Control of Total Voltage in the Large Distributed RF System of LEP

E. Ciapala and L. Arnaudon

SL Division, CERN, 1211 Geneva 23, Switzerland

Abstract

The LEP RF system is made up of a large number of independent RF units situated around the ring near the interaction points. These have different available RF voltages depending on their type and they may be inactive or unable to provide full voltage for certain periods. The original RF voltage control system was based on local RF unit voltage function generators pre-loaded with individual tables for energy ramping. This was replaced this year by a more flexible global RF voltage control system. A central controller in the main control room has direct access to the units over the LEP TDM system via multiplexers and local serial links. It continuously checks the state of all the units and adjusts their voltages to maintain the desired total voltage under all conditions. This voltage is distributed among the individual units to reduce the adverse effects of RF voltage asymmetry around the machine as far as possible.

The central controller is a VME system with a 68040 CPU and real-time multitasking operating system. Event driven communication handlers allow fast reliable concurrent data communication with the remote units. The RF unit low level RF G64 equipment controllers use a VME 68030 CPU to achieve the necessary response time and reliability.

I. INTRODUCTION

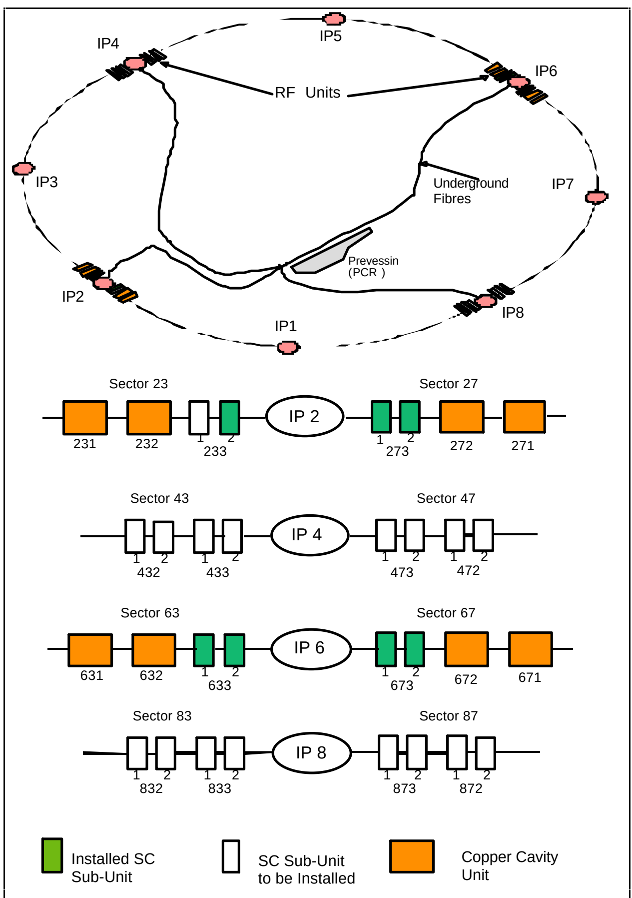

Figure 1. Present Distribution of the RF System in LEP

For the first phase of LEP and operation around 45.5 GeV, 128 room-temperature coupled-cavity assemblies were installed as eight separate RF units distributed around the Interaction Points (IPs) 2 and 6. Each unit consists of 16 cavities, two 1 MW klystron power sources operating at slightly different frequencies, high voltage power supply, auxiliary equipment, low level RF and controls. For the LEP2 upgrade to energies approaching 90 GeV 12 additional RF units based on super-conducting (SC) cavities, 192 in total, are at present being installed and commissioned. These new RF units make use of a similar infrastructure as far as possible. However both klystrons operate at the same frequency and each powers its own group of eight cavities. The RF on the two groups (sub-units) is therefore controlled independently. At the time of writing seven SC cavity sub-units are operational at IPs 2 and 6 together with the original copper cavity units. In the coming year a remaining sub-unit will become operational at IP 2 and four more SC cavity units will be commissioned at IPs 4 and 8. The total number of RF sources to be controlled will then be 32. The distribution of the RF system around the circumference of LEP is illustrated in Figure 1.

Operation of LEP requires that total RF voltage seen by the beam be maintained at a value which gives the required synchrotron tune Q_S at all times i.e. during injection, accumulation, energy ramping and physics running. At low energy, variation in Q_S produces harmful effects on the beam due to the crossing of synchro-betatron resonances. At high energy a value providing sufficient beam quantum lifetime must be maintained. At high energies it also becomes important to maintain symmetrical distribution of the RF voltage around the machine. The RF system is not evenly distributed around the machine and the various types of units and sub-units have different available minimum and maximum RF voltages. Furthermore particular RF units may be subject to field limitations or be in fault condition for certain periods. During running a unit may trip at any time due to any one of a large number of causes.

The method originally used for control of the total RF voltage was based simply on individually setting the voltage of each unit to get the required total. For energy ramping, when the total RF voltage must be increased to maintain Q_S, local RF voltage function generators were used. These were pre-loaded with calculated values prior to the ramp and triggered simultaneously by ramp events transmitted over the LEP general machine timing (GMT) system. This worked satisfactorily provided that all units continued to contribute the expected voltages during the ramp. It did not cope with unexpected changes in the state of individual RF units due to faults or interlock trips. In addition the calculation and loading of the individual ramp tables (300 values) for each new configuration was time consuming.

A single overall RF voltage control system is necessary. The problems in implementing this with classical analog techniques lie in the increased complexity of the local interface and the large distances involved. A computer based system with access to the RF units, monitoring their states and controlling individual voltages as required, can be made to provide sufficient performance with minimum RF hardware modification and can provide a high degree of flexibility. Initially a simple software system, running on a central workstation using the existing Ethernet and local GPIB connections to the low-level RF controllers of each RF unit was used to successfully maintain fixed voltage at injection or at top energy. However this was much too slow to follow the ramp with the necessary precision. Fixed bounds on the response of the system could not be estimated since both Ethernet and GPIB bus transaction times were dependent on other traffic and activities.

II. THE GLOBAL VOLTAGE CONTROL SYSTEM

An independent dedicated global RF voltage control (GVC) system based on a central controller with direct links to the equipment was first tested in 1993 [1]. This overcame the limitations described above and could maintain the RF voltage at its required value at all times, including the ramp. An improved version having better communications handling and increased functionality was made operational at the beginning of this year. This new system is also capable of adjusting the distribution of the RF voltage around the machine to avoid or at least minimize the effects of RF asymmetries on machine performance. Individual operating levels for the various units are now determined by a fixed strategy rather than by operator choice and this helps to provide better overall machine reproducibility.

General Layout

The general layout of the present system is shown in Figure 2. The central controller is situated in the Prevessin control room (PCR). TDM channels at 2 Mbit/s have been allocated for each of the points of LEP where RF is already installed (IPs 2 and 6) or will be installed (IPs 4 and 8). Serial line multiplexers at the end of each TDM link provide individual connection between the central controller and the RF units at each point. In the PCR connection is by sets of RS232 lines, one for each unit. In the underground klystron gallery where the distances are up to 500 metres the connection to the remote RF units is by RS422 differential transmission.

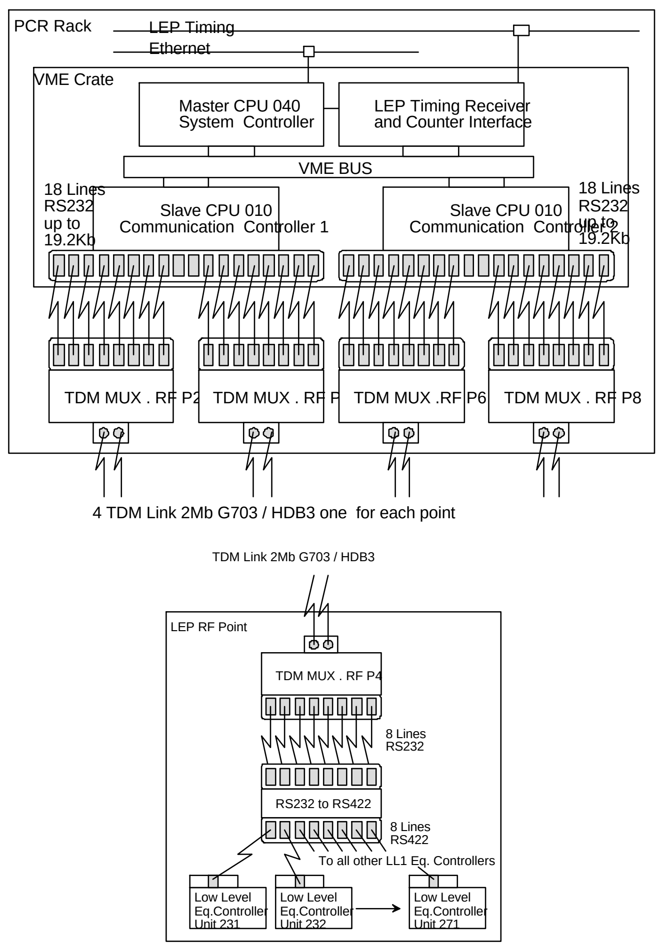

Figure 2. The Global Voltage Control System

GVC Controller

The central controller is a VME crate containing a 68040-based CPU module. Two slave 68010 CPU modules carry the multiple serial IO controllers for communication with the RF units. The OS-9 operating system is used. The global voltage control function is carried out by a C program which continuously monitors the state and RF level of each of the RF units or sub-units and applies corrections as required. Information on current unit states, operating levels (minimum and maximum) required voltage and symmetry method are stored in a local data module. Concurrent data transfer to the different units is implemented by having multiple communications handlers, one for each unit or sub-unit. These are in a sleep state until triggered simultaneously by operating system events sent by the main program when data is to be transferred. All data, previously received or waiting to be sent, is stored in the main data module. Other control and status acquisition programs read or set data in this module.

Data Transmission and Communication

The LEP time domain multiplexing (TDM) system is used for the dedicated connections needed to guarantee fixed maximum access time. This system uses fiber optic point-to-point links between the PCR and each of the IPs of LEP. It is used to carry machine timing systems and for other dedicated loop control applications. The lowest level provides 2 Mbits/s data channels with HDB3 protocol, the physical connection being to the CCITT G703 standard. Commercial equipment is used to further multiplex serial data channels within this bandwidth, 31 channels of 64 kbit/sec data being available. For each IP eight bi-directional serial channels presently operating at 9,600 Baud are used to connect the RF units and sub-units.

Low Level Equipment Interface

The serial RS422 line is connected to the low level Equipment Controller (EC) of the RF unit. This G64 hardware based EC contains the interfaces which allow the setting of RF voltage and phase, the reading of the RF sum of all cavity voltages and the state of the voltage control loop. The Low Level ECs in all units are fitted with a VME 68030 type processor module and VME to G64 converter [2]. Interrupt driven multi-tasking software is used. The global voltage control system can therefore set values and read information in the same way as for normal control via GPIB but independently of all other internal processes and with maximum priority.

System Operation

The main control program operates in a loop, continuously monitoring the state and voltage levels of the active RF units. This is shown in detail in Figure 3. If a new total voltage reference is required the voltages on the individual units are incremented or decremented accordingly. If a change in state of an active unit is found the voltages are redistributed in order to maintain the required total. The system is not a closed loop in the normal sense, since the actual voltage read by the cavity voltage detectors on the RF cavities is not used, but instead the current setting is used, together with a status bit indicating correct operation of the unit. This was done to avoid problems of

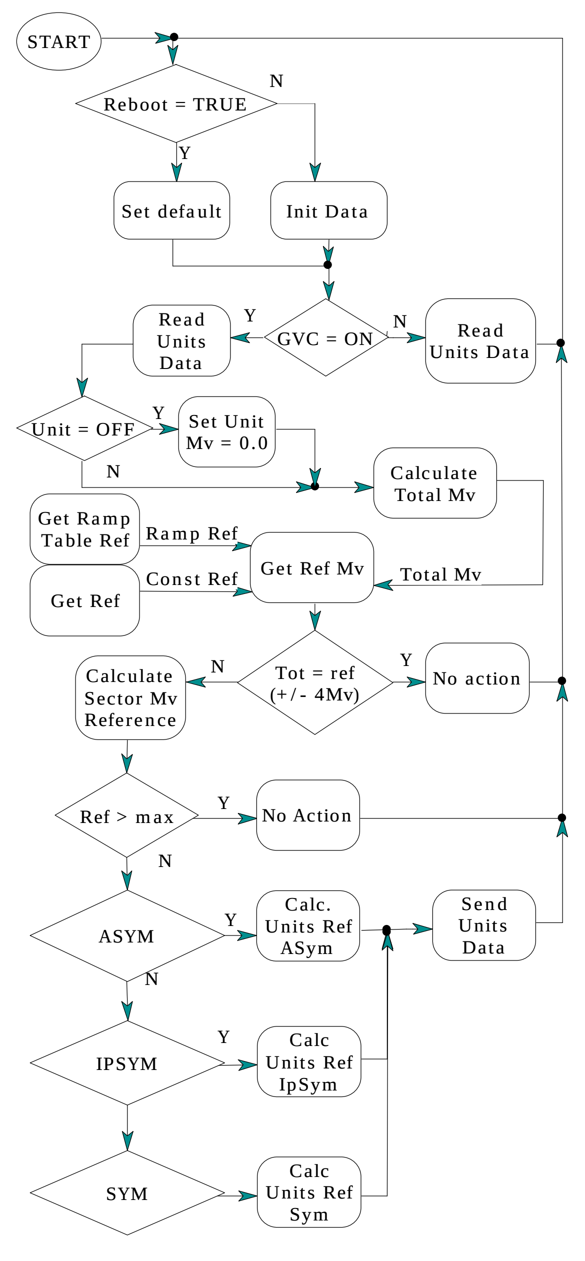

Figure 3. GVC Program Flow

instability resulting from noise and field oscillations on the RF units. The two modes of operation are defined in terms of the source of the voltage reference :

1) CONSTANT mode

This mode is applicable to injection and coast. The reference is a value of total RF voltage in MV. The operator selects the Q_S value required. Sloppysoft application software calculates the corresponding voltage reference for the GVC system taking the relevant machine parameters and settings into account.

2) RAMP mode

At the beginning of the fill the total RF voltages required at each 0.125 GeV step in energy during the ramp are loaded into a table in the central controller. The reference voltage during the ramp is derived from this table using a timer started and stopped by the ramp events sent over the GMT. At the end of the ramp CONSTANT mode is selected and Q_S trims are made if required.

Operations Interface

The system is set up and controlled for normal operation by the standard LEP operations software package, 'Sloppysoft'. Information about which units are to read, which units may be acted on, their available levels and other relevant information, is stored in an ORACLE database. This data, known as the RF Current Data Set (CDS), is used by all applications programs which deal with the RF system. The CDS is transferred to the GVC system when the running configuration is changed and during the setting up procedure prior to each LEP fill.

An X-window-based application, using a commercial graphics package, has been written to monitor the operation of the system and to display the current RF voltage and its distribution around the machine. An example of the data display is shown in Figure 4. This shows symmetrical distribution of RF voltage at each side of IPs 2 and 6.

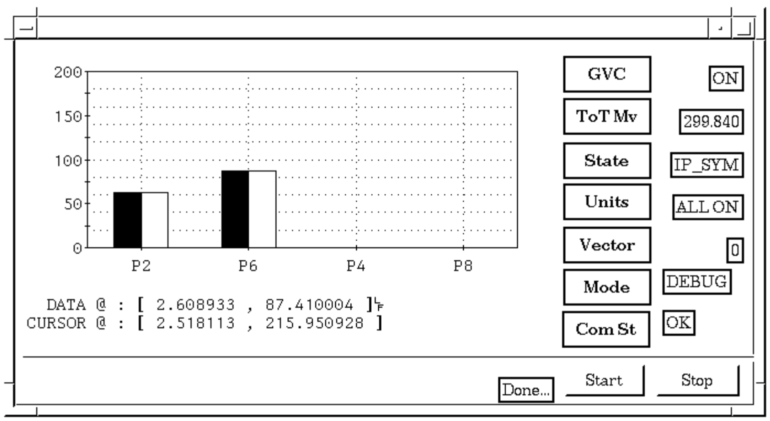

Figure 4. Display of Voltage in RF Sectors.

III. Control of Total RF Voltage and RF Asymmetry

The total voltage must be maintained at a value which avoids synchrotron resonances (important at injection) and provides sufficient quantum lifetime at top energy. Quantum lifetime decreases rapidly once the RF voltage decreases below a certain value as shown in Figure 5 and the RF system must be run with sufficient reserve (80 MV at least) in order that the GVC system can restore the effect of a unit trip before other trips occur.

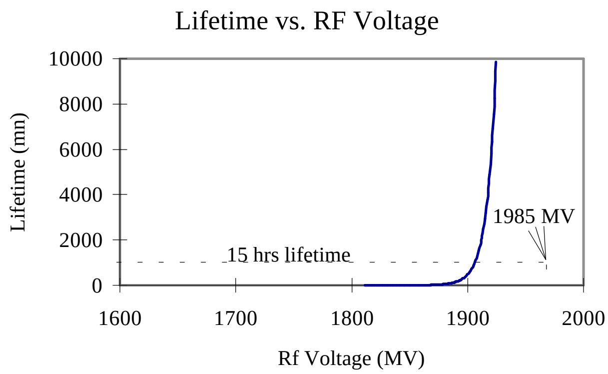

Figure 5. Quantum Lifetime vs. RF Voltage at 88 GeV.

The effects of IP RF asymmetry on machine operation and performance are mainly related to differences produced between electron and positron energy variations around the machine. Synchrotron radiation losses will be enormous in LEP2, around 1730 MV per turn at 88 GeV and this represents a significant fraction of the total beam energy. There is a gradual, almost linear, decrease in energy as the particles traverse the arcs. Energy is restored by the RF units around the RF equipped IPs, by an amount V_{RF} sin$Ø_S$ where V_{RF} is the RF voltage amplitude and $Ø_S$ is the synchronous phase angle. This effect is known as the energy sawtooth. The shape is directly dependent on energy and on the RF distribution around the machine.

Examples of different energy sawtooth variation for different RF distributions are shown in Figure 6 for the simple case of RF installed at IPs 2 and 6 only. With completely symmetric RF distribution electrons and positrons have equal and opposite energy (and position) variations from the center. With IP 6 providing more RF voltage the amplitudes are increased, there are energy differences between electrons and positrons at IPs 4 and 8 but the center-of-mass collision energy is the same. Similarly if RF voltage is not equal on both sides of a given IP the same effect occurs. The IPs are equipped with low beta insertions which have strongly focusing super conducting quadrupoles. The insertion can only be correctly matched for one particular energy and errors produce modulation of the beta functions, phase advance differences in the cells for either or both particle types and a vertical tune difference (Q split). These effects are difficult to handle in operations and result in lost luminosity and background problems. The RF voltages around the machine must therefore be set to minimize these effects as far as possible under all conditions.

The GVC system can be operated with various conditions on symmetrical RF distribution. These can be specified by the operator and the system will maintain these as long as the available voltage at each point or individual unit permits. After limiting values for symmetry have been reached the RF voltage at each sector or on each unit is simply increased by an amount proportional to that which remains. The following conditions are allowed for :

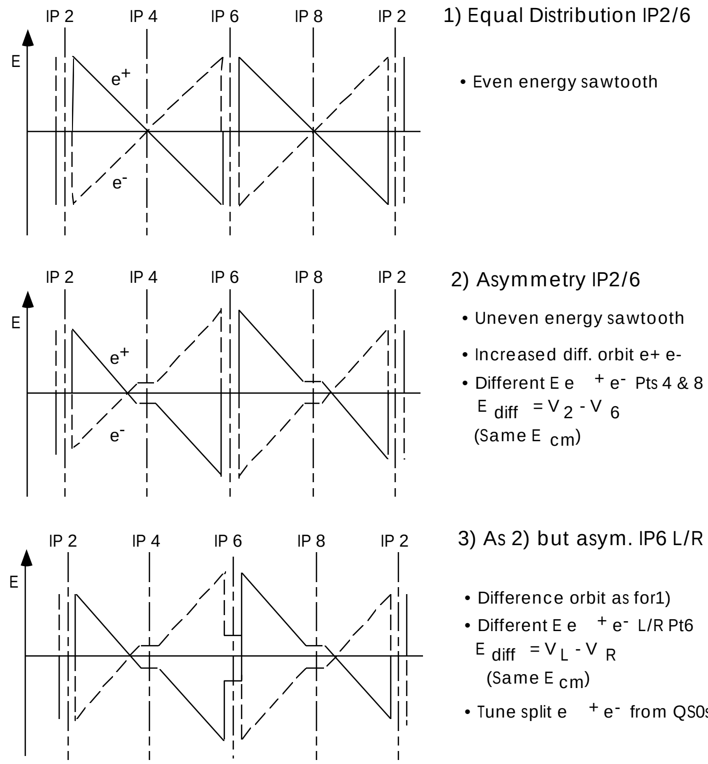

Figure 6. Energy Sawtoothing and RF Asymmetry.

- Asymmetrical **-** All units maintained at the same fraction of their individual maximum voltage. This allows ramping to maximum voltage with all units reaching maximum at the same time, without symmetry considerations

- IP symmetry **-** Equal voltages from RF on either side of the IP, all units at each side having the same fraction of their maximum.

- Symmetrical **-** Equal voltages at opposite interaction points, This can be with or without IP symmetry.

During 1995 the RF system was run with IP symmetry, to minimize Q split between electrons and positrons in the interaction points equipped with RF.

IV. System Performance

The effect of switching an active unit off is shown in Figure 7. The detector sum of all units was logged at 2 second intervals using a commercial instrument control package independently of the GVC system. Unit 231 tripped just before the start of the ramp. The system increased unit 232 to maximum, decreased sector 27 to maintain IP symmetry and increased all units at IP 6 to maintain the reference total voltage. This was done within one logging interval. The time of response to a change in RF reference is dependent mainly on the time taken to change the RF units to the new values. The normal ramp rate for the RF unit is 10% of maximum per second, but this can be increased to 40 % per second. The complete cycle of data acquisition, RF unit voltage recalculation and initiation of the voltage changes required in the RF units and sub-units is of the order of 200 ms. If an RF unit trips and Q_S is not too close to a harmful resonance or near the limit for very low quantum lifetime the voltage will be restored before critical beam loss. The overall response is also sufficiently fast to allow the voltage ramp function to be followed with an undetectable error in Q_S.

.

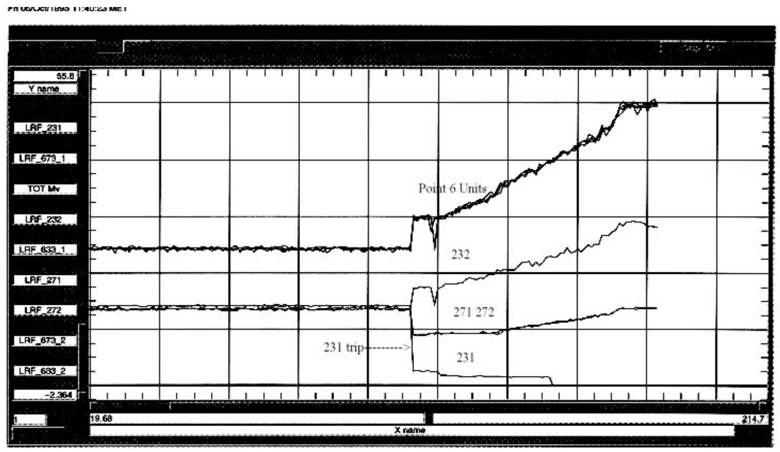

Figure 7. Response to Unit Trip at Start of Ramp

V. Improvements for Higher Energies

For running with SC cavities it may be necessary to de-tune certain RF cavities and perhaps adjust RF unit phases during acceleration. This can be done by the GVC system which can issue direct commands directly to the low level equipment or over the general control network to other equipment where time is less critical. To improve performance and to simplify operation the SC cavity units will be equipped with a fast RF feedback loop operating on klystron drive level instead of modulating anode voltage. This will allow a much faster ramp rate and the limitation in overall response will then be that of the GVC system. The speed of the system will therefore be increased during the shutdown by increasing the baud rate from 9600 to 19200. Individual commands sent to the RF unit will also be grouped to cut down the number of transactions.

A further general improvement would be the replacement of the RS232/TDM based communication system with direct links. The available options are being evaluated.

VI. Conclusions

A global RF voltage system has completely replaced the original local function generator based system. It was made operational for the 1995 startup and used routinely throughout the running period. It has successfully prevented beam losses due to RF unit trips. It has maintained symmetric RF distributions and helped to provide improved and more reproducible beam conditions. The addition of new RF units for LEP2 is straightforward and the system is able to handle all future requirements which can be envisaged at present. Software improvements will continue to be implemented and high speed data links evaluated for the replacement of the multiplexed TDM system.

VII. Acknowledgments

The TDM channels were provided by the SL-CO group and we are grateful to the specialists concerned for their assistance. The addition of GVC control in LEP operations software was made by Paul Collier.

VIII. References

[1] E. Ciapala, A. Butterworth, E. Peschardt, "Global Voltage Control for the LEP RF System," Proceedings of the 1993 Particle Accelerator Conference, Vol. 3, p1903 (1993)

[2] E. Ciapala, L. Arnaudon, "Use of VME CPU Modules for the Performance Upgrade of G64 Equipment Controllers for the LEP RF System," Proceedings of the Fourth European Particle Accelerator Conference, Vol. 3, p1833 (1994)