

# KEK C-BAND RF-SYSTEM R&D STATUS FOR LINEAR COLLIDER

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## Abstract

Hardware R&D on the C-band (5712-MHz) RF-system for an  $e^+e^-$  linear collider started in 1996 at KEK. We have already developed three conventional and one periodic permanent magnet (PPM) type 50-MW class C-band klystrons (TOSHIBA E3746 series and E3748 series), a smart modulator, and the first HOM-free accelerator structure (Choke-mode type, full-scale high power model) [1], [2], [3], [4].

A very stable ceramic high voltage monitor was successfully tested up to 367-kV with a 4.5- $\mu$ sec pulse. A very good agreement with the expected division ratio and signal waveforms was obtained from high power tests.

The first high power prototype of an rf compressor cavity made of a low thermal expansion material (super Invar) was designed to provide stable operation even with a very high Q of 200-k [5], it is now under high power testing at KEK.

A new C-band SiC type high power rf-load, advancing the power handling capability up to 50-MW is now being designed. It should have excellent mass production characteristics as it uses circularly symmetric  $TM_{011}$  chained cavities. The first high power test should be completed at KEK by the end of 2003.

The C-band linac rf-system will be used for the SASE-FEL (SCSS) production project at SPring-8 [6], but SCSS will also serve to verify the design and components, which can eventually be deployed for the main linac rf system in a future linear collider.

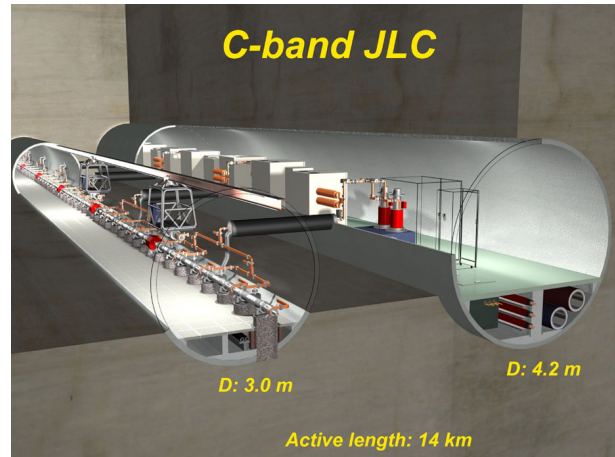


Fig.1: C-band main linac tunnels. The klystron gallery is 4.5-m in diameter and the linac tunnel is 3.0-m in diameter.

## 1 INTRODUCTION

To be interesting, an  $e^+e^-$  linear collider must be a very large-scale machine. For example, the  $e^+e^-$  collider under conceptual design now at KEK would have a main linac for each of two beams, and in total more than 7000 accelerating structures, 3500 klystrons and modulators would be used. Therefore, the hardware we develop has to meet very strict demands for: (1) High reliability, (2) Simplicity, (3) Reduced construction cost, (4) Reasonable power efficiency, and (5) Operational ease. This list provides a guideline and the boundary conditions for our design work. Of all the free system parameters that we may vary, the choice of the drive rf frequency plays the determinative role in setting the system performance as well as most other hardware details. For reasons previously argued in [2], we propose that the C-band frequency is the best choice to meet all of the demands.

## 2 SYSTEM DISCRIPTION

Each unit in the main linac rf-system is composed of two 50-MW klystrons, their pulse modulators, one rf-pulse compressor, four 1.8-m-long choke-mode accelerating structures and associated wave-guide-system as shown in Figure 2. The accelerating gradient is 36-MV/m under full beam loading. This accelerating gradient was chosen as practicable after studying results

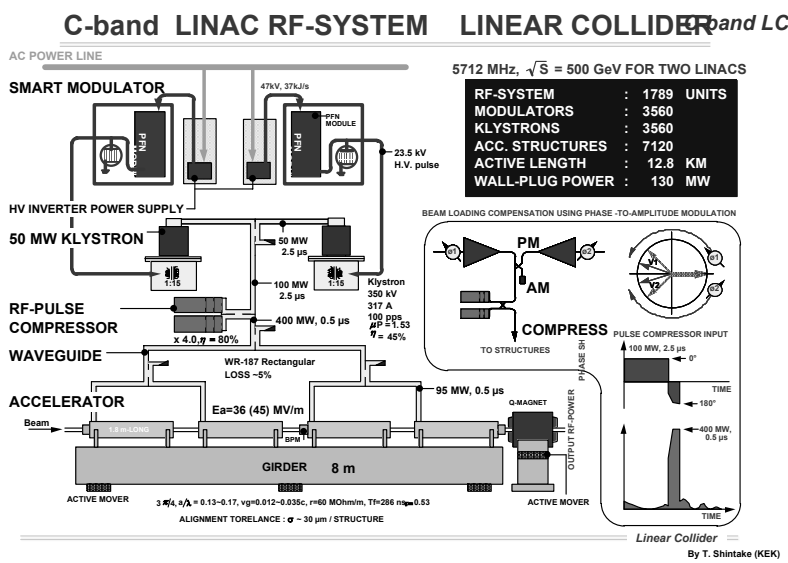


Fig. 2: One unit of the C-band main linac.

from S-band frequency high gradient tests done between 1987 and 1994 at KEK. The total RF-system to achieve 500-GeV c.m. energy would be on the order of 2000 units.

### 3 RESULTS OF HARDWARE R&D

In April 1996, we started hardware R&D, and as of June 2002 we had developed most of the hardware components and tested their performances, with the exception of the high-power rf pulse compressor.

#### 3.1 Klystron R&D

We have successfully developed a 50-MW class solenoid focus type klystron, which meets the required specifications of the 500-GeV linear collider. In Phase-II R&D, we have to refine the design details to reduce costs before starting mass-production. As a part of the R&D program aiming toward a 1-TeV c.m. energy scale linear collider, we developed the first PPM klystron in 1999 [4]. We chose a NdFeB magnet material (Model N40A, Shin-Etsu Co. in Japan). The Hot Isostatic Pressing (HIP) technique has been applied for the first time to fabricate the magnetic circuit for the PPM klystron. An output power of 37-MW was generated with a 2.5- $\mu$ sec pulse at a 50-pps repetition rate.

#### 3.2 Modulator Power Supply

We focussed our modulator R&D work on reducing the fabrication cost and improving the reliability. In 1993, the concept of a ‘‘Smart Modulator’’ was proposed by Prof. M. H. Cho and the author [7]. As a first step, we developed a prototype modulator, whose features are:

- (1) Direct HV charging from an inverter power supply,
- (2) No de’Q-ing circuit,
- (3) Much smaller in size than the usual modulator,
- (4) Use existing low-risk reliable circuit components.

To reduce the modulator size and allow removing the de’Q-ing circuit from PFN, we employed an inverter type DC-HV power supply: the Electric Measurement Inc. Model EMI-303L. The smart modulator was built in a metal cabinet of compact size 160 (w) x 200 (H) x 120 (D) cm. It is now in daily use driving a 50-MW klystron. The total accumulated run time has exceeded 20,000 hours. The fluctuation in the measured output voltage was measured to be lower than  $\pm 0.17\%$  (at  $3\sigma$ ), which meets the energy stability requirement for the linear collider. The timing variation (jitter and drift) of the pulse output is around 2-nsec (at  $3\sigma$ ) over a 4 hour run at 50 pps [8].

The next step in the smart modulator development was to install everything except for the inverting H.V. supply in an insulation oil filled metal tank or cabinet of very compact size: 150 (Width) x 100 (Height) x 100 (Deep) cm, see Figure 3 [8]. The first prototype was developed by NICHIKON Co. Testing was begun in March 2003 at SPring-8. We obtained the results expected for the pulse wave shape, voltage and flatness, as well as verification of the operational repeatability and also markedly reduced EMI and noise generation.

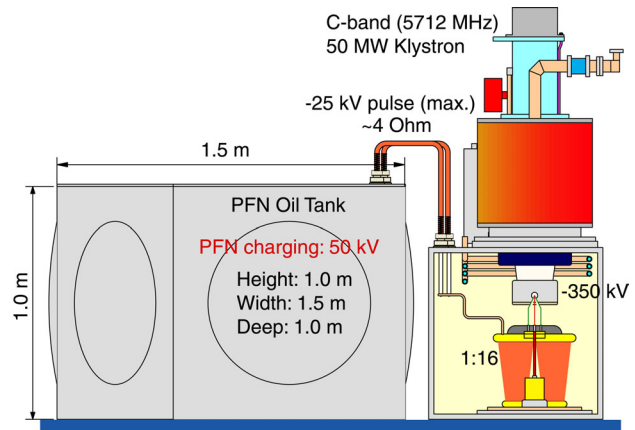


Fig 3: Closed type compact modulator.

#### 3.3 Pulsed High-Voltage Monitor

We have developed a very stable and accurate high-voltage monitor, to be used for monitoring the klystron pulse voltage, see Figure 4 [9]. Since it uses a ceramic material for the capacitive type voltage divider (CVD), the monitoring capacitance division ratio can be kept quite stable even under temperature changes, or changes in the set-up configuration, or mechanical stresses applied to the monitor port through the input lead. We successfully operated the monitor up to 367-kV, and 5- $\mu$ sec pulse widths at a 50-pps repetition rate. The maximum voltage in the CVD test was limited by the modulator output.

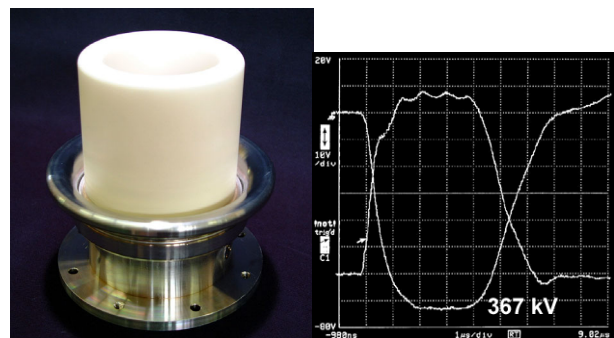


Fig. 4: Ceramic high-voltage monitor. Left: A cup type monitor. Right: High voltage waveform at 367-kV and 4.5- $\mu$ sec.

#### 3.4 RF Pulse Compressor

At the present the initial test of a high power model has begun at KEK. This prototype uses a copper plated invar metal for the rf cavity [10], this permits the temperature control system for the rf compressor to be simplified and thus contributes to reducing the cost of the total system. The current experimental result is a 90-MW pulse, 0.5- $\mu$ sec wide at a 50-pps repetition rate with a total multiplication factor of 3.0. The rf compressor provide the very good thermal stabilities, which is better than conventional copper cavities. There is no unusual vacuum out-gassing found even at the high power operation. The test set up is shown in Figure 5.

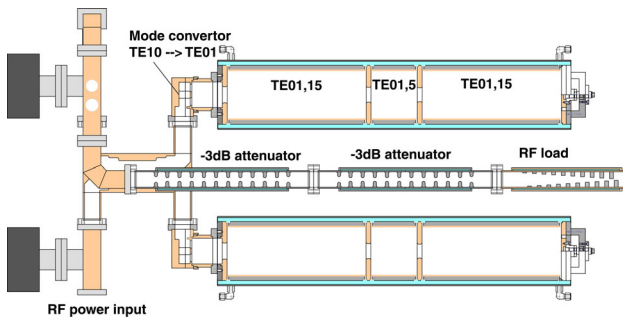


Fig 5: High power test stand for the rf pulse compressor cavity.

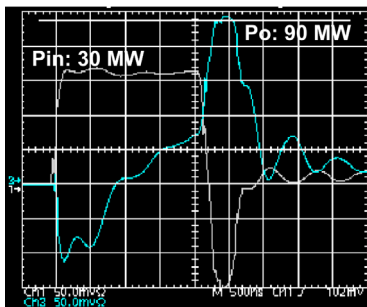


Fig. 6: Typical pulse compressor cavity rf power waveforms.

### 3.5 A New C-band 50-MW SiC Type RF Load

There are no available 50-MW class rf loads for C-band (5712-MHz) frequencies in the world. Therefore we have constructed a new type rf load using SiC ceramic with an indirect water-cooling structure, this upgraded the power handling density of the SiC material from 100-W per cc to 300-W per cc, allowing a much more compact size. Also, using circular mode  $TM_{011}$  chained cavities as shown in Figure 7. One particular advantage is that since the main parts are completely axially symmetric, they can be machined on a turning lathe; thus this type of cavity has a big advantage in mass production because of its easier machining. The load is now at the detailed design stage, and we expect that high power tests at KEK will be completed by the end of 2003.

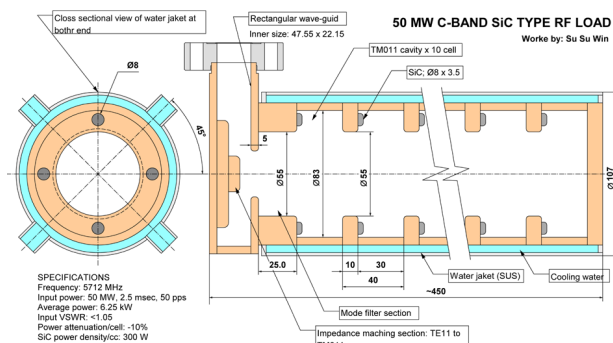


Fig. 7: First model of 50-MW SiC type C-band rf load.

### 3.6 C-band Accelerating Structure

A C-band Choke-Mode type damped structure was developed in 1998; its performance was tested with

ASSET at SLAC. As expected, its powerful HOM damping performance was proven. We found parasitic resonance at very high frequencies around 23-GHz. The resonance was caused by EM fields trapped inside the cavity. This problem can be resolved by changing the cavity dimensions by a small amount. The new structure is fabricated by brazing. High power tests of the structure will begin at Spring-8 in November 2003.

## 4 FUTURE R&D

The first stage of the C-band R&D between 1996 and 1998 was successfully completed. Beginning in 1999, the next priority is to develop a 50-MW class PPM type klystron with power efficiency of higher than 50%.

On a parallel track, in order to evaluate the system performance in a realistic situation, at least one unit of the C-band system has to be built, installed and beam tested in an operational machine.

To this end, a c-band linac rf system is now under fabricating for the 1-GeV electron injector linac for the SCSS project (SASE-FEL) at SPring-8 [11]. SCSS is comprised of a buncher system and 1-GeV injector followed by a 20-m long in-vacuum undulator. It should be able to produce X-rays in the water-window range of 1- to 10-nm wavelength. The first operation of the c-band linac at an initial beam energy of 500-MeV.

## 5 REFERENCE

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