A VME Board Prototype of High Voltage Power Supply Incorporating Piezoelectric Ceramic Transformer

Masatosi Imori, Takashi Taniguchi[1], Toshiyuki Kimura[2], and Satoru Imada[2]

International Center for Elementary Particle Physics, University of Tokyo

7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

[1]High Energy Accelerator Research Organization (KEK)

1-1 Oho, Tsukuba-shi, Ibaraki-ken 305-0801, Japan

[2]NF Corporation, 6-3-20 Tsunashima Higashi, Kohoku-ku, Yokohama 223-8508, Japan

Abstract

A high voltage power supply channel produces a stabilized direct current high voltage, utilizing a piezoelectric ceramic transformer to generate high voltage. With the intention of developing a 16-channel VME board, a single channel VME board was prototyped, where a high voltage power supply was implemented on a VME board so that a computer could control the power supply. The power supply is capable of functioning under a magnetic field of 1.5 tesla. The power supply is protected against overload. The computer is enabled to control the power supply in the channel. The computer can turn on and off the power supply, set the output high voltage, monitor the change in the output current and recover the power supply from the overload.

I. HIGH VOLTAGE POWER SUPPLY

With the intention of developing a 16-channel VME board, a single high voltage power supply channel was prototyped on a VME board so as to be brought under the control of a computer. The computer is enabled to control the power supply in the channel. The computer can turn on and off the power supply, set the output high voltage, monitor the change in the output current and recover the power supply from the overload.

The channel includes a high voltage power supply which incorporates a piezoelectric ceramic transformer, where the ceramic transformer takes the place of a conventional magnetic transformer. The ceramic transformer generates high voltage with the piezoelectric effect efficiently. The ceramic transformer does not include any magnetic material, and can be operated under strong magnetic field. An inductance element is required to obtain efficient high voltage generation, being implemented by an air-core coil.

The power supply is capable of supplying stabilized high voltage from 2500 V to 3500 V to a load of more than 25 MΩ at efficiency of better than 55 percent from a supply voltage of 3 V under a magnetic field of 1.5 tesla. Noises on the high voltage are around a hundred milli-volts in peak-to-peak amplitude. The power supply is protected against overload such as short-circuiting [1].

II. STABILIZATION OF OUTPUT VOLTAGE

The high voltage power supply includes feedback to stabilize the output voltage. The output voltage is fed to the error amplifier to be compared with a reference voltage. The output of the error amplifier is supplied to a voltage-controlled oscillator (VCO), which generates the frequency of the carrier, where the carrier is sinusoidal voltage wave generated by a driver circuit. The carrier drives the transformer, where the carrier is amplified in amplitude and supplied to the CW circuit. The carrier is further multiplied in voltage and rectified by the Cockcroft Walton (CW) circuit. The voltage at the output of the CW circuit is the output voltage of the power supply [2, 4].

The ceramic transformer includes an internal resonance circuit. The amplitude of the carrier at the input of the transformer is amplified at the output, with the input to output voltage ratio of the amplitude being an amplitude ratio that shows a resonance as a function of the driving frequency: the frequency of the carrier. Fig. 1 plots the amplitude ratio against the driving frequency. Voltage amplification at the transformer depends on the driving frequency. The dependence is utilized for stabilization. Controlling the driving frequency, the feedback adjusts the amplification so as to stabilize the output voltage.

III. BREAKDOWN OF FEEDBACK

The range of the driving frequency is designed to be higher than a resonance frequency of the ceramic transformer as shown in Fig. 1. So the feedback increases the driving frequency when the output voltage is higher than the reference voltage at the input of the error amplifier. Similarly the driving frequency decreases when output voltage is lower than the voltage specified by the reference voltage.

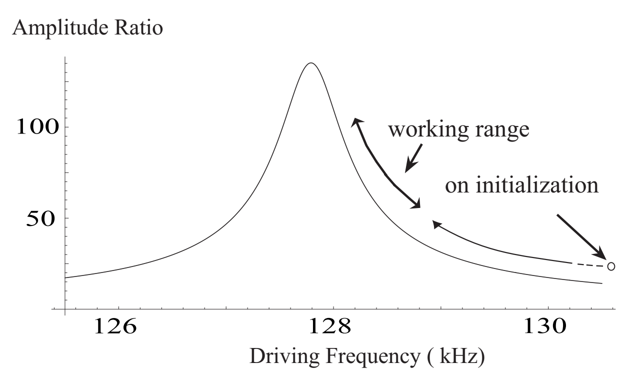

Figure 1: Range of driving frequency for feedback

If the load of the power supply falls within an allowable range, the driving frequency is maintained higher than the resonance frequency such that the feedback is negative as designed. The allowable range of load is sufficient in most cases, but it cannot cover, for example, short-circuiting the output voltage to ground. When the load deviates beyond the allowable range, the driving frequency may decrease below the resonance frequency; a condition that will not provide the required negative feedback, i.e., positive feedback locks the circuit such that it is independent of load. In order to recover the negative feedback, the driving frequency must be reset externally in addition to removing the cause of the feedback breakdown .

A. Protection

The load deviated beyond the allowable range causes the breakdown of feedback decreasing the driving frequency beyond the resonance frequency. Such decrease of the driving frequency, accompanied with the breakdown of the feedback, lowers the output voltage. Thus the breakdown of feedback works as protection against, for example, short-circuiting the output voltage to ground.

IV. Channel

A. Output Voltage

The channel includes a digital-to-analog converter under the control of the computer. The reference voltage being generated by the converter defines the output voltage of the power supply. Yet the output voltage cannot be lowered under the offset voltage which is built up at the output of the power supply autonomously so far as the carrier is supplied to the ceramic transformer.

B. Driver Switch

So a driver switch was introduced into the driver circuit so that the computer could disable the driver circuit. Disabling the driver circuit stops supplying the carrier to the transformer and nulls the output voltage of the power supply. When the driver switch is enabled, the driver circuit starts to supply the carrier. The driver circuit is provided with input called EN: the abbreviation of Enable. The assertion and the negation of EN enable and disable the driver circuit, turning on and off the power supply.

C. Detection of Feedback Breakdown

The VCO voltage, being the output of the error amplifier, is applied to the input of the VCO, controlling the driving frequency of the carrier. The feedback breakdown results in deviation of the VCO voltage from its normal range. The deviation is detected by a voltage comparator. The output of the comparator, called Breakdown (BD), is asserted by the deviation, which interrupts the computer. The assertion of BD makes the feedback breakdown to be recognized by the computer. Once the breakdown is acknowledged by the computer, procedure for recovery is initiated. The assertion of BD negates EN synchronously, disabling the driver circuit and turning off the power supply.

D. Recovery from Feedback Breakdown

Once interrupted by BD, the computer reports the feedback breakdown. Then the cause of the feedback breakdown needs to be investigated. If the cause is removed, then the recovery can be attained by the computer without manual intervention. Following instructions given to the computer, the computer starts to recover the power supply from the breakdown, where firstly the reference voltage is reset with EN being asserted, which builds up the offset voltage at the output and initializes the driving frequency, and secondly the computer increases the reference voltage to a prescribed value, restoring the output voltage.

E. Current Monitor

The carrier is amplified in amplitude by the transformer and then further multiplied in voltage and rectified by the CW circuit. Assuming that the driving frequency is fixed, the amplification at the transformer and the multiplication at the CW circuit depend on the load on the output voltage. Both decrease in magnitude as the increase of the output current. Then, as the load becomes heavier, the feedback increases the amplification at the transformer so as to keep the output voltage fixed, which means that driving frequency moves towards the resonance frequency. So the magnitude of the output current is reflected on the driving frequency. Then it is possible to compute the change in the output current from the shift of the driving frequency. Fig. 2 shows the correspondence between the driving frequency and the output current at an output voltage of 3500 V

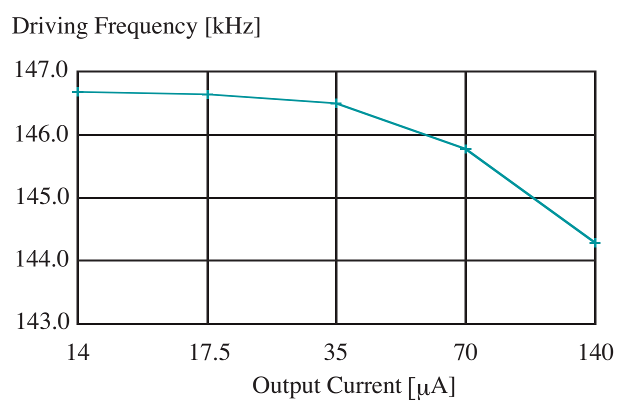

Figure 2: Correspondence between the driving frequency and the output current at an output voltage of 3500 V

The VCO generates the driving frequency and outputs the driving frequency on a square wave. The square wave called FQ, which is outputted by the VCO, enables a simple logic circuit to count pulses. The channel contains a frequency counter, which sums pulses of the square wave in a fixed time interval. The computer reads the frequency counter periodically and calculates the driving frequency. The shift of the driving frequency thus obtained from the frequency counter allows calculating the change in the output current.

1) Frequency Counter

The frequency counter is composed of a 20-bit counter. a latch of the same bit length and control logic.. The 20-bit counter is driven by the square wave, summing the pulse for one second. The latch is updated by the sum of the pulses every one second. The latch holds the latest sum of the pulses. The computer reads the latch asynchronously. So it may happen that computer reads the latch while the update is in progress. On such occasions, the control logic reconciles the collision of access so that the computer can read either the latest sum or the sum before the latest update.

F. Block Diagram of Channel

A block diagram of the channel is shown in Fig 3. Plural channels will be implemented on the VME board. The VME board is installed in a crate. The crate powers the VME boards and then the channels. The crate supplies direct-current voltages for the driver circuit and for the circuitry in the channel.

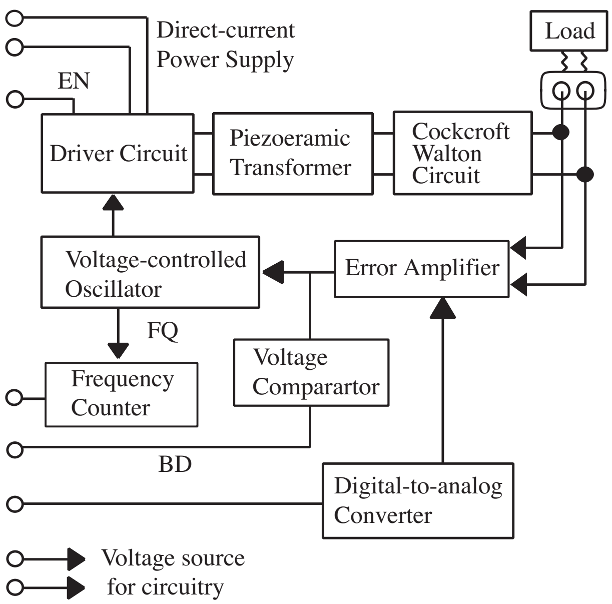

Figure 3: Block diagram of the channel

V. Single Channel VME Module

The high voltage power supply is tailored to LHC experiments [1]. A large number of high voltage channels need to be implement in a compact volume for practical usage in the experiments. A purpose of prototyping the single channel VME board is to estimate the volume required for the channel. The circuit of the high voltage power supply in the channel is essentially identical with the one in [1]. Yet the board is housed in a VME module occupying a single slot as is shown in Fig. 4. So the circuit is kept low in profile. Keeping the profile low restricts components in the circuit, which may produce an effect on performance. So noises on the output voltage from the VME module are monitored under various conditions .

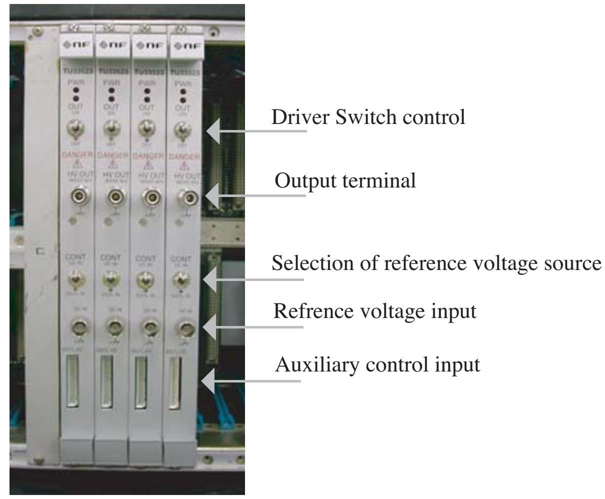

Figure 4: Picture of 4 single channel VME module installed in crate

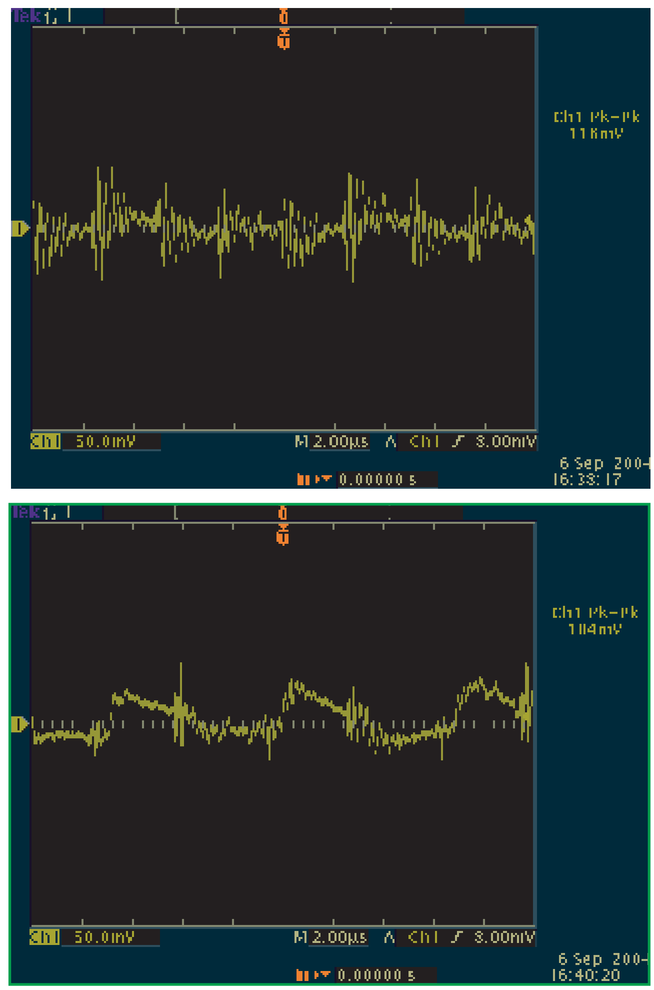

Figure 5: The output voltage from the module is 2000 V at the upper trace and 3000 V at the lower trace where the output voltage is loaded by 25 MΩ.

VI. Noises

A. Noises on Output Voltage

The output voltage from the VME module is observed by the method described in [1]. The traces of the output voltage are shown in Fig. 5 where the output voltage is loaded with 25 MΩ. In Fig. 5, the output voltage is 2000 V at the upper trace while 3000 V at the lower trace. The vertical and the horizontal divisions are 50 mV and 2 μ sec respectively. From the figures it can be seen that the noises on the output voltage are around 100 mV in peak-to-peak amplitude for a load of 25 MΩ.

Good ground and the capacitor with little leak current will reduce the noises to the level shown in [1]. Yet such the capacitor may be large in size. So selection of the capacitor is important for high-density packing of the channels.

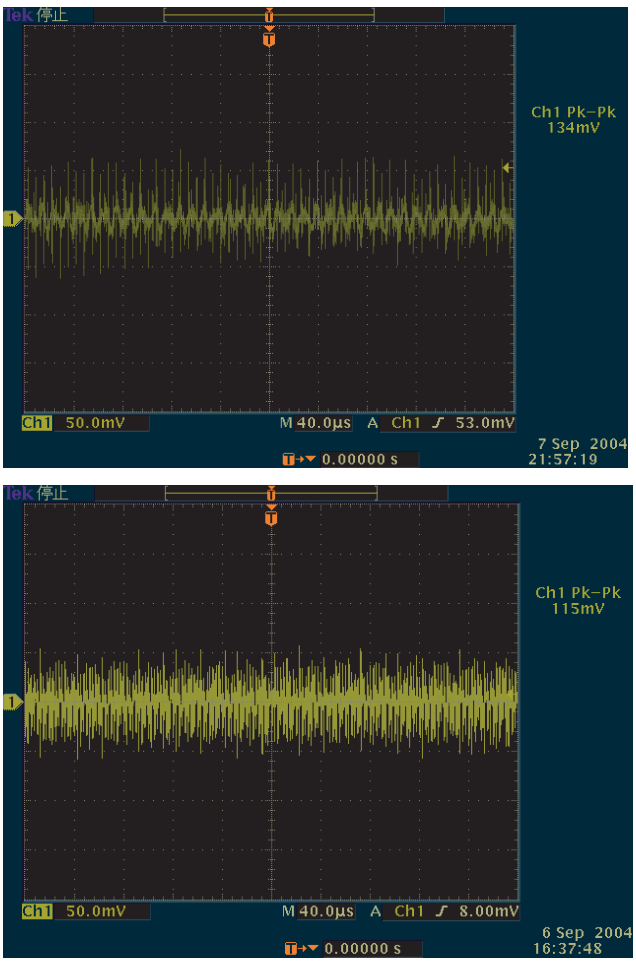

Figure 6: The upper trace shows the output voltage not externally loaded and the lower trace the output voltage loaded with 25 MΩ at an output voltage of 2000 V.

B. Dependence on Load

Noises on the output voltage may depend on load of the output voltage. Two traces of the output voltage shown in Fig. 6 and 7 gives the dependence. In the figures, the upper trace shows the output voltage not externally loaded while the lower trace shows the output voltage loaded with 25 MΩ. The output voltage is 2000 V in Fig. 6 and 3000 V in Fig. 7. The vertical and the horizontal divisions are 50 mV and 40 μsec.

The noises at the upper trace is less than two hundred milli-volts in amplitude while the lower trace shows the noises of the amplitude around a hundred milli-volts. The output voltage with heavier load shows smaller noises because the bandwidth of the noises is out of a feedback range. So the noises can be reduced by extending the bandwidth of feedback. A circuit for the bandwidth extension is under test and will be integrated into the power supply if the test is successful. The circuit is expected to fairly reduce the noises.

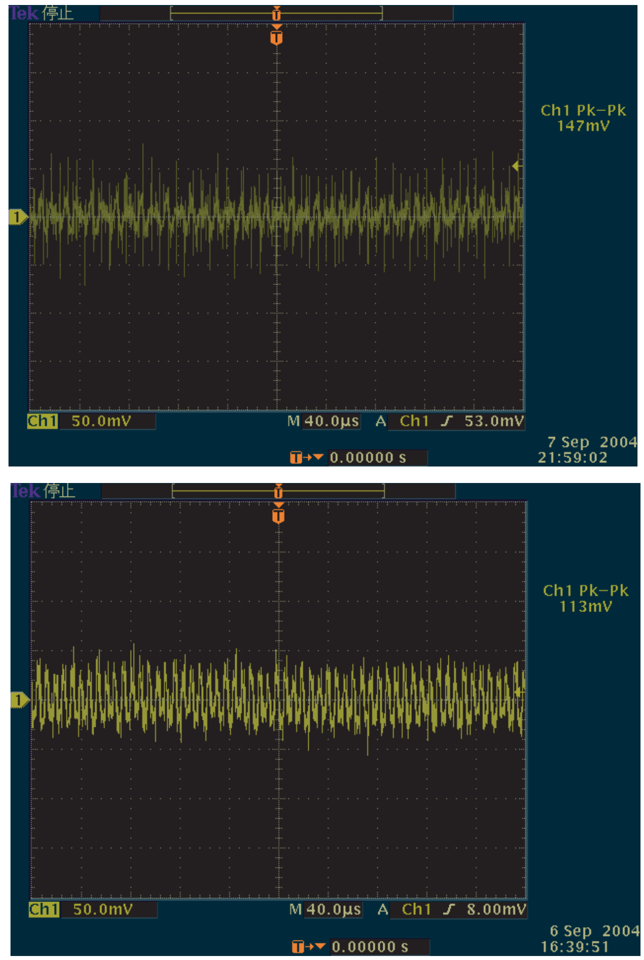

Figure 7: The noise dependence on the load at an output voltage of 3000 V.

C. Dependence on Parallel Operation

Noises on the output voltage may depend on the number of the modules in parallel operation. Fig. 8 shows the traces of the output voltage from the module in parallel operation with other 3 modules, where the output voltage is not externally loaded. The output voltage is 2000 V at the upper trace and 3000 V at the lower trace. The vertical and the horizontal divisions are 50 mV and 40 μsec.

The upper traces in Fig. 6 and 7 show the output voltages at

2000 V and at 3000 V respectively from the module in stand-alone operation. Comparing these traces with the traces of the parallel operation, it can be seen that the parallel operation does not increase the noises for these range of the output voltage.

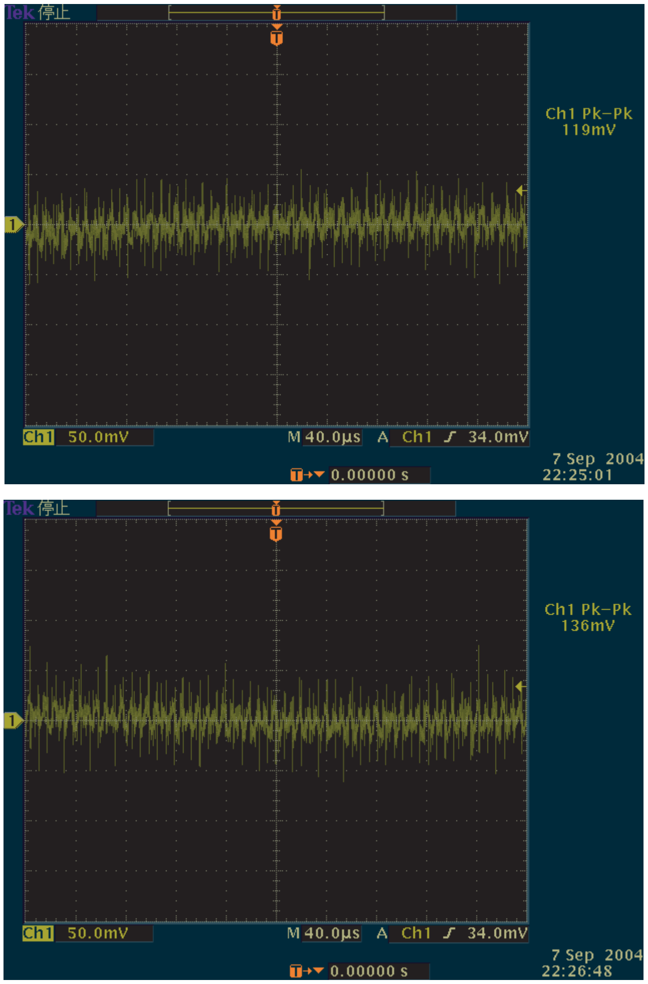

Figure 8: The upper and the lower traces show the output voltages at 2000 V and at 3000 V respectively from the module operating in parallel with other 3 modules where the output voltage is not externally loaded.

VII. Concluding Remarks

There are many things to be considered on designing the 16-channel VME board such as the volume for the channel, selection of the capacitor across the output terminals, and the circuit for the bandwidth extension in addition to lingering problems which the present prototype leaves untouched; low efficiency of the power supply at the output voltage being low. The 16-channel VME board is now under development, and will be available in March 2005, when eight 16-channel VME modules and 128 channels in total can be used for test. The 16-channel VME board occupies 2 slots of the VME crate, providing 160 channels of the high voltage power supply per crate. Radiation test by a gamma source and a neutron beam are now scheduled. A plan for irradiation by a proton beam is under consideration.

VIII. References

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