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Microprocessor based data acquisition and control system for a balloon borne quadrupole mass spectrometer

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Abstract. — A microprocessor based data acquisition and control system has been designed and constructed for use in balloon borne quadrupole mass spectrometers. It combines the capabilities of an ion counter/discriminator, a spectrum accumulator, an intelligent mass scan controller, a multiplexed analog to digital converter, a relay controller, a PCM encoder for serial digital output, multiple analog outputs and an interface to remote control signals. The system has been flown successfully in the stratosphere.

1. Introduction

Recently there has been a growing interest in the measuring and modelling of the positive and negative ion composition of the stratosphere, particularly as a promising new method for the detection of trace gases with very low concentrations [1-3].

Therefore balloon borne mass spectrometers have been built by these authors [4] and others [5-6]. Such an instrument mainly consists of a high speed cryogenic pump [7], a sampling hole, a quadrupole mass filter operated in high vacuum and the associated electronics. The stratospheric ions are sampled through the small hole and are focussed into the mass filter, where they are selected according to their mass to charge ratio. Neutrals are pumped by the high speed pump. After passing the quadrupole, ions reach a high gain electron multiplier working in the pulse counting mode. The charge pulses at the anode of the multiplier are discriminated and counted during a time

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window. The corresponding number of detected ions is then classified within a mass spectrum.

For application in such instruments our group constructed a programmable controller [8] which combined a fast 24-bit ion counter and a remotely controllable mass selection unit. With this controller and a mass filter having a mass range upto 110 amu the first mass spectra of the positive stratospheric ions, obtained by a balloon borne instrument, have been measured [9]. In order to improve the performance of the balloon borne mass spectrometer a new on-board data management system has been designed based upon current 8-bit microprocessor technology. Its premium task was the storage and integration of mass spectra, but we took also benifit of its computing and control power to upgrade other functions of the instrument.

It is the aim of this paper to describe the technical details of the new system, which are applicable to many other balloon-borne or remotely controlled experiments.

2. Review of mass scanning theory

Our stratospheric mass spectrometer [4 and 7] uses an electrical quadrupole filter, the theory of which is well established [10]. In the field of such a quadrupole, supplied with DC voltages U and -U and RF voltages $V \cdot \cos \omega_0 t$ and $-V \cdot \cos \omega_0 t$ and having a field radius r_0 the motion of a charged particle with mass m and charge e is governed by Mathieu differential equations. From the analysis of these equations it follows that stable ion trajectories are only obtained for certain U versus V relations. If the relationship is a linear one, such as

$$U(V) = K_1 \cdot V \quad \text{with} \quad K_1 = 0.16784 \tag{1}$$

ions with mass m will only pass through the filter for V values given by:

$$m = \frac{4eV}{\omega_0^2 \cdot r_0^2 \cdot q_1} \quad \text{with} \quad q_1 = 0.706 \tag{2}$$

When the RF voltage is modulated by a linear ramp function a linear mass versus time relation will evolve and mass peaks with infinite resolution (in theory) will appear. If the amplitude V is limited by the quadrupole power supply to V_{max}, the mass range extends to m_{max}, obtained by formula (2) for $V = V_{max}$.

In the more general case that

$$U(V) = K \cdot V \quad \text{with} \quad 0 \leqq K \leqq K_1 \tag{3}$$

the trajectories of ions with mass *m* and charge *e* become stable from

$$V_2 = \frac{m \cdot \omega_0^2 \cdot r_0^2}{4e} \cdot q_2 \qquad (q_2 < q_1)$$

to

$$V_3 = \frac{m \cdot \omega_0^2 \cdot r_0^2}{4e} \cdot q_3 \qquad (q_3 > q_1)$$

The ions are obviously filtered with a constant, finite resolution ($= m/\Delta m$) because $(V_2 + V_3)/(V_2 - V_3)$ is independent of mass. By lowering K well below 0·16784 one can make appear the rising edge of a given mass peak at a much lower RF amplitude. The range of the detectable masses will then expand to

$$m_{\max,q_2} = m_{\max,q_1} \cdot q_1/q_2 > m_{\max,q_1}$$

while the relation between V_2 and mass remains linear.

This technique of " rising edge detection " offers the possibility of extending the mass range beyond the RF limited mass range associated with infinite resolution. It has been applied successfully by our group for the measurement of stratospheric negative ion abundances up to 391 a.m.u. [11]. A special case exists when no DC is applied to the quadrupole rods ($q_2 = 0$; $q_3 = 0.908$). The quadrupole then acts as a high pass filter : only masses above $4\,eV/(0.908 \times \omega_0^2 \cdot r_0^2)$ are transmitted.

Finally a third mode of operation can be imagined in which the peak width Δm of the mass peaks is a constant. This condition can be satisfied when operating the mass filter close to the tip of the stability diagram and when we make the ratio U/V a non linear function of V [10] :

$$U/V = K_1 - K_2 \cdot \frac{\Delta m}{V} \quad \text{with} \quad K_2 = 0.178\, \omega_0^2 r_0^2 / 8e$$

or

$$U = K_1 \cdot V - K_2 \Delta m$$

The constant peak-width (CPW) mode can thus be realized either by off-setting the operating line $U = K_1 \cdot V$ by an amount $-K_2 \cdot \Delta m$ which varies linearly with desired peak-width, or by making the slope of the scan line $U = U(V)$ mass dependent.

The latter solution is employed in our instrument for flexibility reasons. The CPW mode produces peaks which are broader at low masses (and result in a higher transmission) when compared to the fixed resolution mode if high mass peak-widths are made equal in both modes.

3. Design objectives

a) *Spectra management*

From previous flights with an earlier version of our stratospheric mass spectrometer we learned the extreme importance of a very flexible communication link between the ground-borne experimenter and the balloon-borne instrument. In this mass spectrometer the observed ion count rates were not stored on-board but instead directly transmitted by telemetry as a pulse code modulated (PCM) digital data stream.

This involved that storage of mass spectra and their integration over long time periods was done on ground, so that every disturbance in the telemetry link or in the data handling system could severely spoil the measurements. Furthermore the data transmission format, which was solely based upon the use of digital (PCM) data, implicated that realtime interpretation of spectra was impossible without a computer.

Therefore it was decided to move the spectrum storage function to the other end of the telemetry link, i.e. to the instrument. This implementation made it possible to let the mass spectrometer produce simultaneously on-board slow analog, paper recorder compatible, spectrum output as well as computer compatible, serial PCM spectrum data. So, even when no real-time PCM treatment is done or can be done, the experimenter will still have access to real-time copies of the currently observed ion mass spectrum. The analog copy is made available on 3 analog telemetry channels, each with a different, software selectable scale factor. Spectrum excursions become thus adaptable to signal abundance. The 3 analog spectrum outputs can also be reconfigured by software, under remote control, so that sequence rotation of these 3 telemetry channels results. This feature helps to circumvent failure of a single telemetry channel.

b) *Mass scanning*

A main objective of a stratospheric mass spectrometer flight is to measure the relative abundances of the different ion species at different altitudes and to deduce from this concentration profiles of trace gases (such as : H_2O, CH_3CN, NaOH, HNO_3, H_2SO_4, etc.) influencing the positive or negative ambient ion composition. The stratospheric ions are few abundant (approx. 10^3 cm^{-3}), so that a considerable amount of flight time is consumed for building up a single spectrum. In practice therefore, we try to make a very efficient signal usage taking into account both time consumption and desired information.

Considerable time can be gained by selecting an appropriate mass scanning mode. In our new microprocessor controlled instrument we have the possibility to select the following scan parameters by software backed remote control : 1) resolution mode 2) extend of the scan range 3) number of spectrum channels 4) total scan time. Two resolution modes are implemented. In the first mode the resolution is held constant all over the mass range, resulting in a linear relationship between peak-width and mass number (see previous section). This mode is primarely used in cases where the mass numbers of the ions are known beforehand and one only wants to measure relative abundances of these ions. A very coarse resolution can be used together with the " rising edge detection " technique. This results in a high quadrupole transmission and consequently a faster spectrum built-up. In the constant peak-width mode the resolution is made a linear function of mass. It is used for the unambiguous determination of ion mass numbers by in-flight calibration because mass peaks can be resolved equally well all over the mass range.

The RF scan range is the second parameter we can modify to optimize our measurement technique. In our system a choice can be made between the full scan range and a number of medium and small sized scan ranges. Each scan range is related to a mass number range, the extent of which depends upon the selected peak resolution and the criterion used for ion identification (either peak or rising edge). The full mass range is used primarely for a coarse resolution first look at the ion mass distribution. Obviously the small sized mass ranges have been introduced to yield a reduction in scan time. They extend only over a few (10) a.m.u. and are employed, mostly in a constant peak-width mode, to enhance the signal-to-background ratio in parts of the spectrum where interesting features are expected. Such features are: isotopically related peaks, very small peaks, etc. The medium sized mass ranges compromise between range span (56 a.m.u.) and scan time. They are distributed over the full mass range so as to cover an optimum number of mass peaks usable for mass scale calibration. Their main application is in the determination of unknown ion mass numbers.

The next scan parameter we can optimize is the number of spectrum channels. Its value is varied in function of resolution: scans producing wide flat-topped peaks are always performed at approximately 2 channels per a.m.u., while fine resolution spectra demand for 6 channels per a.m.u..

Total scan time does not affect efficiency. It is equal to the product of the number of channels and the counting window time per channel and is determined by two factors. The scan repetition rate must be fast enough to show short-term ion population variations and on the other hand, it must be slow enough to stay in pace with the transmission of analog spectrum copies. Therefore a duration of 250 msec has been assigned to the window.

c) *Other control functions*

The principal tasks of the described system are the management of spectra and the mass scanning procedure. Besides those however, some other duties are performed by the microprocessor without interference with the mass scanning, analog spectra transmission or PCM generation. A very important job executed by the microprocessor is the remote control procedure. It checks the received remote control code for validity and reacts on it with the execution of service programs or scan definition programs. The latter programs are used to define future mass scans. They run totally concurrent with the present mass scan in order to save measurement time. The service programs take care of the following functions: fine or coarse incrementing or decrementing of the draw-in-potential at the sampling hole, polarity switching between positive or negative ions, switching between ion sampling mode and neutral (ion source) mode, opening of the protective cap of the mass spectrometer [7], rotation of telemetry channels and selecting of spectrum scale factors (see section 3.a). Again they run totally transparent to the principal tasks of the microprocessor.

4. Hardware implementation

Figure 1 shows a block diagram of our balloon-borne microprocessor based data acquisition and control system. The heart of this system is formed by 3 boards which are interconnected by a system bus consisting of a data bus (8 bits), an address bus (16 bits) and a control bus (MEMR, MEMW, INTA, interrupt). These boards are : a microprocessor board, a memory board and an input/output (I/O) service board. The microprocessor board contains an 8-bit microprocessor (Intel M8080A) and its associated clock generator (M8224) and bus

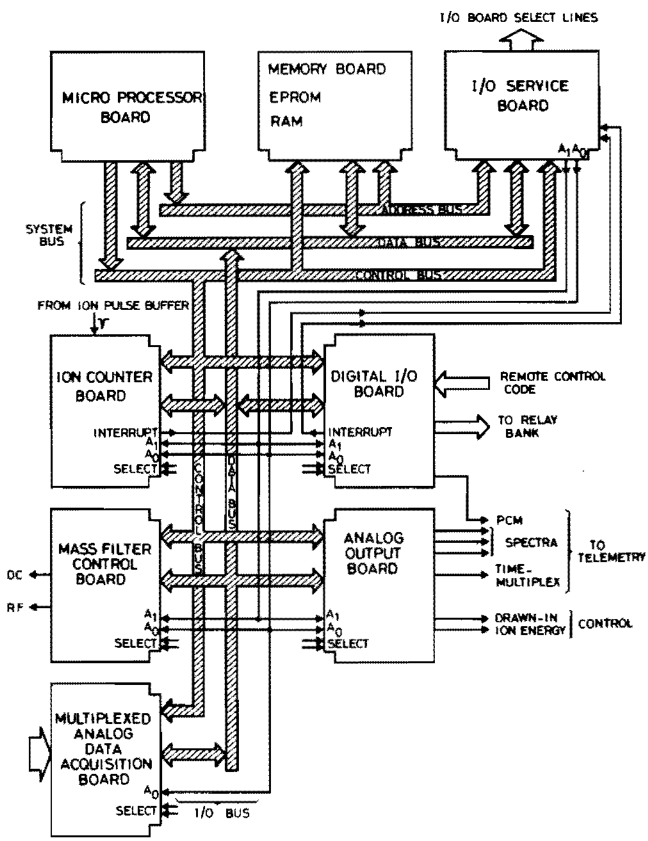

FIG. 1. — Block diagram of the balloon borne, microprocessor based data acquisition and control system.

control circuits (M8228). The microprocessor executes instructions fetched from the memory board which packs a program and a work area. Programs are stored in erasable reprogrammable read only memories (Intel M2716, 2K bytes each) so that program loading from a mass storage device is not required.

The work area is constituted of static random access memories (Mostek MKB 4118, 1K bytes each) and stores program stack, program variables, alterable instructions, mass spectra, PCM frames, scan parameters, etc. This memory board has been designed for EPROM/RAM interchangebility and can be reconfigured for upgrading to future software needs. Currently memory space can be defined as any combination of 2N K EPROM memory + (6 − N)K RAM memory with N = 1 to 5. The third board connected to the system bus is the input/output service board. It functions as a link between the other system boards and the I/O interface boards described hereafter. On this board the interrupt controller (Intel M8259) is located. It handles interrupt requests from the I/O boards and is programmed by the microprocessor software to work in the nested mode, i.e. requests are ordered in priority. In order to reduce local address decoding requirements on the I/O boards the same board is also equipped with an I/O address decoder which produces I/O board select strobes (2 per board). The addresses of the boards are memory mapped so that no specific I/O instructions are required for input/output.

The I/O interface boards are interconnected by an I/O bus and communicate with the outside world : the quadrupole supply, the ion detector, telemetry, remote control and a set of relays. The I/O bus is constituted of the system data bus (8 bits), the system control bus, a reduced address bus (A_0 and A_1) and an interrupt bus (8 lines, wired-orable). In the current hardware implementation the following interface boards are installed : 1) an ion counter/discriminator board 2) a mass filter control board 3) a parallel and serial digital I/O board 4) an analog output board 5) a multiplexed analog data acquisition board.

The ion counter/discriminator (fig. 2) receives negative pulses from an ultra fast pulse buffer (NS LHOO33) connected to the anode of the ion detector (a Galileo Spiraltron type 4219). These pulses are checked by a pulse height discriminator (NS LM160, high speed comparator) and are subsequently counted by a programmable interval timer (Intel M8253). The latter circuit is organized as three inde-

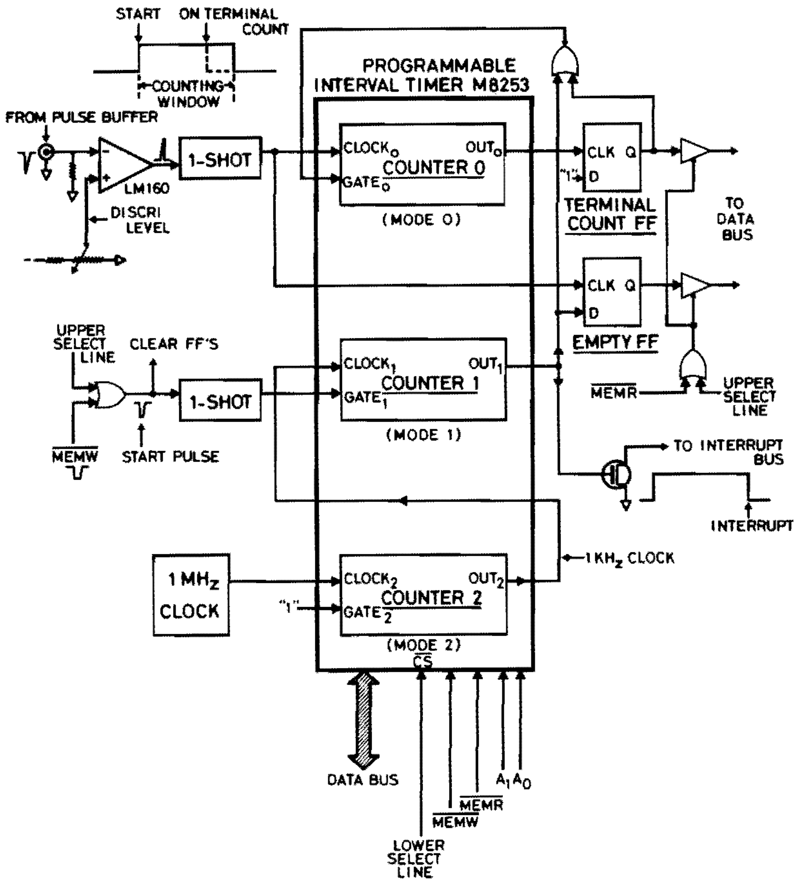

FIG. 2. — Ion counter discriminator board. Counting window : 1 to $2^{16}-1$ msec ; number of ions counted : max. $2^{16}-1$.

pendent 16-bit counters, programmable by software to perform in a specific mode of operation. Counter O is configured as an event counter (mode O) and counts the number of ion pulses received during a counting window. The window pulse duration is determined by counter 1 acting as a programmable one-shot (mode 1), while the third counter is programmed as a frequency divider (mode 2) producing a 1 KHz clock rate. Consequently, ions can be counted during counting windows ranging from 1 msec upto $2^{16}-1$ msec or more than 1 minute. Additional circuits are required to make the event counter behave properly. First of all, when the latter reaches terminal count ($2^{16}-1$) the counting procedure must be stopped by gating off the window pulse in order to prevent misleading results. Also when no pulses at all have arrived during a window pulse the ion counter contents, as acquired by the microprocessor read instructions, may look erroneous. These 2 conditions — terminal count and empty counter — are therefore detected by 2 flag flip-flops and made accessible for read-out by the counter software routine.

The mass filter control board (fig. 3) masters the mass and resolution setting of the quadrupole mass filter. It generates 2 voltages V_c

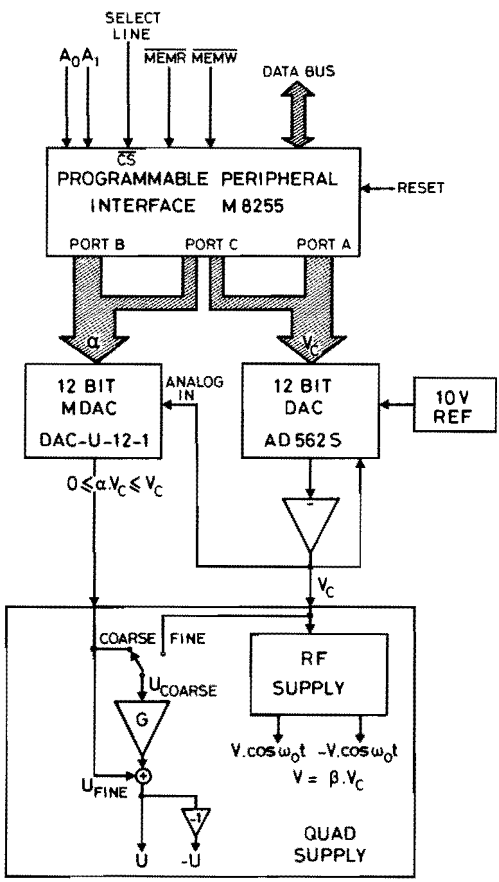

FIG. 3. — Mass filter control board and its connection to the quadrupole supply. G is choosen equal to $\beta \cdot K_1 - 1$ for convenience.

and $a \cdot V_c$ which are used to control the quadrupole power supply. Digital information concerning V_c and a is sent by the microprocessor via a programmable peripheral interface (Intel M8255). Ports are combined to form digital inputs to a 12-bit digital-to-analog (DAC) converter and a 12-bit multiplying DAC (MDAC). The RF output of the quadrupole supply is made linearly proportional to the DAC output V_c, which can take 4096 values between 0 and 9,9976 Volts ($V = \beta \cdot V_c$). The MDAC functions as a digital potentiometer and governs the slope of the operating line $a = 2q \cdot U/V$ in the stability diagram of the quadrupole (see ref. 10). A combination of its output $a \cdot V_c$ and the DAC output V_c drives the DC section of the quadrupole supply, the output of which is given by :

$$U = U_{fine} + G \cdot U_{coarse}$$

Depending upon the position of a software controlled switch in the quadrupole power supply either a coarse or a fine resolution mode can be selected. In the first mode U_{coarse} and U_{fine} are both equal to $a \cdot V_c$, so that :

$$U/V = (1 + G) \cdot a/\beta$$

or

$$0 \leqq \frac{U}{V} \leqq \frac{1 + G}{\beta} \qquad \text{with } 0 \leqq a \leqq a_{max} = 0{,}99976$$

If now G is made equal to $\beta \cdot K_1 - 1$ the operating line can be given any slope between the high pass mode (DC = 0) and infinite resolution.

When the fine mode is called on we get :

$$U_{coarse} = V_c$$

$$U_{fine} = a \cdot V_c$$

$$G/\beta \leqq U/V \leqq (G + a_{max})/\beta$$

or

$$K_1 - 1/\beta \leqq U/V \leqq K_1$$

The slope of the operating line (= 2U/V) can thus be varied at will over 4096 positions in a restricted range near the apex of the stability diagram. In the case we hold a constant while V_c is being sweeped, spectra will appear with a constant fine resolution given by [10]:

$$R = \frac{0.178}{2K_1 q_1 - a(q_1)} = \frac{0.126}{K_1 - U/V}$$

or

$$0 \cdot 126\,\beta \leqq R \leqq \infty$$

We can also arrange for constant peak-width spectra. The condition for constant peak-width Δm is:

$$\frac{U}{V} = K_1 - K_2 \cdot \frac{\Delta m}{V}$$

Therefore the following relation must exist between the digital codes sent to the DAC ($= V_c$) and to the MDAC ($= a$):

$$a = \gamma - \delta / V_c$$

with

$$\gamma = K_1 \cdot \beta - G = 1$$
$$\delta = K_2 \cdot \Delta m$$

This relationship has been implemented by a software routine calculating $a(V_c)$ with γ and δ as parameter input. Its application implies a lower mass limit: V_c must be at least equal to δ to yield positive a values. The same software routine computing $a(V_c) = \gamma - \delta/V_c$ can be used for all resolution modes when γ and δ are generalized as in table I.

TABLE I. $a = \beta - \delta/V_c$.

Mode	U_{fine}	U_{coarse}	γ	δ	Resolution
			1	0	infinite
fine	$a \cdot V_c$	V_c	< 1	0	finite
			1	$K_2 \Delta m$	constant Δm
			0	0	high pass
coarse	$a \cdot V_c$	$a\, V_c$	< 1	0	coarse

As mentioned before copies of spectra stored in the microprocessor RAM memory are sent to the receiving station in a serial PCM format. The circuit which is responsible for the conversion process of byte-wide binary information to a serial bit stream is a programmable communication interface (Intel M8251). It is part of the parallel and serial I/O board shown in fig. 4. For our application it is configured by software to work exclusively as a synchronous transmitter. The data at its output appears therefore as a continuous NRZ-L (no-return-to-zero level) encoded serial data stream without any added start, stop or parity bits. The NRZ-L data are further converted by a CMOS encoder (RCA CD4037) into a bi-phase level (bi-ϕ-L) signal, which is an adequate coding scheme for PCM data. The bit rate of the resulting bi-ϕ signal is determined by a baud rate generator consisting of a crystal oscillator and a tapped frequency divider circuit. In the present configuration serial data are transmitted at about 1300 bits/sec

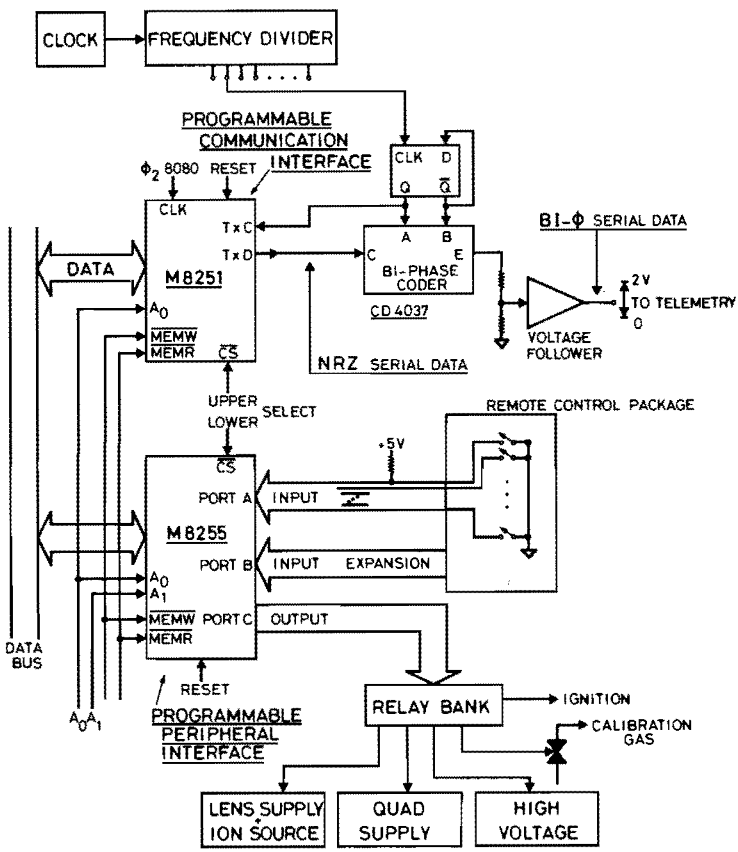

FIG. 4. — Parallel and serial I/O board.
Upper part : serial I/O : PCM output.
Lower part : parallel I/O : remote control input and relay control output.

over an IRIG standard channel E (2.1 KH_z bandwidth). On the same I/O interface board parallel I/O circuitry is incorporated. It consists in a programmable peripheral interface (Intel M8255), the 24 I/O lines of which are accessible at 3 byte-wide ports A, B and C. The functional characteristics of the ports can be defined by software. In our application port A is configured as a nonlatching input port receiving an 8-bit remote control code delivered by telecommand. Port C is programmed as an 8-bit data latch having a single bit set/reset feature. It controls a bank of relays, each switching or activating one of the following items: the polarity of the ion focussing voltages, the polarity and absolute value of the ion detector cone voltage, the ion lens mode (ion source or natural ion sampling), the quadrupole supply mode (fine or coarse), valve positions (atmospheric or calibration gas) and the ignition of cable cutters (opening of the vacuum system). The third port B is reserved for future expansion of the remote control code.

The analog output board simply consists of six 8-bit monolithic DACs (Signetics SE5018). Three of these deliver analog copies of the stored mass spectrum each with a different scale factor. The fourth buffered output carries a time — multiplexed signal, composed by the microprocessor's software and showing technological data measured by the multiplexed analog data acquisition board. Two other DACs are wired to respond to offset binary code and are used to control the potential of the sampling flange and the ion energy, in both polarities.

The function of the multiplexed analog data acquisition board is to collect samples of important technological data such as: pressure and temperature of the ambient air, pressure and temperature inside the instrument, pressure in the mass filter region measured by a Penning gauge, liquid helium levels, the potential of the draw-in flange and the quadrupole's pole bias, etc. These data are acquired by a 16 channel 12-bit data acquisition system consisting of merely two functional blocks (Analog Devices AD364 TD). A/D convertions are started by software and after (typical) 25 μsec converted data ara available as a byte pair.

5. Software

It is obvious that a hardware implementation based upon microprocessor technology must be supported by a powerful software package in order to take full benefit of the microprocessor's capabilities. Since in our case we must deal with 2 well timed processes, namely the mass scan process and the PCM transmission process an interrupted software loop structure has been choosen (see fig. 5).

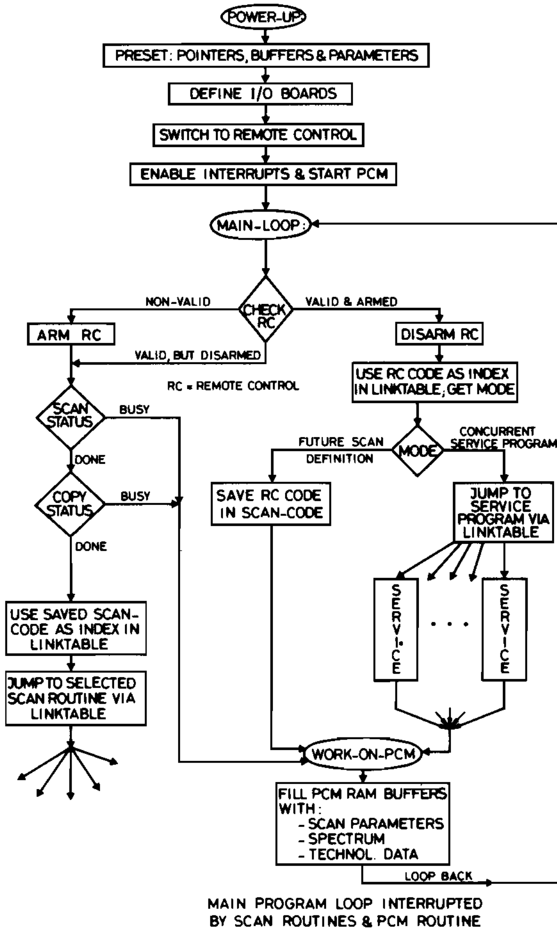

FIG. 5. — Simplified flowchart of the main program loop interrupted by the mass scan process and the PCM transmission process.

When power is applied to the system, a reset pulse, generated by the microprocessor board, is forcing the program counter to point to the power-up section of the main program. In this section the following operations are performed sequentially. First, the programmable interface circuits (such as M8255, M8251, M8253 and M8259) located on the various I/O boards and on the interrupt board are each being programmed to work in the adequate mode of operation. Then pointers, status bytes, PCM buffers and the spectrum area stored in RAM are preset to their initial values. Next the PCM interrupt routine is initiated which involves that the PCM transmitter is enabled and that a first interrupt from the digital I/O board may be expected soon. Finally, the interrupt system of the microprocessor is enabled.

After running through the power-up section the main program arrives at the MAIN-LOOP node where a perpetual program loop is started. In this loop several actions are taken : remote control code, scan status and spectrum copy status are interpreted, service or scan definition routines are possibly executed and PCM buffers are filled. The remote control code, a byte acquired via the digital I/O board, consists of 3 subfields : a 4-bit program selection (PS) field, a 3-bit option field and a 1-bit validation field. Remote control (RC) codes are being accepted as new on condition that they are recognized as valid, while double acception is avoided by an arm/disarm mechanism. On new RC codes the loop branches to a section where it is decided by table look-up (PS field indexed) whether a service routine or a scan definition routine is called next. Scan definition routines are straightforward and merely save the current RC code fields for use by the next mass scan. Service routines however may alter all program parameters, except those affecting the current mass scan. They are used for such simple tasks as : increasing or decreasing the potential of the draw-in plate separately for positive and negative ions, changing scale factors of the spectrum copies, switching polarity, ignition of the uncovering system of the sampling hole, etc. If the mentioned test of the RC code fails, the program checks the mass scan status. In case the mass scanning process is still active the program skips further testing and jumps to the PCM buffer filling section (WORK-ON-PCM node).

Otherwise an additional check is made to see if the terminated spectrum is already fully copied by the PCM routine. If not a jump is made to WORK-ON-PCM. When status information indicates that both mass scanning and spectrum copying are done the program selects a new kind of scan, using the PS field of a previously saved RC code as a pointer (possible unchanged during the last scan). The program loop then branches to one of the many scanning routines permanently stored in EPROM memory. Figure 6 shows the flowchart of a typical scan routine performing scans with constant peak-width in small mass domains (10 a.m.u. wide) selected by the saved option field. These routines all have the same structure. They first set up scan parameters taking into account the option field of the saved RC code. If ion polarity and/or scan parameters differ from those of the previous scan the spectrum storage area in RAM memory is cleared. Next, a call is made to a START-SCAN routine which starts the mass

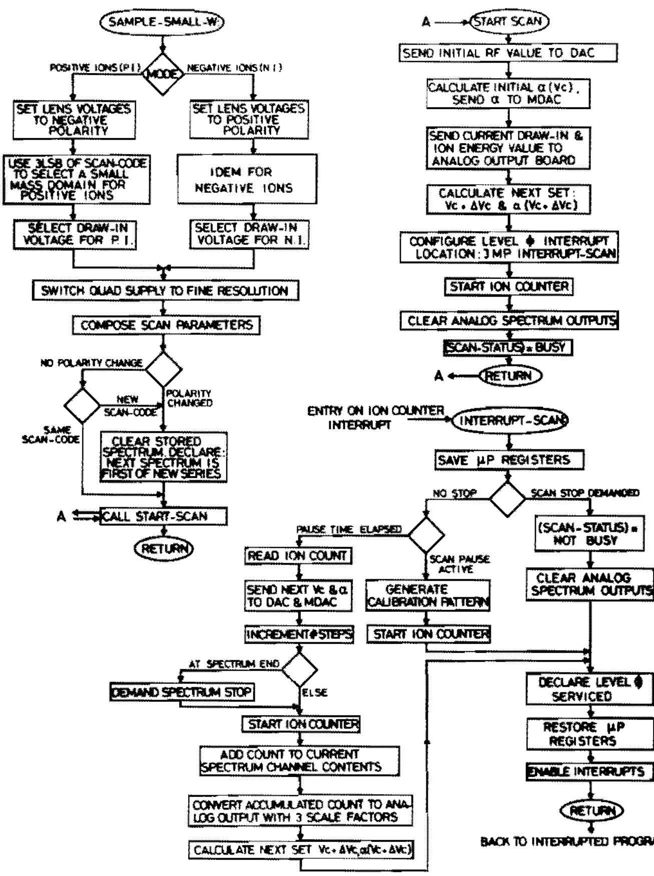

FIG. 6. — Flowchart of a typical mass scan routine. It calls the START-SCAN routine to begin a scan. The latter continues by interrupt driven calls to the INTERRUPT-SCAN routine.

scan process and returns to the main program loop. The latter then continues with the filling of buffers emptied by the PCM routine (not described in detail) and finally loops back to its beginning.

The main program is interrupted on two occasions : 1) at the end of the counting window of the ion counter 2) when the transmitter of the programmable communication interface (M8251) wants one more byte. In the first case the interrupt controller directs program flow to the INTERRUPT-SCAN routine, the flowchart of which is depicted in figure 9. This routine reads the counter contents, adds the count to the spectrum channel contents, proceeds to the next channel, starts the counter, converts the accumulated count to analog output and returns to the interrupted program section. Interrupts are discontinued when the specified number of spectrum channels is reached. The interrupts forced by the M8251 are of lower priority and are handled by the interrupt section of the PCM routine. The latter supplies the M8521 with data from PCM data buffers filled in the main program loop and besides that also composes the time-multiplexed signal output by the analog output board.

6. Performance of the system

The balloon borne mass spectrometer with the new microprocessor based data acquisition and control systems was flown twice in 1980. The first balloon flight was performed from the CNES launching base in Gap-Tallard in Southern France on 16 June 1980. Spectra were obtained for positive and negative ions in the rising peak edge mode. An unambiguous determination of the masses of the major positive ions at 35 km altitude was possible through the use of the C.P.W. mode [9]. The second flight took place at the CNES launching base at Aire sur l'Adour on 18 September 1980. During the flight again positive and negative ions have been measured in different modes. The use of the C.P.W. mode for the negative ions permitted an unambiguous identification of the negative ions up to 200 amu at an altitude of 35 km. Furthermore an ion with mass 391 amu was detected for the first time, by using the technique of rising edge detection. Mass spectra obtained in the different modes have been published in the literature [9 and 11]. In view of the results obtained in flight, as well as the extensive laboratory tests the performance of the system may be called very satisfactory in every respect.

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