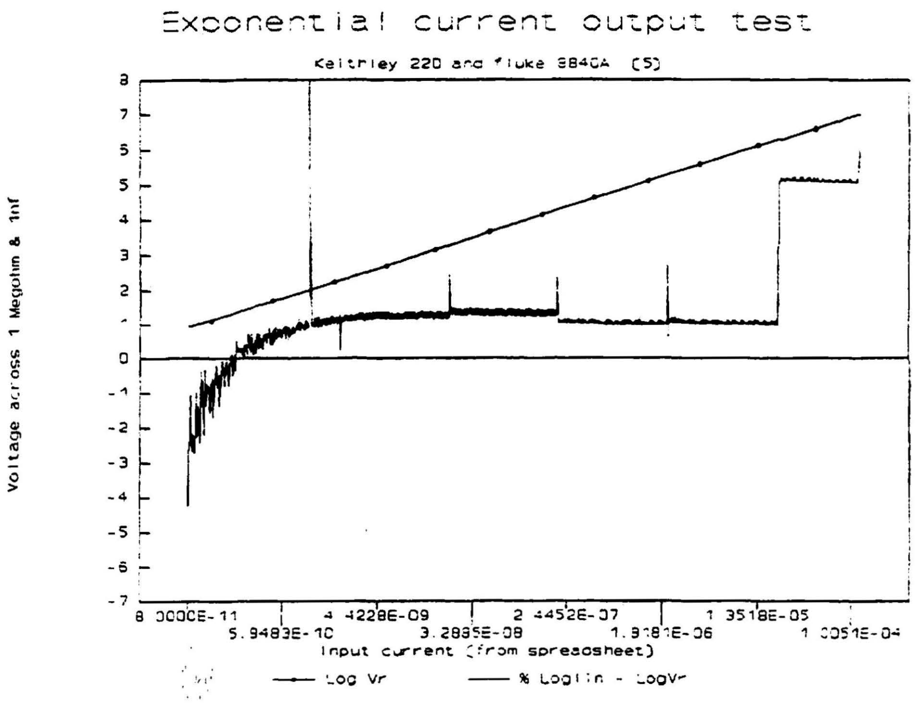

Figure 2

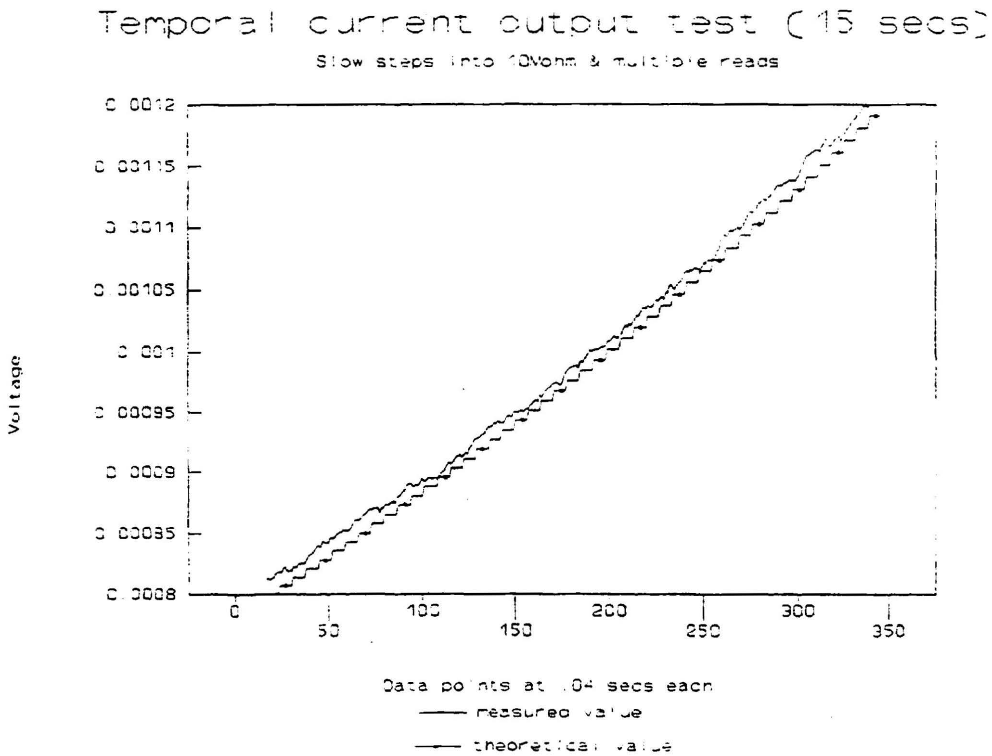

Figure 3

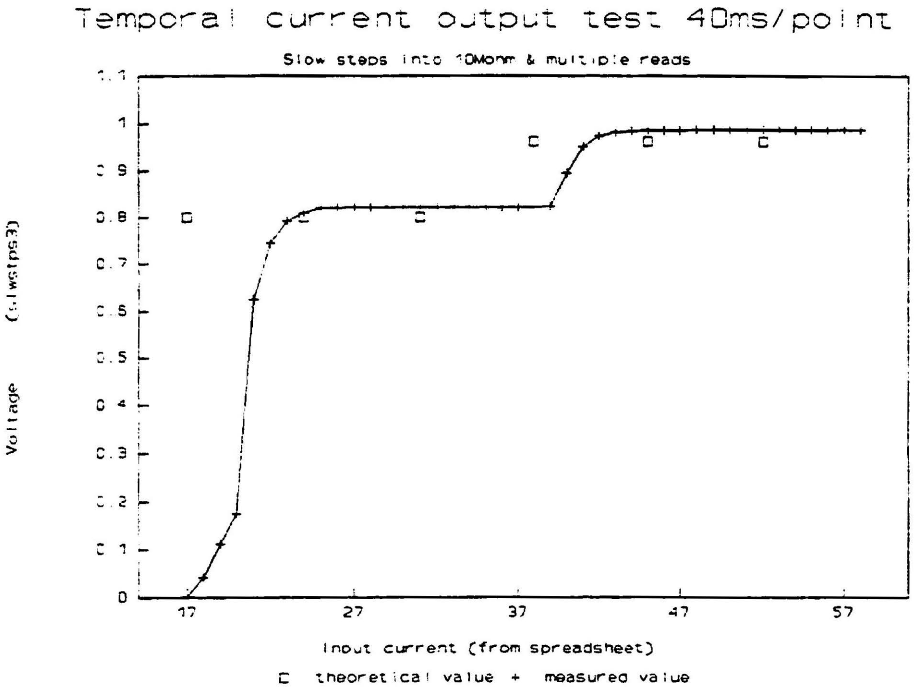

Figure 4

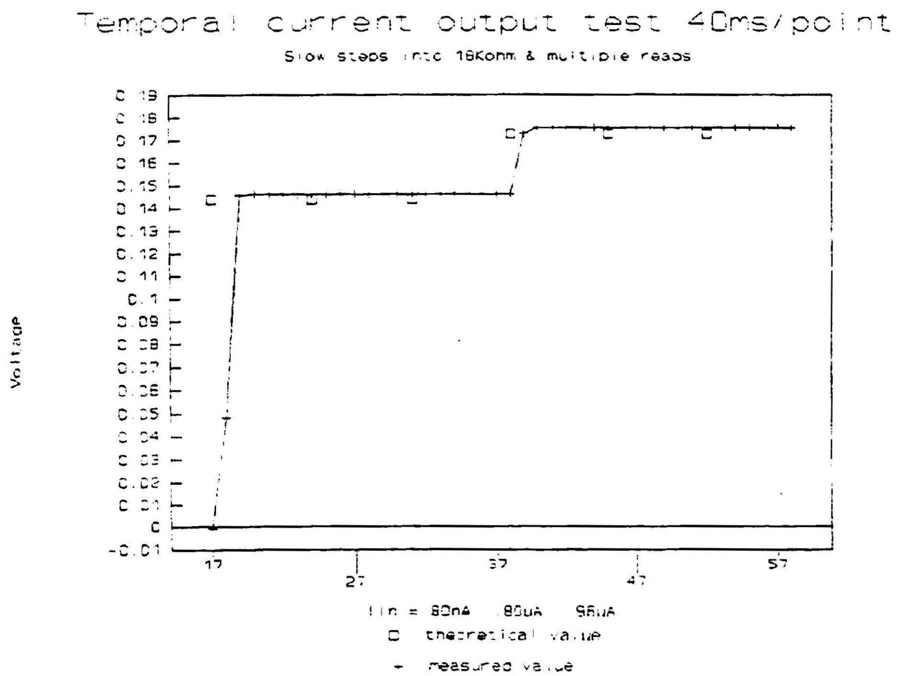

Figure 5

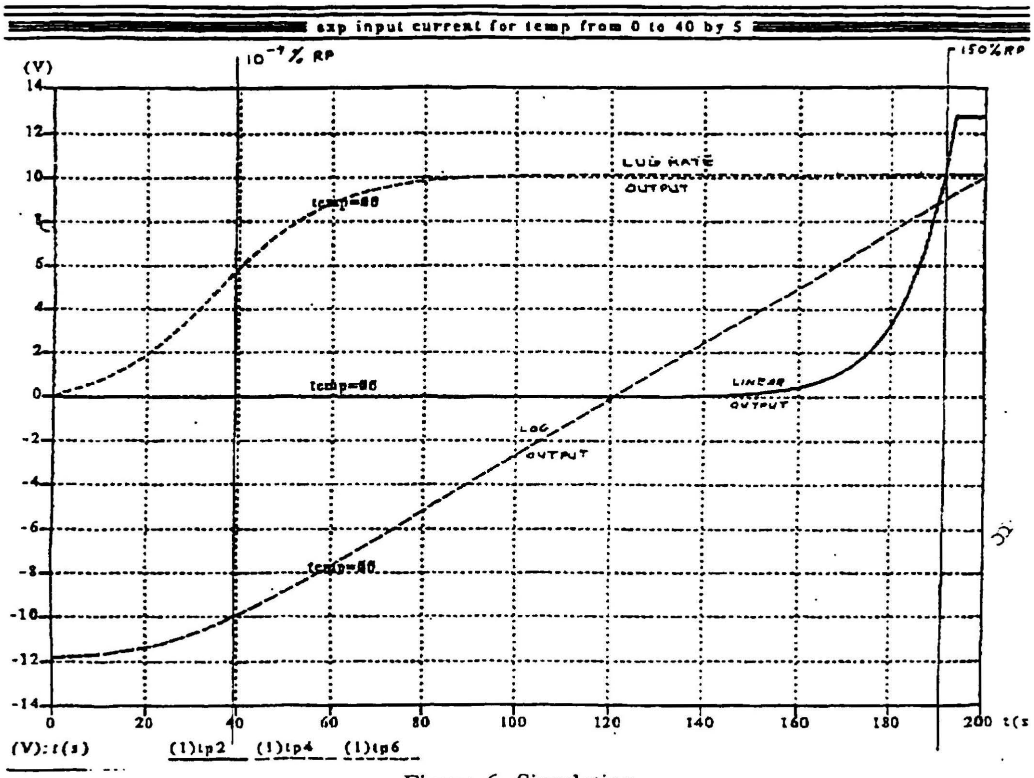

Figure 6 Simulation

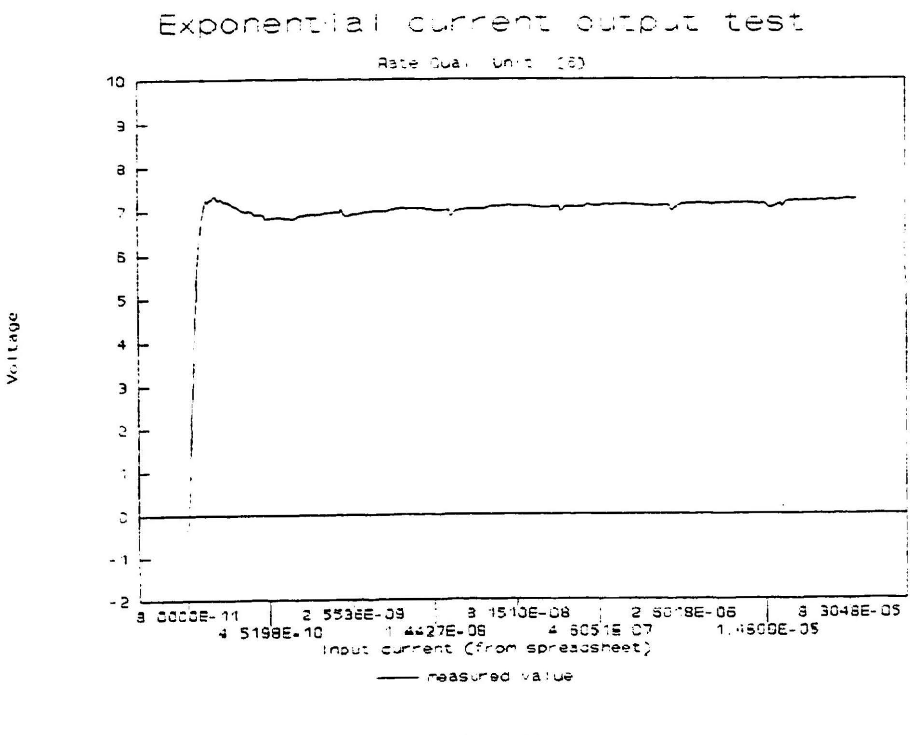

Figure 7

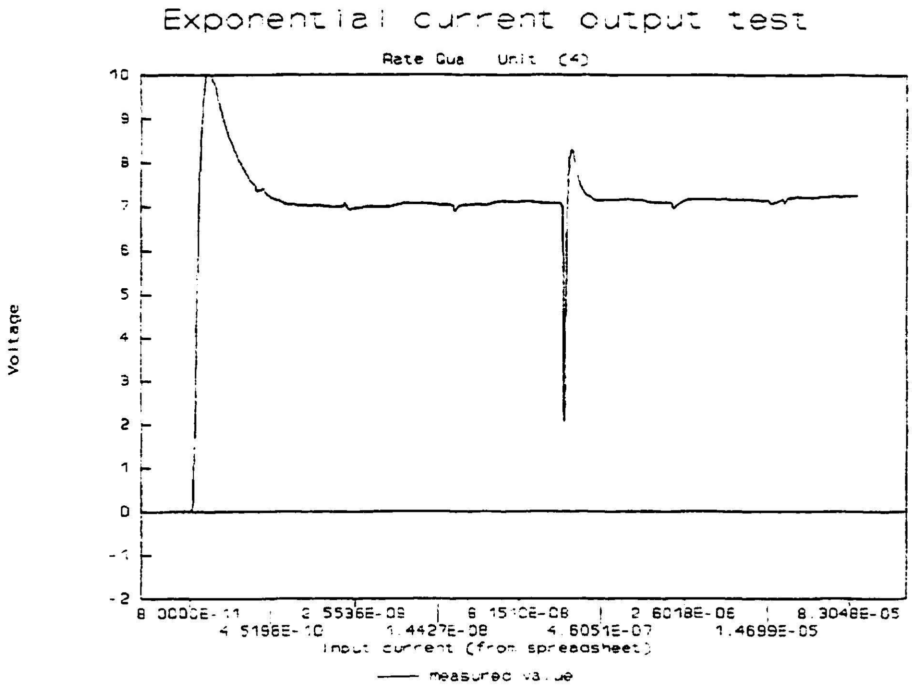

Figure 8, -ve Bias Error

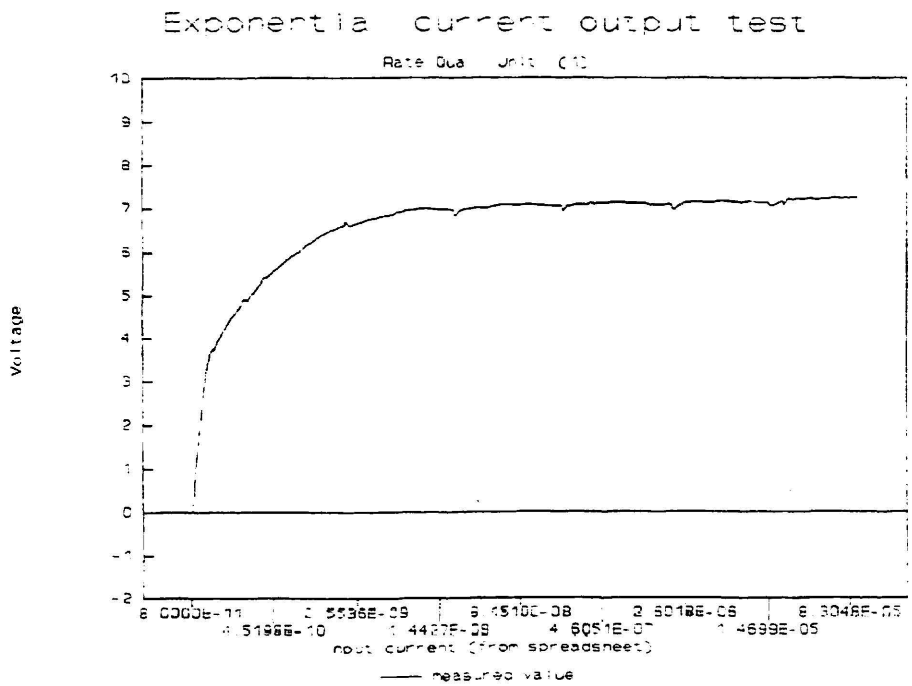

Figure 9, +ve Bias Error