PORTABLE DIGITAL INTEGRATOR

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1. INTRODUCTION

The portable digital integrator described in this note was developed to perform magnetic measurements either as a stand alone instrument or as part of a system controlled by a PC or other GPIB controller. A voltage to frequency converter followed by a digital counter is used to integrate an input voltage over a given measurement period. The instrument is microprocessor based and can be controlled from the front panel, which has an 8 digit display, or remotely by the IEEE-488 interface bus (GPIB). The latter permits all parameters to be programmed (e.g. range, trigger source etc.) and measured data can be transferred to the controller. Measurements may be triggered by an external signal, the internal one second time base or by a GPIB command.

The precision of the instrument is $10^{-4}$ of full scale. There are four input ranges, giving resolutions of between 0.3µV and 20 µV. An analogue output is included, which provides a voltage, selectable in seven ranges, proportional to the integrator value. The complete unit is housed in a 3 unity, 60 TE wide Europe chassis requiring only 220 V mains for operation.

2. PRINCIPLE

The integrator utilizes the voltage to frequency conversion/digital counter technique which has already been outlined, in detail, elsewhere.\footnote{1,2}

A 10 V, 500 kHz unipolar voltage to frequency converter (VFC) is used, its input being offset by 5 V to allow +/- 5 V bipolar operation. An over-range comparator indicates if the input exceeds this +/- 5 V limit. A high quality instrumentation amplifier placed before the VFC, provides a very high input impedance and allows different values of gain to be selected. The offset of this amplifier (i.e. the drift of the integrator) is adjusted by means of two potentiometers (fine,coarse) on the front panel. An external offset voltage input is also provided.

The VFC has two pulse outputs, one which is proportional to the input voltage (Fo) and the other, a fixed reference frequency (Fr). Both these outputs are fed to 32 bit binary counters and at the end of the measurement period the difference of their contents (Count_Fo - Count_Fr) gives a value which is proportional to the integral of the input voltage during this period. Two sets of counters are used, so that while one is monitoring the VFC outputs, the other may be read by the microprocessor. The data from the counters is then converted into volt.seconds, tesla, gauss or volts, taking into account the selected gain and units.

For normal operation, the integrator is triggered (i.e. the counters are switched and read) every 200 ms, synchronized to the mains frequency to eliminate 50 Hz components on the input signal. When the integrator is started, the values thus obtained are totalized and the display is updated with each new total. Stopping the integrator freezes this total, while resetting the integrator zeroes it, and in both cases new triggers are ignored. Operation similar to that of an analogue integrator is therefore obtained. If a GPIB trigger is sent, in this mode, the current total value is transferred. When using the GPIB, values can be sent immediately after each measurement or else saved in memory and sent after a block of measurements. When the external trigger or the internal 1s time base
is being used, the measurements are not totalized and the value displayed is that integrated since the previous trigger.

In addition, a 12 bit digital to analogue convertor provides an output voltage, proportional to the integrator value, and selectable in seven ranges of units/volt. This can be used, for example, to drive a recorder.

The block diagram of the complete instrument is shown in Figure 1 and that of the integrator module in Figure 2.

3. CIRCUIT DESCRIPTION

The instrument is based around the G64 microprocessor bus and comprises six such modules including the integrator and analogue output cards. Each board is briefly described below.

a) Integrator AT 680-2036-050

This card incorporates the instrumentation amplifier, voltage to frequency convertor, 10 volt precision reference, 32 bit binary counters and the associated logic.

The gain of the amplifier (AD625) is set by three precision resistors which are switched by a dual analogue multiplexer, to select gains of 1,4,16 and 64. The precision voltage source is used to offset the unipolar VFC to allow a +/- 5 V range on its input, thus giving integrator input ranges of +/-5 , 1.25, 0.3125 and 0.078125 V respectively. A window comparator indicates if the VFC input voltage exceeds +/- 4.9 V.

The amplifier offset is adjusted using two multi-turn potentiometers (fine, coarse) on the front panel. An external offset input is also provided, and applying a +/- 10 V signal results in a +/- 10 mV offset on the VFC input.

The input impedance of the integrator can be either 2 Mohms, balanced, if both R36 and R37 are installed, or 1000 Mohms, unbalanced with only R37. Over-voltage input protection is provided by R33, R34 and D3 - D6. Low pass filtering may be added before and/or after the instrumentation amplifier, if required. The desired capacitors should be installed in positions C14 and C10 respectively.

The analogue and digital grounds are isolated by opto-couplers, but they may be connected if required, by installing the "0v connect " jumper.

The integrator is normally triggered by a 5 Hz, mains derived signal in order to eliminate 50 Hz input components. It can however be triggered by an external signal on the front panel or the internal one second time base. The external signal can be configured as required using jumpers Act-5, Act-0 and resistors R1, R2. The internal time base is set to one second by jumpers Ctl1 - Ctl6.

Finally, the G64 address of the card is $E200, selected on jumpers A2 - A9.

b) Analogue output (A-D convertor) LEP 680-2012-200

This module, used to provide an output voltage proportional to the integrator value, comprises a 12 bit opto-isolated +/- 10 V digital to analogue convertor. The analogue and digital grounds may be connected if required, by fitting jumper ST1. The G64 address is $E220 selected on jumpers A2 - A9.
c) Display driver AT 680-2036-150

This module interfaces the G64 bus to the front panel display described below. Its G64 address is $E360 selected on jumpers A4 - A9.

d) Display AT 680-2036-200

Mounted directly on the front panel, this card incorporates the push buttons, leds, 8 digit display and three Lemo co-ax connectors. These three inputs, for the start, stop and reset control signals have opto-couplers and can be configured to suit most signal levels, positive or negative going, isolated or not, by means of jumpers and resistors R4 - R12.

This card is connected to the display driver, described above, by two 34 way flat cables.

e) CPU 6809 P-ISR-7500

This is a standard 6809 microprocessor card and has 6 k of RAM and 4k of EPROM on board, as well as an RS232 serial port.

The memory mapping used for the integrator application is shown in Table 1.

f) GPIB Interface P-ISR-7507

This module provides the interface between the G64 bus and the GPIB. Its G64 address is $E240 and is selected on DIP switch SW1.

The GPIB address is selected on switch SW2, and is set to 5 at test. It is displayed on the front panel, during the power-on reset routine, with the message "Ad = 5".

g) Memory module EFS-64U2

This is a standard G64 memory card, and is configured for 4 x 8k of EPROM and 3 x 8k of RAM.

h) Power Supplies

A 50 watt plug-in power supply provides +5 V and +/- 12 V. In addition, the 50 Hz generator card AT 680-2036-100 is used to derive the 5 Hz trigger signal on the integrator board.

4. FRONT PANEL

The front panel of the integrator is shown in Figure 3.
a) Controls

- INPUT RANGE
  Keeping this button depressed or repeatedly pressing it selects one of the four input ranges. The full scale input voltage is displayed in volts.

- OUTPUT RANGE
  Keeping this button depressed or repeatedly pressing it selects one of the seven analogue output ranges. The output range is displayed in units/volt.

- START/UNITS
  Pressing this button briefly, starts the integrator. Keeping it depressed for about 2 seconds changes the units between volt.seconds, gauss and tesla, assuming that a coil has been selected using the STOP/COIL button. Otherwise the units remain volt.seconds.

- STOP/COIL
  Pressing this button briefly, stops the integrator. Keeping it depressed for about 2 seconds selects, and displays briefly, one of the pre-programmed coil surfaces and changes the units accordingly. Continuing to press this button will, after another 2 seconds, advance the display to the next coil surface or return to the normal units of Vs.

- RESET/TRIGGER
  Pressing this button briefly, resets the integrator. Keeping it pressed for about 2 seconds selects, in sequence, the external trigger and then the one second time base. Pressing the button again briefly, returns to normal operation.

- DRIFT ADJUST
  Two multi-turn potentiometers provide fine and coarse adjustment of the integrator drift.

b) Inputs/outputs

- integrator input (Lemo 2 pin).

- external offset voltage input (Lemo co-ax).

- external trigger, start, stop, and reset inputs (Lemo co-ax).

- analogue voltage output (Lemo co-ax).

c) Displays

- 8 digit, 10 mm high led display.

- green leds for power on and analogue output zero indication.
- yellow leds for remote, measure, external trigger, trigger, G, T and Vs indication.

- a red led for over-range indication.

The 220 V mains and GPIB connectors are mounted on the rear panel, shown in Figure 4.

5. **REMOTE CONTROL**

The following features of the IEEE 488 Bus (GPIB) are implemented in the digital integrator:

- LOCAL/REMOTE operation, fully implemented.
- Addressable TALK and LISTEN states.
- Serial Poll.
- Selected Device Clear (SDC), Device Clear (DCL) and Interface Clear (IFC).
- Group Execute Trigger (GET) to trigger a measurement.

The device address (MLA, MTA) is set on the GPIB Interface module as described previously.
A complete list of all the GPIB commands and Serial Poll status is given in Appendix 2.

6. **PROGRAM DESCRIPTION**

The microprocessor program is written in Pascal and Assembler languages. It is divided roughly into three main parts.

a) An initialization routine to set up all variables and configure the various G64 modules. This routine displays, on the front panel, the VFC type in kHz, the program version and the GPIB address of the instrument.

b) A main program to execute the commands coming from either the front panel switches or the GPIB, depending on the LOCAL/REMOTE state.

c) Interrupt routines to handle the integrator and GPIB modules.

The complete program occupies approximately 20 kbytes of EPROM.
7. **CALIBRATION**

The calibration procedure for the integrator is given in Appendix 3.

8. **SPECIFICATIONS**

The complete specifications of the integrator are listed in Appendix 1.

9. **CIRCUIT DIAGRAMS**

Circuit diagrams and layouts for all the instrument modules are included in Appendix 4.

10. **CONCLUSION**

A portable microprocessor based digital integrator, using the voltage to frequency conversion technique and having a precision of $10^{-4}$ of full scale, has been developed. It can be controlled locally by the front panel switches or remotely via the IEEE 488 Interface Bus.

Twelve units have so far been built and are in use at the PS, SPS and ECP divisions, as well as in our own group. In addition, a rack mounting version has been incorporated in the general purpose measuring bench, situated in II of the ISR tunnel.

**REFERENCES**

Figure 1: Digital Integrator Block Diagram

Integrator module
AT 680-2036-050

Analogue to digital converter
LEP 680-2012-200

Display + switches
AT 680-2036-200

Display driver
AT 680-2036-150

EPROM/RAM module
EFS-64U2

6809 CPU module
P-ISR-7500

GPIB Interface module
P-ISR-7507
FIGURE 2 BLOCK DIAGRAM OF INTEGRATOR MODULE AT 680-2036-050
INTEGRATOR

FUSE: 0.4A SLOW BLOW

IEEE 488

220V

REAR PANEL
MATERIE: ANTICORODAL EP 2.5mm

PORTABLE INTEGRATOR
REAR PANEL ENGRAVING

FIGURE 4
## G64 Memory Map for the Digital Integrator

### System Stack:
- Start: $F7FF
- End: $E800
- Length: 4k

### Vectors:
- Start: $F800
- End: $FFFF
- Length: 2k

### VPA Area:
- Start: $E000
- End: $E7FF
- Length: 2k

### Program Area:
- Start: $0000
- End: $7FFF
- Length: 32k

### Data Stack:
- Start: $D7FF
- End: $8000
- Length: 22k

### RAM on CPU Card:
- Start: $D800
- End: $DFFFF
- Length: 2k

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**Table 1**
SPECIFICATIONS FOR PORTABLE INTEGRATOR AT 680-2036

INPUT

input impedance: 1000 MOhms unbalanced or 2 MOhms || 2pF balanced input.
input voltage range: +/- 5V divided by selected preamplifier gain. Over-range detection.
input resolution: 20µV divided by selected preamplifier gain with 500kHz VFC.
input protection: +/- 50V d.c. +/- 200V for 10ms.
common mode voltage: +/- 12V with respect to the connector shield.
                        +/- 500V with respect to digital ground in floating mode ("0V connect" jumper removed).
filters: possible before and after pre-amplification by installing capacitors.

GAIN

Gain selection: 1.4,16 or 64 selected from front panel or programmed over the GPIB.
This gives input ranges of +/-5.0, 1.25, 0.3125 and 0.078125 V respectively.
Gain non-linearity: +/- 50 ppm max. of F.S. (500kHz).
Gain stability: 9 ppm/deg. max. of F.S. (500kHz).

OFFSET

Input offset drift vs. temp

G=1: 10µV/deg. max.
G=4: 3.5µV/deg. max.
G=16: 1µV/deg. max.
G=64: 0.4µV/deg. max.

Offset adjustment: Fine and coarse multi-turn potentiometers on the front panel.
External offset input: +/- 10V on this input gives +/- 10mV offset on the VFC input.

NOISE

R.T.I. 0.1 Hz to 10 Hz

G=1: 10µV p-p.
G=4: 2.5µV p-p.
G=16: 0.6µV p-p.
G=64: 0.3µV p-p.

ANALOGUE OUTPUT

+/-10V output, proportional to the integrator value. Selectable in seven ranges of units/volt.

APPENDIX 1
TRIGGER

- 50 Hz derived trigger, for normal operation.
- GPIB "GET" (Group Execute Trigger).
- external via opto-coupler input.
- internal 1 second time base.

minimum integration interval (display disabled): 10 ms.
minimum integration interval (display enabled): 40 ms.

FRONT PANEL CONTROLS

- integrator START, STOP and RESET.
- input voltage range selection.
- analogue output voltage range selection.
- trigger selection.
- units selection.
- pre-programmed coil surface selection.
- drift adjustment using two multi-turn potentiometers (Coarse/fine).

FRONT PANEL INPUTS/OUTPUTS

- integrator input (Lemo 2 pin).
- external offset voltage input (Lemo co-ax).
- external trigger, start, stop and reset inputs (Lemo co-ax).
- analog voltage output (Lemo co-ax).

FRONT PANEL INDICATIONS

- 8 digit, 10 mm high Led display.
- green leds for power on and analog output zero indication.
- yellow leds for remote, measure, external trigger, trigger, gauss, tesla and Vs indication.
- a red led for over-range indication.

REMOTE CONTROL

- using the GPIB (IEEE 488). See Appendix 2 for the description of the GPIB commands and Serial Poll status.

REAR PANEL CONNECTIONS

- 220volts with 0.4A slow - blow fuse.
- GPIB.

CHASSIS

- Europe chassis, 3u (130 mm) high, 60 TE (335 mm) wide and 300 mm deep.
PORTABLE INTEGRATOR - GPIB COMMANDS

ADDRESS = 5

IDENTIFY

IDENTIFY!

Outputs ID string of integrator.

ENDING

ENDING:EOI!
ENDING:CR!
ENDING:CRLF!

Selects ending of character string sent by integrator.

Terminates with EOI (End Or Identify). Default.
Terminates with Carriage Return + EOI.
Terminates with Carriage Return Line Feed + EOI.

TRIGGER

TRIGGER:GPIB_GET!
TRIGGER:EXTERNAL!
TRIGGER:TIME_BASE!

SELECTS type of trigger to be used.

GPIB Group Execute Trigger (GET). Default.
Integrator external trigger.
One second time base trigger.

GAIN

GAIN!
GAIN:1!
GAIN:4!
GAIN:16!
GAIN:64!

Selects gain of preamplifier.

Outputs actual gain value.
Gain = 1. Range: 5 V. Default.
Gain = 4. Range: 1.25 V.
Gain = 16. Range: 0.3125 V.
Gain = 64. Range: 0.078125 V.

ANALOG_OUTPUT

ANALOG_OUTPUT!
ANALOG_OUTPUT:1!
ANALOG_OUTPUT:2!
to
ANALOG_OUTPUT:7!

Selects sensitivity of analog output.

Outputs actual analog output sensitivity (1 - 7).
Analog output = 10μVs, 10μT or 0.01G/volt. Default.
Analog output = 100μVs, 100μT or 0.1G/volt. to
Analog output = 10Vs, 10T or 1000G/volt.

UNITS

UNITS!
UNITS:VS!
UNITS:VOLTS!
UNITS:GAUSS!
UNITS:TESLA!

Selects the units of the integrator values.

Outputs actual units.
Vs. Default.
Volts.
Gauss.
Tesla.

GAUSS_FACTOR

GAUSS_FACTOR!
GAUSS_FACTOR:1.2345!

Selects multiplication factor to be used with GAUSS units.

Outputs actual Gauss_factor.
Default = 1.00 .

APPENDIX 2
TESLA_FACTOR

Selects multiplication factor to be used with TESLA units.

TESLA_FACTOR!
TESLA_FACTOR:1.2345!

Outputs actual Tesla_factor.
Default = 1.00.

START

Puts the integrator into the measurement state.

START!

STOP

Puts the integrator into the stop state.

STOP!

RESET

Puts the integrator into the reset state.

RESET!

DISPLAY

Enables or disables the front panel display.

DISPLAY:ON!
DISPLAY:OFF!

Display enabled. Default.
Display disabled.

MODE

Selects measurement mode of integrator.

MODE:IMMEDIATE!
MODE:BLOCK!

Integrator values are sent to the GPIB after each trigger.
Default.
Integrator values are stored in memory after each trigger,
(1000 max.) and are sent to the GPIB afterwards.

NO_OF_POINTS

Sets the number of measurements to be done when in
the BLOCK mode. Default = 0, maximum = 1000.

NO_OF_POINTS:100!

RESET_POINTER

Resets the output pointer to the first integrator value.
Used to read the integrator values: a) if the number of
points programmed has not been reached or b) to re-read
the integrator values.

RESET_POINTER!

All complete commands must be terminated, as shown, by the character "!". Line feed and
carriage return characters are ignored.
GPIB SERIAL POLL STATUS

S8  SRQ  S6  S5  S4  S3  S2  S1

S1  DATA READY.
Set when data or text (after IDENTIFY) is available to be read. In the BLOCK mode, it is set when the number of measurement points programmed has been reached or if the output buffer is full (1000 points). In the BLOCK mode, the first value to be read is always the number of points available to be read. The string termination, defined by the ENDING command, is sent after each measurement value.

S2  OVER-RANGE.
Set if over-range has been detected during the measurement of the value to be read. It is valid only when DATA READY is set. Applies also in BLOCK mode.

S3  NO OF POINTS REACHED.
Set in the BLOCK mode, when the number of measurement points equals the number of points programmed. DATA READY is set at the same time, to indicate that data is available to be read.

S4  BUFFER FULL
Set in the BLOCK mode, when the number of measurement points equals 1000, the maximum buffer size. DATA READY is set at the same time, to indicate that data is available to be read.

S5  LAST VALUE
Set in the BLOCK mode, to indicate that the value being read is the last one in the buffer.

S6  READY FOR TRIGGERS
Set in response to the START command. Ensures that the integrator has decoded this command and is, in fact ready to receive triggers.

SRQ  Not used.

S8  INTEGRATOR DOING POWER-ON RESET
The integrator enters this state when it is switched on, after a microprocessor reset and when it receives a Device Clear (DCL) or Selected Device Clear (SDL) over the GPIB.
This reset takes about 10 seconds, after which the status byte is set to zero.
PORTABLE INTEGRATOR CALIBRATION PROCEDURE

This complete calibration procedure for the integrator module AT 680-2036-050 is intended for a unit which has never previously been set up and calibrated. When re-calibrating, only steps 10, 11 and 12 should be required.

1  Install input resistors R37 and/or R36 (1 Megohm). Install filter capacitors C10 and C14 if required.

2  Provisionally install on the solder side, resistors R6 (220Kohms), R27 (10 ohms) and R53 (100 ohms).

3  Set up potentiometers P1 and P2 to approximately their mid-way positions.

4  Install a short circuit on the input Lemo and select the time base trigger with the 5 volt range. Verify that the offset can easily be adjusted to zero using P1. If not, then change the value of R53.

5  Connect the front panel potentiometers and adjust them to give a reading of 0.00000. Set the input voltage to plus and minus 4.00000 volts and verify that the gain can easily be adjusted to the correct value using P2. If not, then change the value of R6.

6  Install definitively R6 and R53, then let the card warm up for 30 minutes.

7  On the 5 volt range, adjust the offset to zero, then, using P2 adjust the gain to the best possible value i.e. equal positive and negative errors.

8  On the 1.25 volt range, adjust the offset to zero. Verify the accuracy of the gain using inputs of plus and minus 1.00000 volts. If the errors are not symmetric then adjust the value of R27 up or down one resistance value. The gains of the remaining two ranges are guaranteed by a precision resistor network and are not adjustable.

9  Install R27 definitively and clean the PCB.

10 Allow card to heat up for 1 hour, then verify gains on all ranges, adjusting the offset to zero on each range. If necessary, re-adjust P2.

11 Check over-range indication on the 5 volt range to be +/- 4.9 volts.

12 Set both front panel potentiometers to 5.0 (mid-way), and on the 5 volt range adjust the offset to zero using P1, with a short circuit on the input.

The instrument can then be verified using the program "POINT" installed on an HP85 computer connected to a GPIB controlled voltage calibrator. This program makes measurements at zero and every 10% of the full scale input voltage of the range selected and prints out the linearity in ppm. The required range is selected manually on the front panel. The offset should be adjusted to zero before making the measurements.

APPENDIX 3
PORTABLE INTEGRATOR

INTEGRATOR (2)
CPU 6809

CERN-ISR
CPU-6809
P-ISR-1503-8

I:1

DESSINE: GE/ELS
27.10.82

REPLACE
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