Various Pulse Forming of Pulsed CO_2 laser using Multi-pulse Superposition Technique

Hyun-Ju Chung and Hee-Je Kim

Abstract - We describe the pulse forming of pulsed CO_2 laser using multi-pulse superposition technique. A various pulse length, high duty cycle pulse forming network(PFN) is constructed by time sequence. That is, this study shows a technology that makes it possible to make various pulse shapes by turning on SCRs of three PFN modules consecutively at a desirable delay time with the aid of a PIC one-chip microprocessor. The power supply for this experiment consists of three PFN modules. Each PFN module uses a capacitor, a pulse forming inductor, a SCR, a High voltage pulse transformer, and a bridge rectifier on each transformer secondary. The PFN modules operate at low voltage and drive the primary of HV pulse transformer. The secondary of the transformer has a full-wave rectifier, which passes the pulse energy to the load in a continuous sequence.

We investigated laser pulse shape and duration as various trigger time intervals of SCRs among three PFN modules. As a result, we can obtain laser beam with various pulse shapes and durations from about 250 μs to 600 μs.

Keywords - pulsed CO_2 laser, multi-pulse superposition, laser pulse shapes, pulse forming network(PFN) and power supply

1. Introduction

Pulsed TEA CO_2 lasers, as reported earlier, have very short pulses of less than a hundred nanoseconds and power peaks of a few kilowatts. Longitudinally pulsed CO_2 lasers using a pulse transformer have pulses of less than 100 microseconds and power peaks of 1 kilowatt.[1~3] First of all, the commercially available transversely excited atmosphere (TEA) CO_2 lasers using conventional charge transfer circuits generate optical pulses with a 1 ~ 2 μs long tail. Discharge circuits in these lasers are designed to have low inductance so that excitation currents(<1 μs long) that are shorter than the glow to arc transition times are generated. These lasers can be used for many purposes, for example as rangefinders, remote gas sensors, and in nonlinear spectroscopy. On the other hand, Wilder-Smith evaluated CO_2 lasers in the surgical treatment of pulpal exposures in canines by using lasers with a pulse duration of 0.01s, a pulse interval of 1.0s, and a peak power density of 276 J/cm^2.[4] Ross studied the effects of pulse duration of CO_2 lasers on ablation and thermal damage over the millisecond(0.25~10 ms) region.[5] Thus, lasers with long pulses on the order of milliseconds and a few hundredths of second can be used for surgery and other medical applications, such as skin rejuvenation and tissue type ablation.

During manufacturing, various pulse shapes are required in order to process materials. Pulse shape is regarded as a dominant factor due to the specific properties required by the processing of materials.

Recently several groups have reported the production of long pulse CO_2 lasers using the conventional laser heads and substituting rapid discharge capacitors with a suitable pulse forming network (PFN). However those lasers generate laser beam with a pulse duration of less than a few microseconds.[6] Therefore they are not suitable for generating laser pulses of longer durations and it is very difficult to control the shape and duration of the laser pulse because of the high voltage that they require.

In ref. 7, it becomes possible to shape a current pulse that is very rectangular and thus well suited for electric launcher applications. This shape is achieved by triggering single PFN units at corresponding times.[7] James also constructed a variable pulse length with a high duty cycle pulse forming network sequenced in time, by transforming and switching single sections of a Guilliman type B PFN element with a high duty cycle magnetron.[8]

In this paper, we propose to shape laser pulses by triggering the single pulse forming units configuring the PFN with different time delays and describe the design and properties of a power supply for a longitudinally pulsed CO_2 laser with various optical pulse shapes and durations of a few hundred microseconds. The power supply generates suitable pulse shapes and durations by using a three pulse superposition technique adapting multi-discharge method. Moreover the laser operates at low voltage and drives the primary of a step-up transformer, thus it is easier to control than those which operate at high voltage.

The shape and duration of laser pulses that were generated with various time delay among three PFN

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Hyun-Ju Chung and Hee-Je Kim are with Department of Electrical Engineering, Pusan National University, 30, Changjeon-Dong, Keumjeong-Ku, Pusan, 609-735, South Korea.

modules were investigated. The shape and width of the laser output beams were measured by adjusting the time delay intervals of three SCRs. This delay is controlled by a microprocessor such as a PIC.

2. Design

2.1 Laser resonator

The type of lasers that we investigated is sealed water-cooled devices made of pyrex as shown in Fig.1. The experiment is equipped with a plano-concave resonator. The optical resonator is formed by a totally reflecting Mo mirror with the radius of curvature 10 m and a 90 % reflecting ZnSe flat output coupler separated by 100 cm. The discharge length is about 90 cm. The construction of a hollow cylinder for an aluminum cathode is employed to minimize the sputtering.

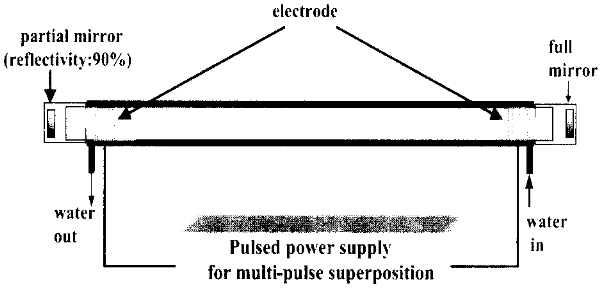


Fig. 1 Schematic diagram of a pulsed CO2 laser system for multi-pulse superposition technique.

2.2 Pulsed Power Supply

The pulsed power supply is composed of three PFN modules discharging into a laser tube and a control circuit consecutively activating SCRs.

2.2.1 PFN(Pulse Forming Network) module

Each PFN module consists of a capacitor, a pulse forming inductor, a SCR as a main switch, a HV pulse transformer, and a full bridge rectifier on each transformer secondary. The modules are shown in Fig. 2. The bridge rectifier consists of four high power diodes (blocking voltage 15kV) and a snubber circuit (diode, D, resistor, R and capacitor, C) is connected in parallel to the pulse transformer.

The SCRs of each PFN module are consecutively activated at consistent time delays and the energy of the storage capacitor is transferred into the laser tube through the HV pulse transformer in time sequence. In this experiment, the capacitance, C, inductance, L, and the charging voltage of the capacitor are set at 10 μF, 40 μH, and 600 V respectively. The input energy at each PFN module is 1.8 J.

The secondary voltage of the step-up pulse transformer is induced by the turn ratio of 1:30, and it is applied to two electrodes in the laser tube through the bridge rectifier. The transformer produces high voltage pulses up to 20 kV. The inductance of the primary transformer is 13.2 mH and that of the secondary is 13 H.

The transformer uses a low voltage solid state switch with a high voltage load. The rectified, but not filtered, outputs from the transformers are combined and passed to the laser tube but are isolated from each other by the bridge rectifiers.

As shown in Fig. 3, it is possible to change current pulse shape by triggering the single modules at the corresponding time.

A diode, D and a resistor, R are connected with the primary winding. If these elements don't exist in the

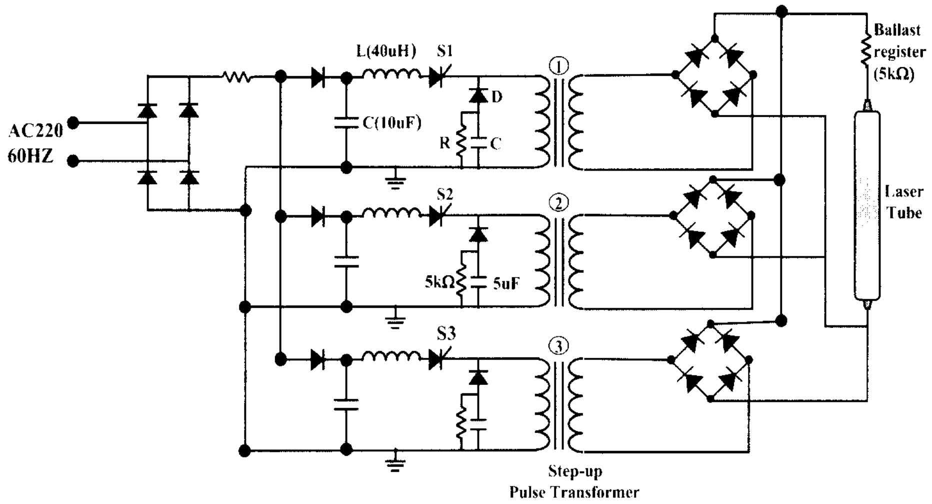


Fig. 2 A power supply for multi-pulse superposition technique of a longitudinally pulsed CO_2 laser. It consists of three PFN modules.

discharge circuit, input energy would be trapped in the inductance for appreciable period and might be further increased by the subsequent closing of the SCR. The inductance of the transformer might be saturated by the energy stored in transformer subsequently. Thus, this circuit requires resistor and diode to dissipate trapped energy in the transformer.

A ballast resistor is inserted between bridge rectifiers and electrode of laser tube. This is to limit the peak discharge current. The resistor inhibits the glow-to-arc transition at the center of the discharge tube caused by the rise in the gas temperature and reduction in gas density at higher discharge currents.

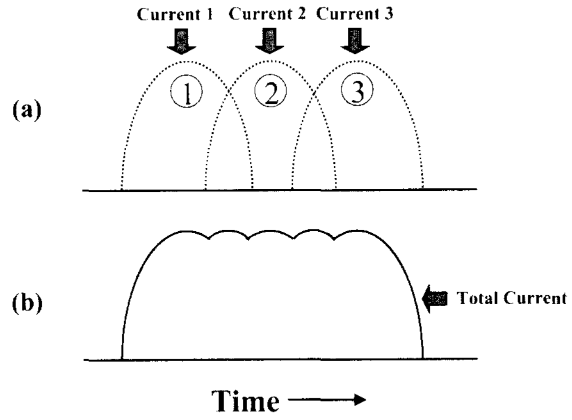


Fig. 3 (a) Current pulses switched from each PFN module in time sequence.
(b) Total current pulse shaped by triggering each single module at corresponding time.

2.2.2 Control Circuit

Each SCR trigger control of three PFN modules is achieved by using PIC one chip microprocessor. Fig.4 shows block diagram of time delay control circuit for multi-pulse superposition technique.

The control circuit consists of three parts. One is keyboard for being taken information of desirable delay time. Another is FND display part to show operational delay time among three SCRs. The other is PIC one-chip microprocessor which is the most important in this control circuit.

Operational sequence of control circuit can be explained as follows. An information of delay time is input by keyboard, and the information is transferred to PIC which generates four different signals in accordance with the predetermined program.

One signal from PIC is for driving FND. Other three signals are trigger signals to turn on three SCRs of each PFN module in the desirable delay time. The voltage and the current of output signals from PIC is not enough to turn on the SCR. Therfore an power amplification circuit should be added to increase their current and voltage. These amplified signals turn on SCR S1, S2, and S3 consecutively with a precision of up to 5 μs and the delay time among SCR1, SCR2, and SCR3 can be varied from 0 μs to 990 μs.

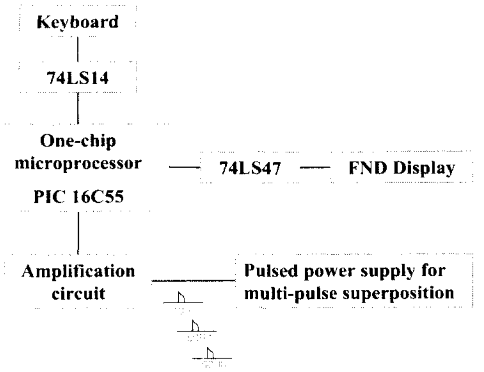


Fig. 4 block diagram of time delay control circuit for multi-pulse superposition technique.

3. Laser performance

For basic experimental investigations a pulse forming network composed of three PFN modules operated in parallel was built. We know that PFNs could reliably be operated and that the single module could work together to generate a laser beam. Moreover, the extent to which it is feasible to arbitrarily shape a total laser beam pulse was investigated.

The experiment has been conducted with a CO_2 / N_2 / He = 1 / 9 / 15 gas mix at low pressure of 20 Torr. Laser beam pulse shapes were recorded with a pyroelectric element (Molectron : P5-01).

First some measurements were made in order to demonstrate that the single modules can be triggered at different times.

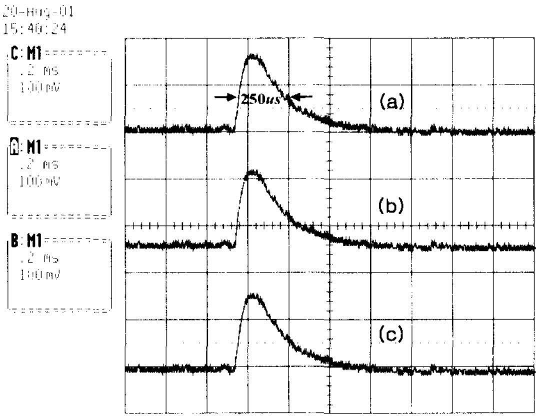
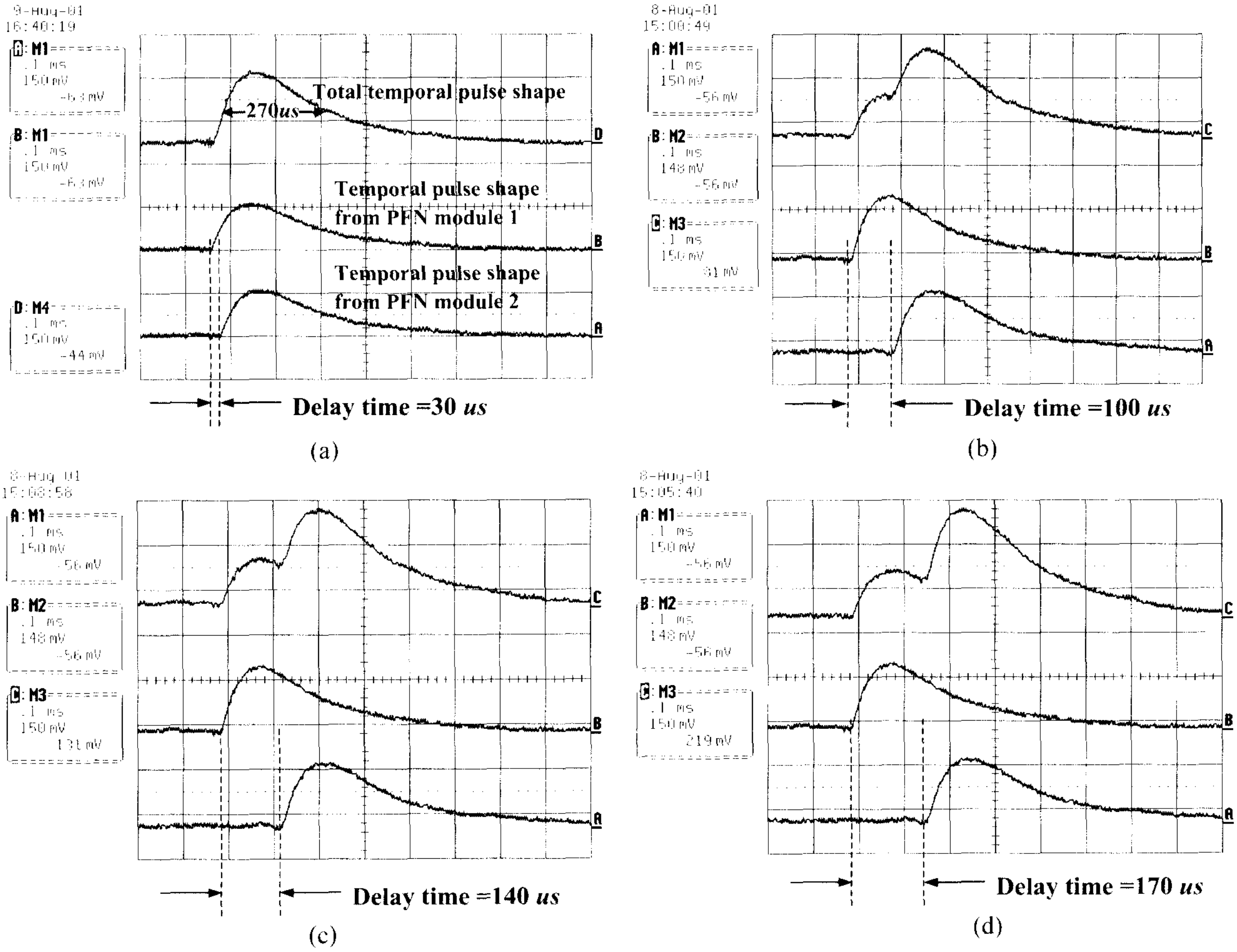


Fig. 5 The laser beam pulse shapes when the SCRs from PFN modules are turned on individually
(a) Temporal pulse shape from PFN module 1
(b) Temporal pulse shape from PFN module 2
(c) Temporal pulse shape from PFN module 3



(a) (b) (c) (d)

Fig. 6 laser pulse shapes obtained by the two pulse superposition technique when only two SCRs(SCR1 and SCR2) regardless of SCR3 are turned on at the delay times of 30 μs, 100 μs, 140 μs, and 170 μs.

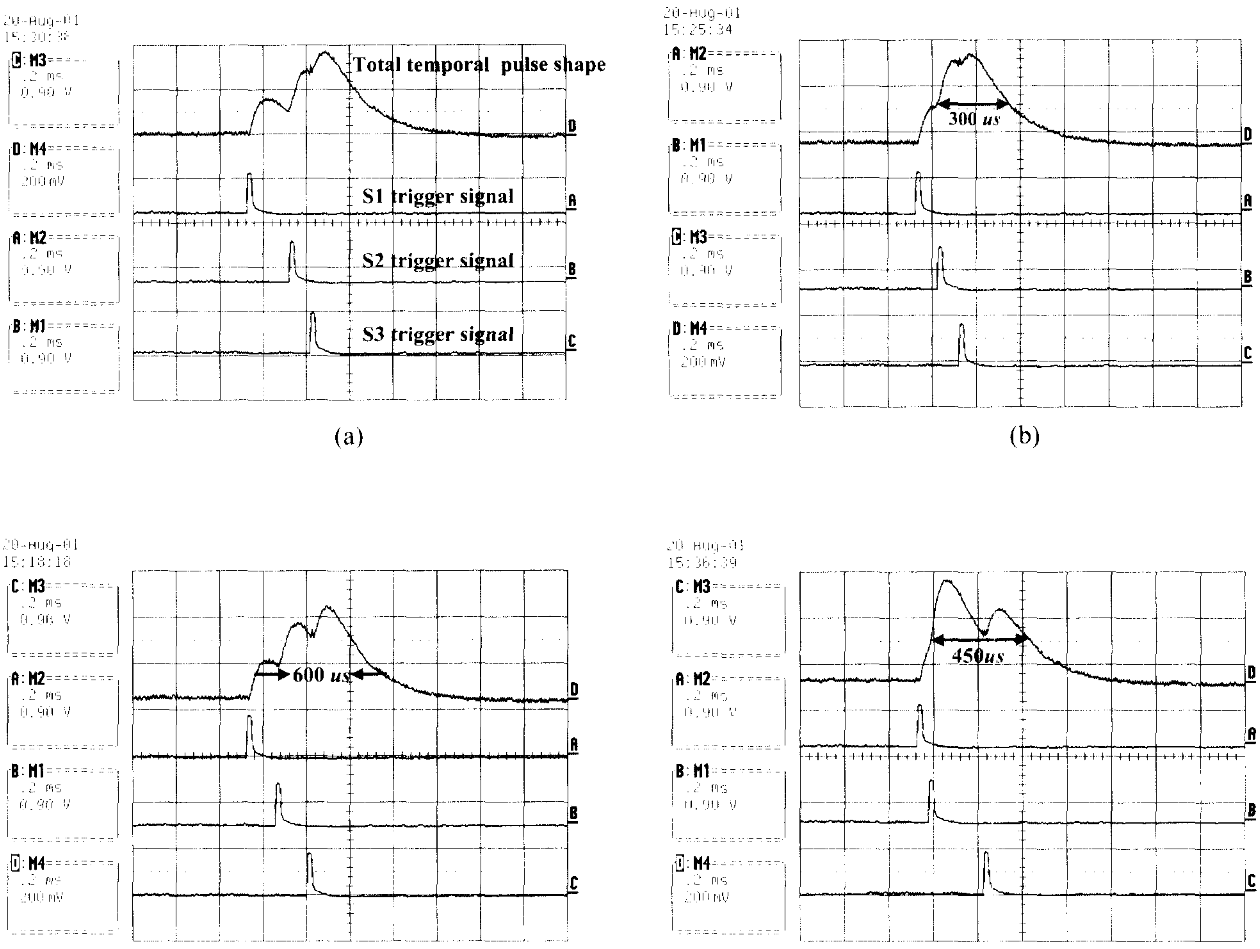
Fig. 5 shows the laser beam pulse shapes when the SCRs from PFN modules are turned on individually. At this time, the pulse duration[FWHM] of each laser pulse is approximately 250 μs and the laser beam shapes produced by each PFN module are nearly identical. These waveforms were obtained with a capacitor of 10 μl and a charged voltage of 600 V. Thus, the input energy of each PFN module is 1.8 J and the obtained laser output is about 150 mJ.

Fig. 6 shows the laser pulse shapes obtained by the two pulse superposition techniques when only two SCRs (SCR1 and SCR2) are turned on at time delays of 30 μs, 100 μs, 140 μs, and 170 μs. The total input energy of the two PFN modules is about 3.6 J and the obtained laser output is about 290 mJ regardless of time delay interval.

In Fig. 6(a), the time delay interval is 30 μs, the pulse duration is approximately 270 μs and the peak value is about 1.7 times than that of single pulse from each PFN module.

In Fig. 7, the total laser pulse shapes obtained by the three pulses superposition technique can be seen. In Fig. 7(c), the individual modules have been successfully triggered after intervals of 150 μs at a time and the pulse duration is approximately 600 μs. Although the PFN is built with only three modules, a large variety of total laser pulse shapes can be obtained by triggering the three modules at different time delay intervals. If a large number of modules is used, then a large number of laser pulse shapes could be achieved. This could be improved by continuously activating the switches in time sequence using a high speed switching element such as IGBT instead of the SCR. The laser output is also about 430 mJ regardless of the time delay interval. From these results it can be concluded that the single units do not influence each other and that they are electrically decoupled. Therefore, by triggering the single unit at corresponding times, it becomes possible to change laser pulse shapes.

The laser pulse shape and duration are varied with changable pulse duration but the laser output was almost the same without regard to the time delay interval.



(a) (b)

(c) (d)

Fig. 7 Total laser pulse shapes obtained by three pulses superposition technique
(a) S1-S2 time interval : 200 μs, S2-S3 time interval : 100 μs
(b) S1-S2 time interval : 100 μs, S2-S3 time interval : 100 μs
(c) S1-S2 time interval : 150 μs, S2-S3 time interval : 150 μs
(d) S1-S2 time interval : 50 μs, S2-S3 time interval : 250 μs

4. Conclusion

In a wide range of material processing and medical applications, various laser pulse shapes will be able to enhance the efficiency of the process. Our investigations have identified multi-pulse superposition technology as attractive approach for the generation of CO_2 lasers with various, long pulse shapes. This technology activates SCRs of each PFN module consecutively at the desired time delay interval with the aid of a PIC one-chip microprocessor.

It is possible to change current pulse shapes by triggering the single modules at the corresponding time. Thus, a large variety of total laser pulse shapes can be obtained by triggering three modules with different time delays. Furthermore the obtained laser output has nothing to do with the trigger delay interval among the three SCRs.

In the near future, we will introduce technology to activate IGBTs in continuous cycles to obtain laser pulses from short pulses of on the order of microseconds to very long pulses on the order of milliseconds.

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Hyun-Ju Chung received his BS degrees in electrical engineering from Uusan university, Korea, in 1998 He received MS degree in electrical engineering from Pusan National University, Korea, in 2000. He is currently working toward Ph. D. degree in electrical engineering at Pusan National University. His research interests are include pulsed CO_2 laser, laser pulse shaping, high voltage pulsed power supply, resonant inverters and electric drive systems.

Tel : +82-51-510-2770, Fax : +82-51-513-0212
E-mail : hyunju30@hanmail.net

Hee-Je Kim received his BS and MS degrees in electrical engineering from Pusan National University, Korea, in 1980 and 1982. respectively. He joined the Plasma & Laser Lab of Korea Electro-Technology Institude in 1983 and went to Kyushuy University, Hukulka, Japan, in 1985. 1983-1995, Research Engineer, Korea Electrotechnology Research Institute, Changwon, Korea 9/1995-present, Professor, School of Electrical Engineering, Pusan National University, Pusan, Korea.

Tel : +82-51-510-2364, Fax : +82-51-513-0212
E-mail : heeje@pusan.ac.kr