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ABSTRACT

Heating techniques have been researched and developed for high power and steady state operation of ion cyclotron range of frequencies (ICRF) heating on the Large Helical Device (LHD) in recent years. As a part of the heating system, the waveform control system plays an important role in ICRF heating experiments. This report describes the radio frequency (RF) waveform control system, the programming analysis, and hardware setup. Finally, some typical waveform examples generated by this RF waveform control system, and experimental results are given. The experimental results show that this RF waveform control system works quite well.

Keywords: waveform control system, ICRF heating, multi-pulse, square wave, analog output, LabVIEW

1. Introduction

Research and development of high power ion cyclotron range of frequencies (ICRF) heating has been carried out in recent years on the Large Helical Device (LHD) at the National Institute for Fusion Sciences (NIFS). The LHD is a helical fusion device with a superconducting coil (l = 2, m = 10), a major radius of 3.9 m and a minor radius of 0.6 m. The main purpose is to investigate a currentless and disruption-free plasma. Steady state operation of an ICRF transmitter has already been achieved at 1.6 MW RF output power for 5,000 seconds, and will be applied to the plasma. This ICRF heating system with high output RF power, steady state operation, and a wideband (25 MHz ~ 100 MHz) working range consists of RF power generators, coaxial transmission line, liquid stub tuners, and loop antennas.

As part of this heating system, the waveform control system plays an important role in ICRF heating experiments because the RF power output from a generator should be injected into the plasma with a specific shape, known as the waveform. The commonly used waveform is the square model. However, for certain experimental purposes, RF power must be modulated in many other ways such as sine, multi-pulse, etc. Standard signal generators that can generate simple shapes are available on the market. However, this equipment is not suitable for controlling the RF waveform in real heating experiments. Consequently, this waveform control system has to be built in-house. To build this system, a computer should be used to control a complicate waveform output. This report describes the RF waveform control system, the programming analysis, and hardware setup. Finally, typical waveform examples generated by this RF waveform control system and the experiment results will be given. The experimental results show that this RF waveform control system works quite well.

2. System Basic Function and Configuration

A waveform control system can be used to generate the following waveforms: square, triangular, saw-tooth, sine, multi-pulse, square wave with ramp-up and ramp-down abilities, step-up, step-down, etc., and combinations of these.

A computer-controlled system should have an end user-friendly graphic display interface (GDI) that is easy to use and maintain. To implement these guidelines, the main parts of this waveform system consisted of the following: a personal computer with windows 98/NT operation system, a data acquisition card with analog outputs from National Instruments and LabVIEW 5.1 programming language. Fig. 1 shows a schematic diagram of this waveform system.

3. The Principle of the Waveform System

An ICRF heating system, shown in Fig. 2 includes the RF power generator, matching network, and antenna. High power RF is generated by the RF power generator and sent to an antenna, then injected into the LHD plasma. The control of RF power cannot be achieved by modulating the RF power at the high power components, and must be done at the low RF power components. This means that RF power modulation must be done inside the RF power generator. Figure 3 shows a schematic diagram of the RF power generator system, which includes an RF signal generator, some control circuits, and three RF power amplifiers. The RF signal is generated by the RF signal generator and then amplified by the three power amplifiers. Approximately 2 MW of RF power is obtained from the final power amplifier (FPA). The output power from the FPA depends on the output power of the RF signal generator. If we keep the output power from the RF signal generator constant, an attenuator must be inserted to control the output RF power.

The control signal of the attenuator is a DC signal, which comes from a waveform generator. The amplitude of the RF signal output from an attenuator is proportional to the amplitude of the DC control signal. When this control signal is zero, the RF power output from the RF power generator is zero. If this control signal reaches a certain level, 5 volts for instance, the RF power output from the RF power generator is approximately 2 MW. This means that the output power of the RF power generator can be controlled by the attenuator control signal. This is the point at which the waveform can be controlled.

4. Analysis of a Typical Waveform

In order to generate a waveform signal, it is important to analyse the waveform signal in detail. The shape of the RF waveform used in ICRF experiments depends on the purpose of an experiment. A typical waveform is shown in Fig. 4.

To obtain a waveform signal from a computer, the waveform data must first be generated by the computer and saved in its memory. This data is easily synthesized for simple waveforms. However, for complicate waveforms, such as those shown in Fig. 4, this is quite difficult to express in short sentence. To simplify this problem, we can divide a complicate waveform into several parts that consist of simple waveforms. Using this idea, the above waveform can be divided into three parts as shown in Fig. 4. Each part has a different characteristic.

Part I is the modulation. In this part, many simple waveforms can be generated, such as square wave, sine, multi-pulse, saw-tooth, triangular, etc.

Part II is the main RF pulse. In this part, a square waveform can be generated, which can have ramp-up and ramp-down abilities.

Part III is an offset. This part can only generate a square waveform.

Because each part has a simple function, the waveform data can be easily produced. After the sub-waveforms are generated in each part, the output waveform is the addition of these three parts. This process is shown in Fig. 5.

5. Programming

The waveform signal is time dependent. First, we must decide where the time data and the waveform data should be saved. The simplest way to do this is by placing the waveform data into an array variable with an index that corresponds to time. The array size depends on the pulse length and the number of data stored in an array for one second. Of course, a long pulse and too much data for one second will cost more memory and running time of the computer. In our case, the number of data points for one second was chosen to be 10000. Consequently, there are 10 data points per millisecond.

Because a waveform is divided into three simple parts (shown in Fig. 4), each part can be generated separately. The following sections will discuss how to program this waveform.

5.1 Programming for the Modulation Part

In this part, a waveform such as a square wave, sine wave, multi-pulse, triangular wave, and saw-tooth wave can be generated. The ramp-up and ramp-down features of a waveform are also considered. Note that the ramp-up and ramp-down features are in the same class as the square wave, triangular wave, and saw-tooth wave. Figure 6 shows the multi-pulse case.

Here T_s and T_e are the starting time and ending point times of a pulse, respectively. T_d, T_r, T_f, and T_i are pulse duration, pulse ramp-up duration, pulse-ramp down duration, and the duration of the interval between pulses, respectively. From Fig. 6, it can be seen that the different waveforms are obtained if different T_r, T_f, T_d, and T_i are selected. For examples, if $Tr = T_f = T_d/2$, the triangular waveform can be obtained; if $Tr = T_f = 0$, the square waveform can be obtained, and if $T_r = T_d$ and $T_f = T_i = 0$, the saw-tooth waveform can be obtained.

If a multi-pulse waveform has n pulses, and the *i*th ($1 \leqq i \leqq n$) pulse output value is as follows:

$$V_i(t) = A \times \begin{cases} 0 & t < T_i + (i-1) \times (T_i + T_d) \\ \dfrac{t - [T_i + (i-1) \times (T_i + T_d)]}{T_r} & T_i + (i-1) \times (T_i + T_d) < t \leqq T_i + (i-1) \times (T_i + T_d) + T_r \\ 1 & T_i + (i-1) \times (T_i + T_d) + T_r < t \leqq i \times (T_i + T_d) - T_f \\ \dfrac{i \times (T_i + T_d) - t}{T_f} & i \times (T_i + T_d) - T_f < t \leqq i \times (T_i + T_d) \\ 0 & t > i \times (T_i + T_d) \end{cases} \quad \text{--(1)}$$

where t is time, and A is amplitude. From equation (1), waveform data can be obtained by using the LabVIEW programming language. Figure 7 is the logic diagram for multi-pulse programming, where $T_s(i) = T_i + (i-1) \times (T_i+T_d)$, $T_e(i) = i \times (T_i+T_d)$, and N is the total number of the pulse.

For sine modulation, the output is $V(t) = A \times [1+\sin(\omega \times t)]/2$. Here, A is the amplitude of the waveform, and $\omega = 2\pi f$, where f is the frequency of the sine wave. Figure 8 shows the sine modulation waveform. The logic diagram for sine modulation is shown in Fig. 9.

5.2 Programming for the Main Part

In the main part, only the square waveform is generated. This waveform has the ramp-up and ramp-down features. Figure 10 shows the main square waveform pulse.

Here T_d, T_r, and T_f are pulse duration, pulse ramp-up duration, and pulse-ramp down duration, respectively.

The output value V(t) is as following:

$$V(t) = A \times \begin{cases} 0 & t < T_s \\ \dfrac{t - T_s}{T_r} & T_s < t \leqq T_s - T_r \\ 1 & T_s - T_r < t \leqq T_s + T_d - T_f \\ \dfrac{T_s + T_d - t}{T_f} & T_s + T_d - T_f < t \leqq T_s + T_d \\ 1 & t > T_s + T_d \end{cases}$$

The duration of the RF output power pulse is controlled by the duration of the main square waveform. If the duration in the modulation part is greater than the duration of the main square waveform pulse, then the duration of the RF output power pulse will be exactly same as the duration of the main square waveform. Figure 11 shows the logic diagram of the main square waveform for programming.

5.3 Programming for the Offset Part

In this part, the waveform generated is only a square wave without any ramp-up or ramp-down abilities. Therefore, the programming for this part is quite easy. Figure 12 shows this square waveform, and Fig. 13 is the logic diagram for programming.

5.4 Programming for a Stair Waveform

A stair waveform controls the output RF power level with several steps. These are stair-up and stair-down types, as shown in Fig. 14. The pulse duration T_d is the same the duration of the main pulse duration T_d. The logic diagram for programming is shown in Fig. 15.

The programming processes are carried out for each part, and the waveform data are saved in three different arrays, which are then added together. The process is indicated in Fig. 5.

6. Hardware Setup

The hardware used in this system is from the National Instruments company. A PCI data acquisition card is used, and the model is PCI-MIO-16E-4. This card has 16 analog input channels for data acquisition and 2 analog output channels for analog output applications. For the waveform control system, two channels are used, one is analog output channel number zero (DAC0OUT) and the other is the trigger port (PFIO/TRIG 1). The analog output voltage is in the range of 0 to 10 V (it can be also be adjusted to a range of −5 V to +5 V), and loading resistance should be high (a 1 MΩ resistance is used) since low loading impedance could damage the hardware. The voltages for an analog input signal and trigger signal must be in the range of 0 to 10 V (or ±5V). If the input signal voltage level exceeds this range, the hardware could also be damaged.

The data in one array must be connected to the hardware in order to obtain an output waveform. The connection between the hardware and software is a function in LabVIEW, called AO. Figure 16 shows the diagram of this function.

There are four inputs for the AO function. The first input is "device". The value of the input depends on the hardware setup. In our case, there is only one data acquisition card on the computer, so the data for this input should be 1. The second input is "channel", which should be 0 since analog output channel number 0 is used. The third input is "update rate", which refers to the number of data points per second that can be sent from the data array to the analog output. This input has to be 10000 because 10 data points per millisecond are selected for our system. The fourth input is "waveform". This is where the data from the waveform array can be sent. Figure 17 shows the user graphic display interface of the ICRF waveform control system. The programs for this waveform control system are shown in Fig. 18.

7. Controlling the Output RF Power by the Waveform System

The output power from the RF power generator depends on the voltage of the waveform control system. The relationship between them is not linear. This is due to the non-linearity of the three-stage power amplifier. This non-linear relationship was obtained experimentally. The experimental results are presented in Fig. 19, which shows the results of the output power from number 1 and number 2 RF power generators against the output voltage of the waveform control system. The curves shown in this figure are fitted by a polynomial obtained from the experimental data. The curve with the circle dots is for number 1 RF power generator, and the curve with the square dots is for number 2 RF power generator.

The fitting method uses the following polynomial:

$$P\,(kw) = A_0 + A_1 xU + A_2 xU^2 + A_3 xU^3 + A_4 xU^4$$

Here P is the output power of the RF power generator and U is the output voltage of the waveform control system. The unit for P is the kilowatt and for U it is the volt. Parameters A_0 to A_4 are listing in table 1.

From the above figure (Fig. 19), one can see that due to the non-linear effect, there is a threshold voltage for each RF power generator. The threshold voltage for number 1 RF power generator is about 2.5 volts, and for number 2 RF power generator it is about 2.3 volts. This implies that when the output voltage from RF waveform control system is less than this threshold voltage, no RF output power can be obtained from FPA. In this situation, one should use the "offset part" of the waveform control system to avoid this threshold voltage.

8. Waveform Control System User Guide

Figure 17 shows the user GDI that is the control panel for the ICRF waveform control system. All the parameters needed for the program to build a waveform are displayed there. Different waveforms can be obtained by choosing different parameters.

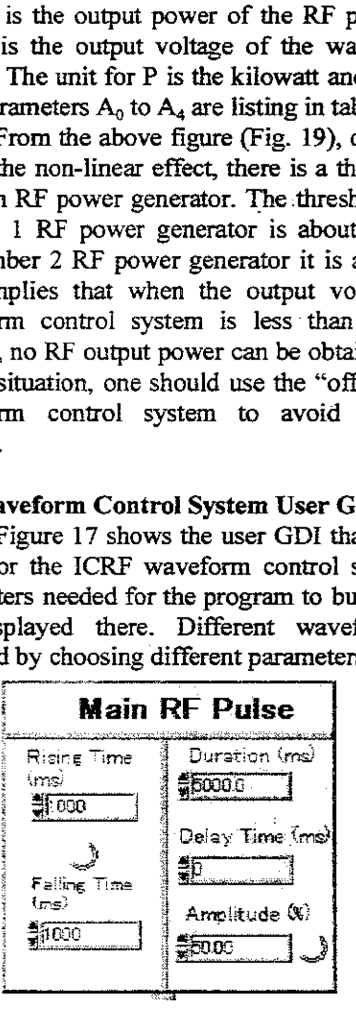

Fig. 20 Main RF pulse section

There are five sections of this waveform control panel: the main RF pulse, multi-square pulse, stair wave, sine modulation, and output window. The first section is the main RF pulse shown in Fig. 20. In this section, five parameters are needed for the program. It generates a square waveform with ramp-up and ramp-down abilities. This section is the Part II that was described in Fig. 4. The meaning of the input parameters is given in Fig. 10. The "Rising Time", "Falling Time", "Duration", "Delay Time" and "Amplitude" correspond to T_r, T_f, T_d, T_s, and A respectively. The unit for T_r, T_f, Td and T_s is the millisecond (ms); whereas, A is a percentage (%). This percentage is the ratio of the main RF pulse voltage to the total waveform output voltage. In this section, there are two alarm lamps. When the entered parameters are wrong, it will be turned on (red). One of these lamps is under the "Rising Time". This alarm lamp will become red when either "Rising Time" or "Falling Time" is greater than "Duration" time.

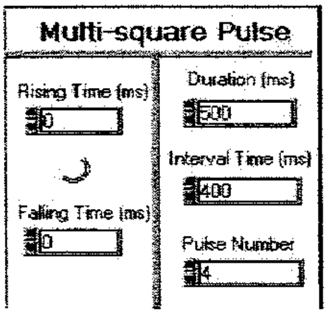

Fig. 21 Multi-square pulse section

Another alarm lamp is beside the "Amplitude" input. This lamp will become red when the entered amplitude is wrong, for instance, if amplitudes greater than 100% for the three parts are entered. When the alarm lamp is lit (red), the program will stop. One has to correct the input error then re-run this program.

The default values for "Rising Time" and "Falling Time" are 1000 ms, "Duration" is 5000 ms, "Delay Time" is 0 and "Amplitude" is 50%. The minimum values for "Rising Time", "Falling Time", "Duration", and "Delay Time" are zero. The data range for "Amplitude" is from 0 to 100. If the inputted data exceeds the data range, the program will be suspended until the error is corrected.

The second section is a multi-square pulse shown in Fig. 21. It generates a multi-square waveform and is the modulation part (Part I) described in Fig. 4. Five parameters are needed as inputs to the program. These are "Rising Time", "Falling Time", "Duration", "Interval Time", and "Pulse Number". Compared to Fig. 6 and Fig. 7, "Rising Time", "Falling Time", "Duration", "Interval Time", and "Pulse Number" correspond to T_r, T_f, T_d, T_i, and N, respectively. The amplitude "A" for the modulation part is not displayed here. We only need to input the amplitudes for two parts since there are three parts in a waveform and the total amplitude should be 100%. The amplitude A is obtained by subtracting the sum of the two entered amplitudes from 100%. There is an alarm lamp under the "Rising Time" that will be lit (red) when either "Rising Time" or "Falling Time" is greater than "Duration" time.

The default values for "Rising Time" and "Falling Time" are zero, "Duration" is 500 ms, "Interval Time" is 400 ms and "Pulse Number" is four. The minimum values for "Rising Time", "Falling Time", "Duration", "Interval Time", and "Pulse Number" are zero.

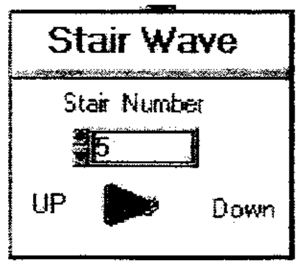

Fig. 22 Stair Wave section

The third section is the "Stair Wave" shown in Fig. 22. It will generate a stair-up or stair-down waveform. One parameter is needed as an input and one switch to be selected. The meaning of the parameters is described in Figs. 14 and 15. The "Stair Number" corresponds to "N". "Up" and "Down" correspond to stair-up (Fig. 14a) and stair-down (Fig. 14b) waveforms. The default value for "Stair Number" is five. The default position for the switch is "Up". The parameters T_d and T_s are the same as in the "Main RF Pulse" section.

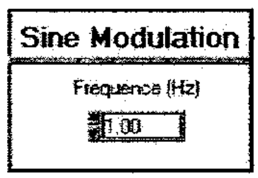

Fig. 23 Sine Modulation section

The fourth section is the "Sine Modulation" shown in Fig. 23. It will generate a sine waveform described in Fig. 8. Only one parameter is needed as an input to the program. The "Frequence" corresponds to *f*, and the default value for "Frequence" is 1.0 Hz. The rest of the parameters needed for the program are described in Fig. 9 and are the same as those in the "Main RF Pulse" section.

The last section is "Output Window" shown in Fig. 24. The output waveform is displayed in this window, and at the same time, the output waveform data in an array is stored in the buffer memory to wait for output. When the trigger signal arrives, the output waveform signal can be obtained immediately from the

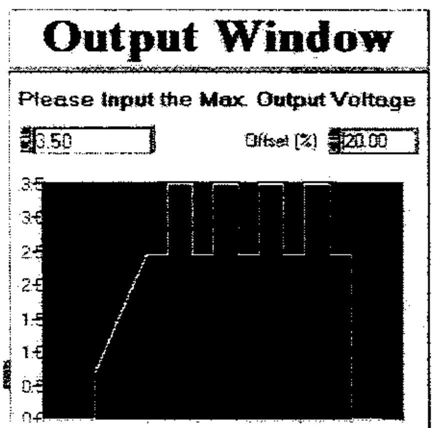

Fig. 24 Output window section

analog output. The scales for the time-axis and Y-axis will be automatically changed to fit the different time and output waveform voltage. The unit for time is the millisecond, and for the Y-axis, it is volts. Two parameters are needed as inputs to the program. One is output waveform voltage, which can be changed from 0 to 10 volts. The maximum voltage of the waveform has to be limited because the output RF power is dependent on this output waveform voltage. In our case, the voltage range is from 0 to 3.5 volts. The default value for output voltage is 3.5 volts. Another parameter is "Offset", which generates a square waveform only. As we discussed before, it is "Part III" of the waveform signal displayed in Fig. 4. The parameters for the offset are displaying in Fig. 12 and Fig. 13. Here, only the square wave amplitude is entered. The rest of the parameters are the same as those in the "Main RF Pulse" section. The unit for offset amplitude is percentage, with a default value of zero.

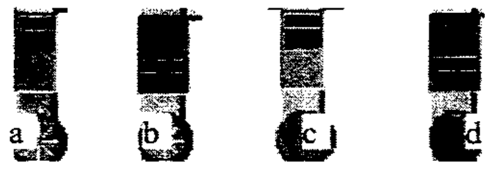

Fig. 25 Modulation Switch

On the program control panel, there are three switches. The function of these switches is to select the different waveform modulation. Only one of these three switches can be switched on at a time because only one type of modulation can be obtained at a time. If you want to switch on more than one switch at a time, then all three switches will be shutdown. Consequently, the output waveform will be obtained only from the "main RF Pulse" part, without any modulation. Fig. 25 shows the switch and the different switching states.

There are four states for these switches, as shown in Fig. 25. Fig. 25a indicates that this switch is at the switching on state. Fig. 25b indicates this switch is at the switching on state, but has been switched to the switching off state and is waiting for the program to change the switching state from on to off. Fig. 25c indicates this switch is in the switching off state, but has been switched to the on state and is waiting for the program to change switching states from off to on. Fig. 25d indicates this switch is in the switching off state.

To run the ICRF waveform control system program, one should press the run button at the top of program window. These buttons are shown in Fig. 26.

a b

Fig. 26 Run Buttons

There are four buttons in this group. The first button  is the run button and only runs the program once. After the waveform is outputted, the program will stop immediately. After pressing the run button, it becomes . The second button, , is for continuous running. This means that when this button is pressed, the program runs continually until the stop button is pressed. When the program is running, the button becomes . The third button is stop . Pressing this button will stop the program running. When the program has stopped, this button becomes . Fig. 26a indicates that the program is in the running state, and Fig. 26b indicates that the program is in the stopped state. The fourth button is pause . This button will suspend the program running until this button is pressed again. After pressing this button, it will become .

When the program is running, one can change some parameters or switch states in order to change the waveform modulations. However, sometimes the program does not respond immediately when the parameters are changed. It will respond after one shot. This is due to the previous waveform data being already stored in the buffer memory, and the program waits for a trigger signal in order to output a waveform. Consequently, the buffer memory is occupied. When the buffer memory is empty, it can receive new waveform data. This means that if someone wants to change the output waveform immediately, the program should be stopped first and then re-run.

9. Waveform Examples

Figure 27 displays some waveform examples generated by this ICRF waveform control system. The parameters needed for generating these waveforms are given in table 2.

Figure 28 shows some examples of the ICRF modulation experiment on LHD. There are two shots concerning RF modulations. One shot is multi-square pulse modulation (shot No. is 10043), and the other is sine modulation (shot No. is 10049). One can see modulated RF power signals displayed on it. The RF power injected into the plasma is not very high in these two shots (about 500 kW). Some evidence of a response can be seen clearly from diagnostic signals such as stored energy of the plasma, radiation power, etc. It can be seen from experiment that this ICRF waveform control system works well.

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References

[1] R. KUMAZAWA, T. MUTOH, et al., Journal of Plasma and Fusion Research Vol. 75, NO.7 (1999), pp. 842~853.

[2] R. KUMAZAWA, T. MUTOH, et al., Review of Scientific Instrument Vol.70, No.6 (1999), pp. 2665~2673.

[3] T. MUTOH, R. KUMAZAWA, et al., 26th EPS Conference on Controlled Fusion and Plasma Physics.

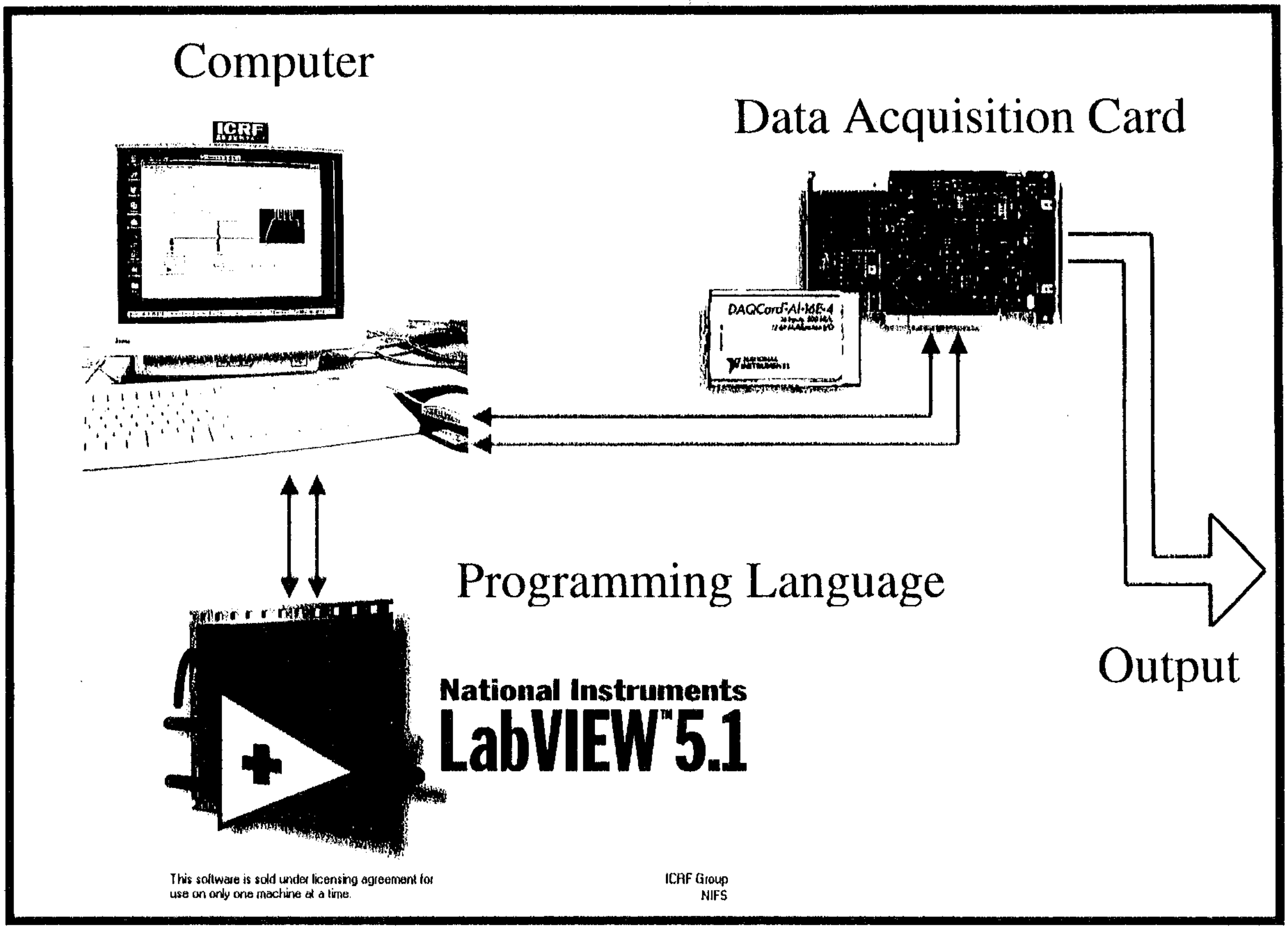

Fig.1 The waveform control system

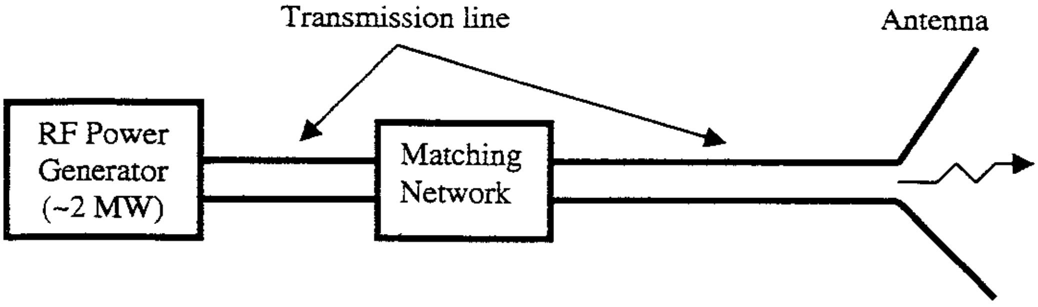

Fig.2 The diagram of ICRF Heating System

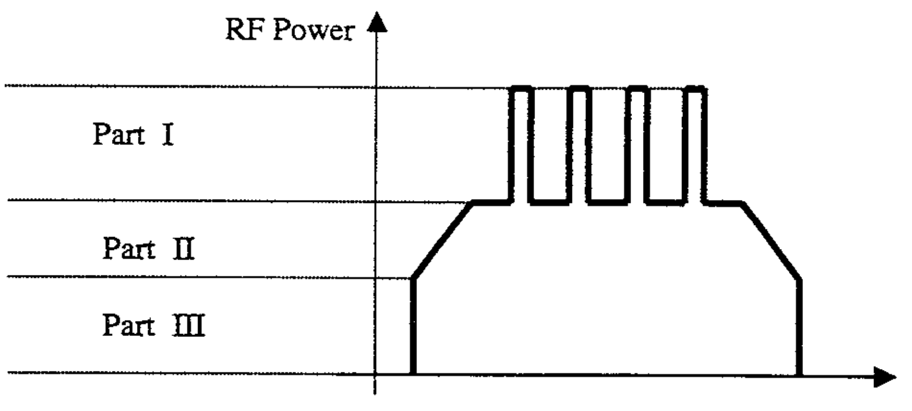

Fig.4 A Typical Waveform

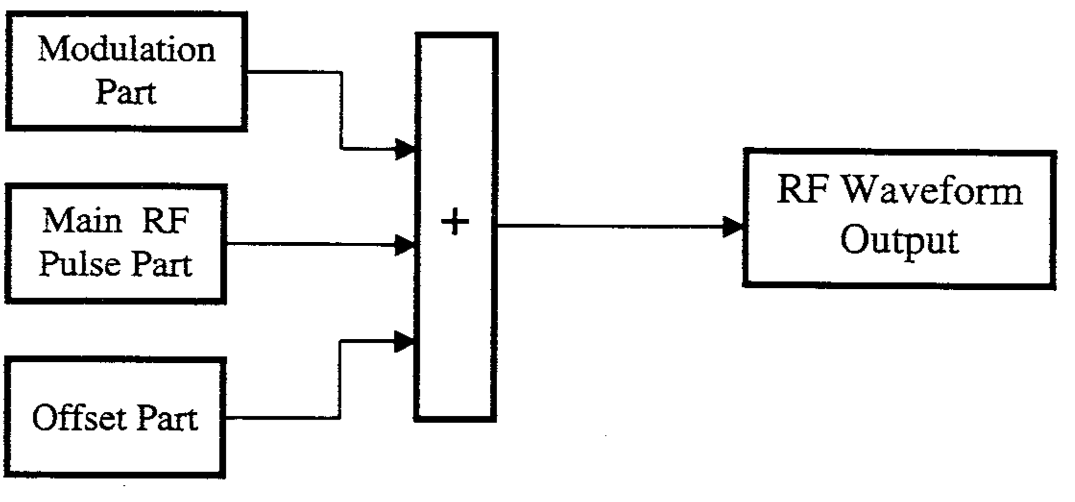

Fig. 5 Addition process for RF waveform generating

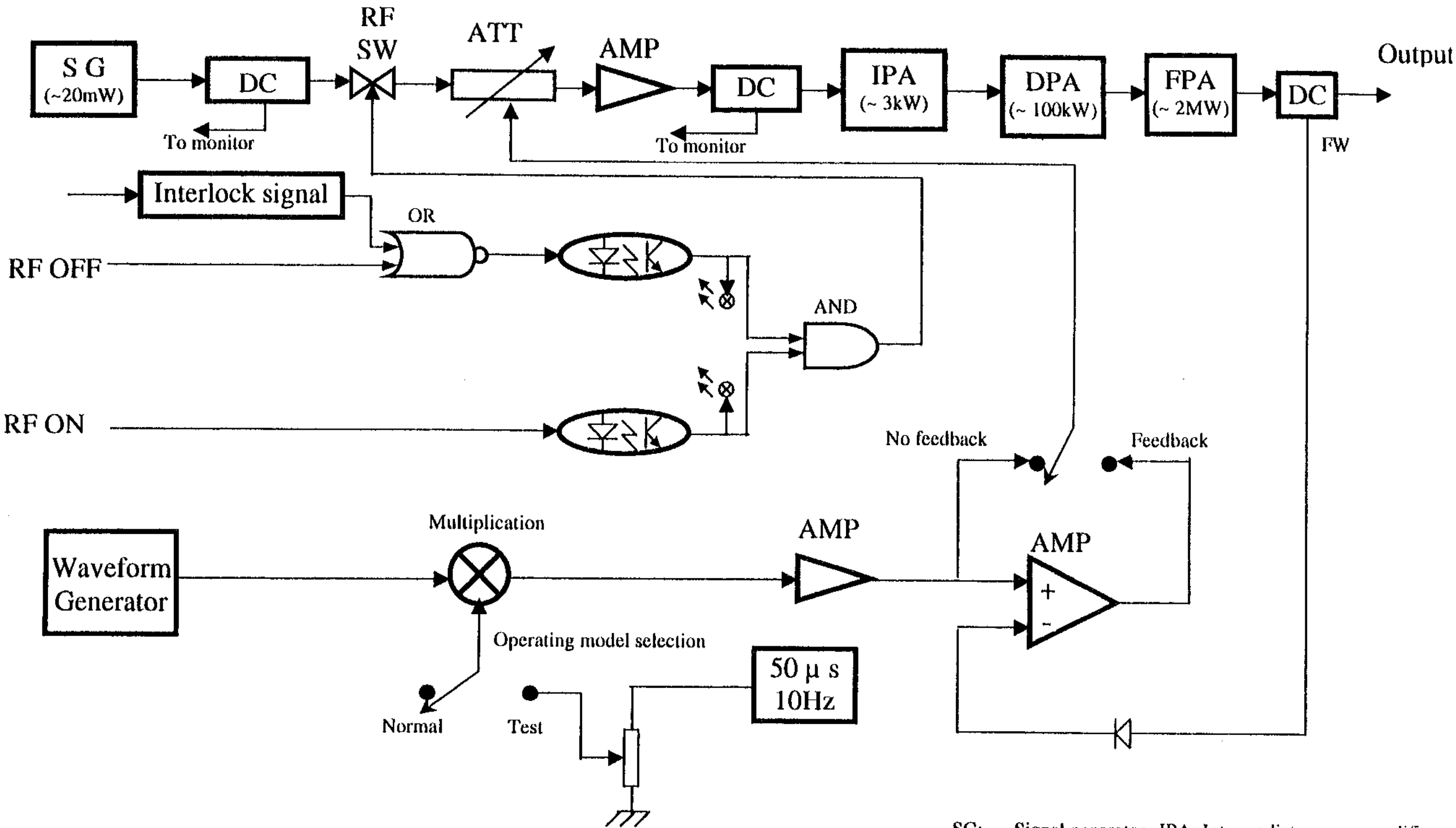

Fig.3 The diagram of RF power generator

SG: Signal generator
DC: Direct coupler
RF SW: RF switcher
ATT: Attenuator
AMP: Amplifier
IPA: Intermediate power amplifier
DPA: Driven power amplifier
FPA: Final power amplifier
FW: Forward wave

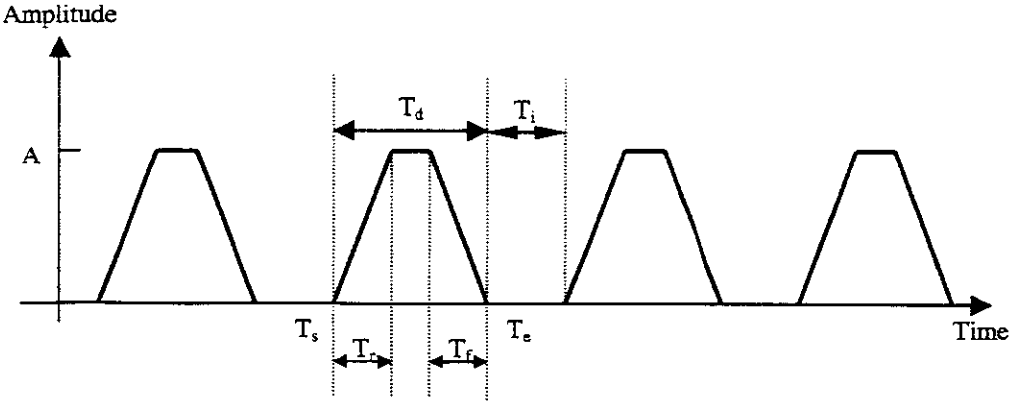

Fig.6 Multi-pulse Waveform

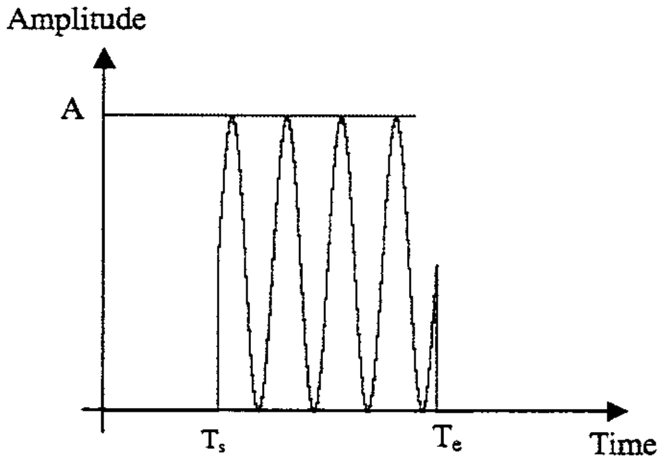

Fig.8 The sine modulation waveform

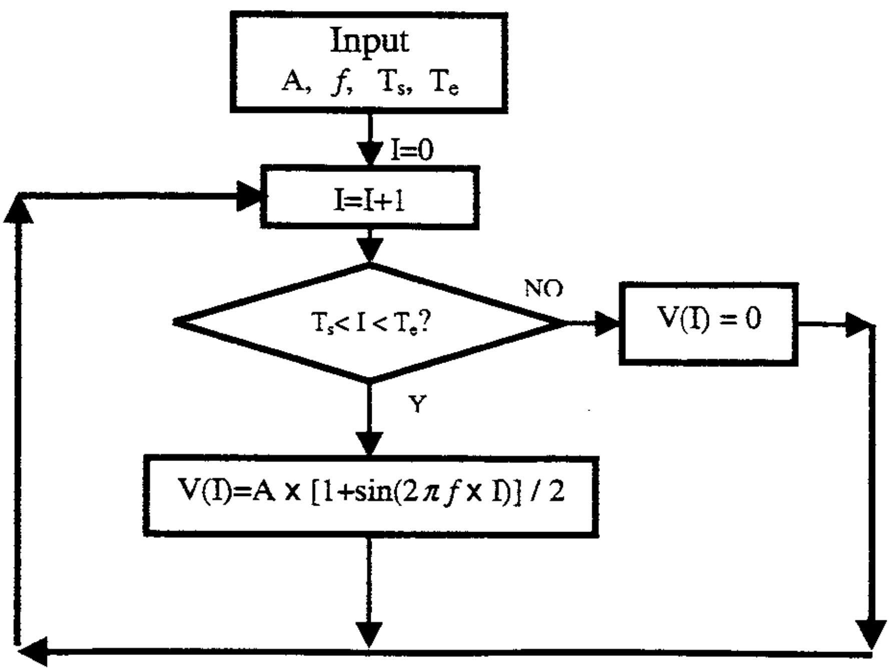

Fig.9 The logic diagram of the sine modulation

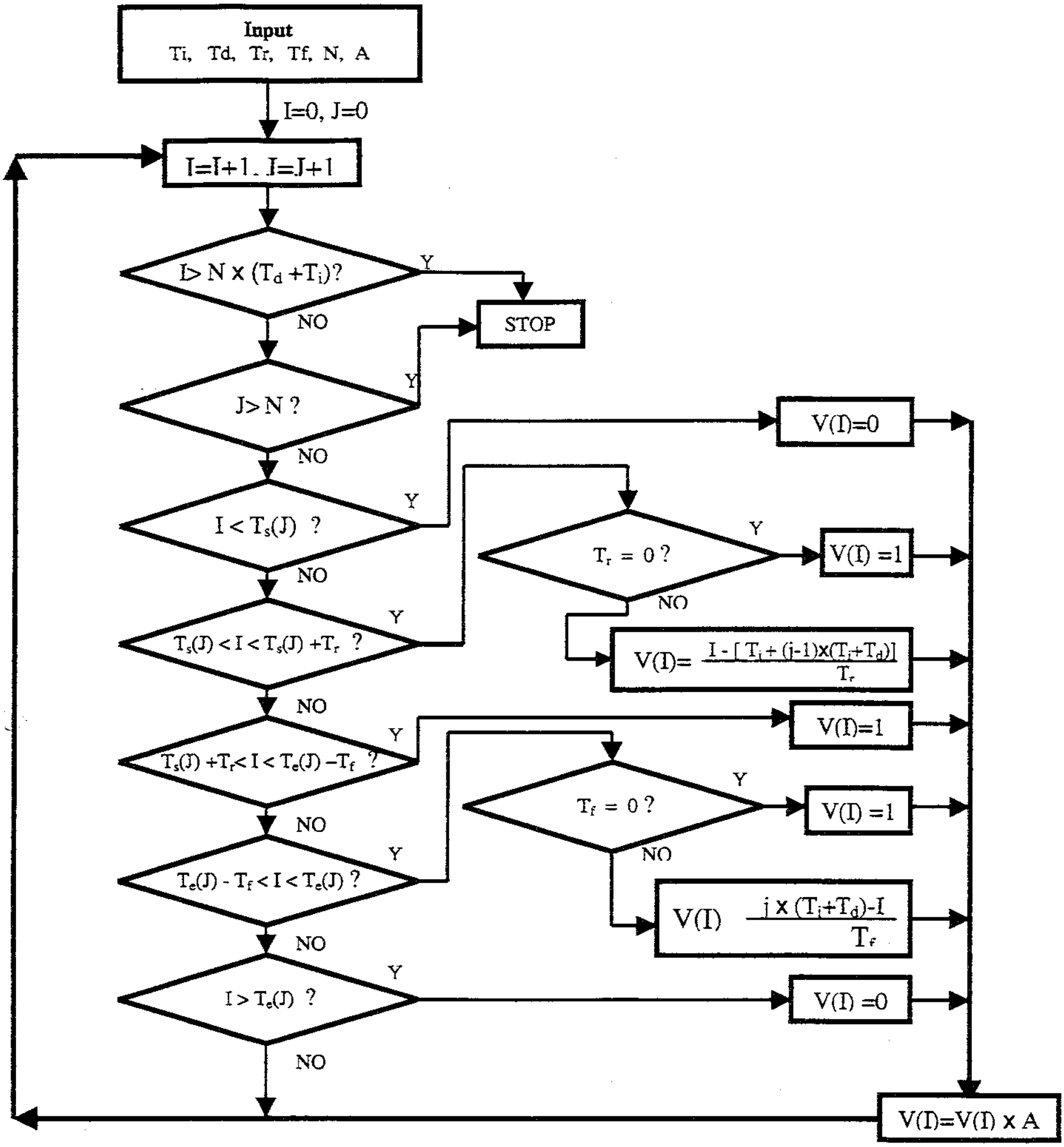

Fig.7 The logic diagram for multi-pulses programming

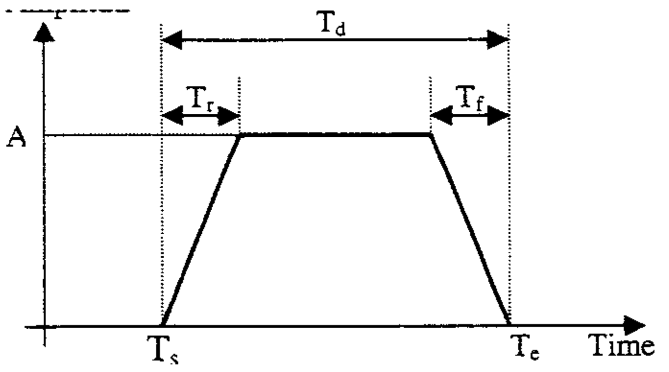

Fig.10 The main square waveform

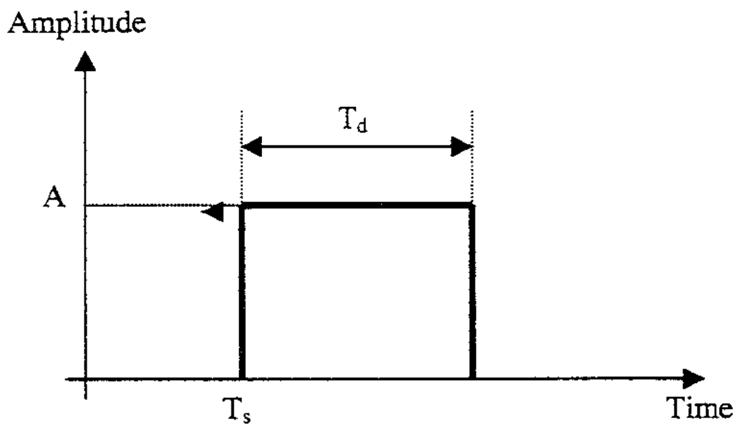

Fig.12 the square wave for offset waveform

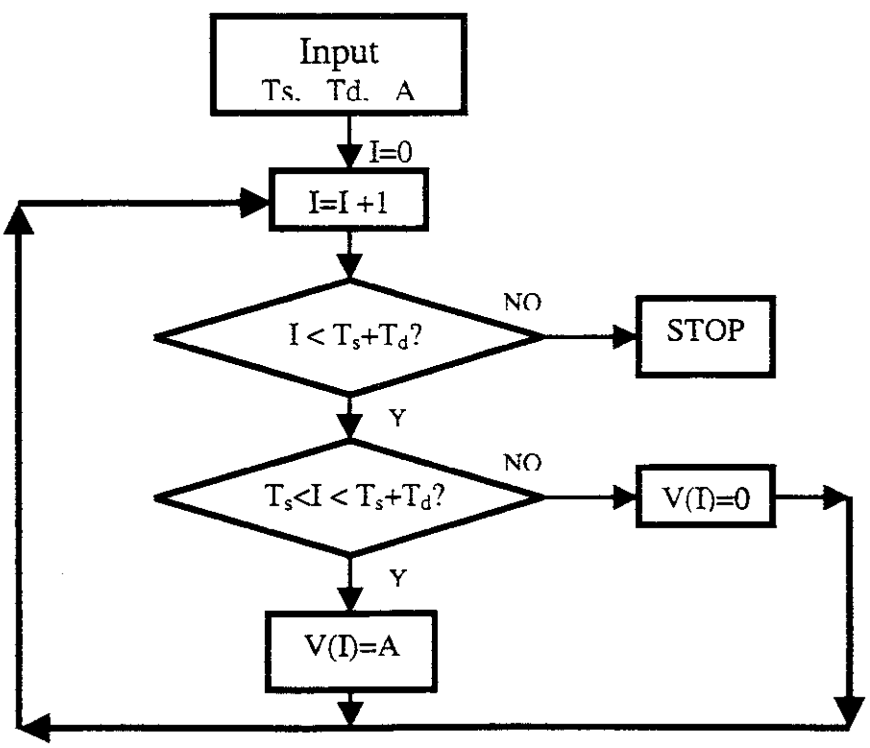

Fig.13 The logic diagram of the offset waveform

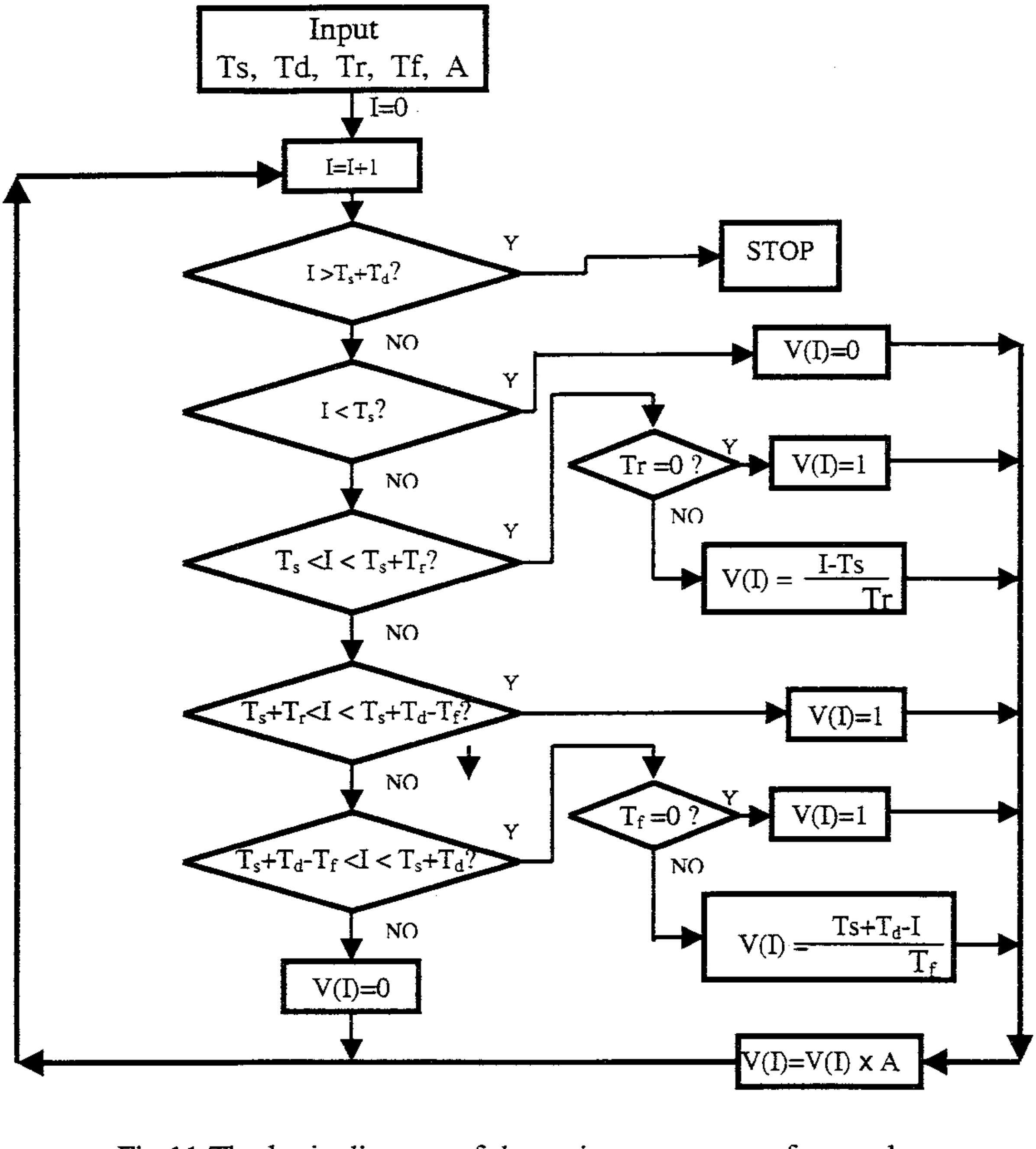

Fig.11 The logic diagram of the main square waveform pulse

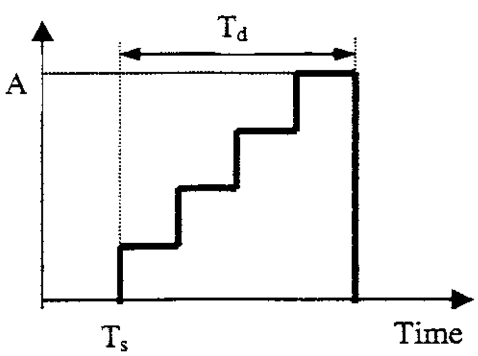

Fig.14a Stair-up waveform

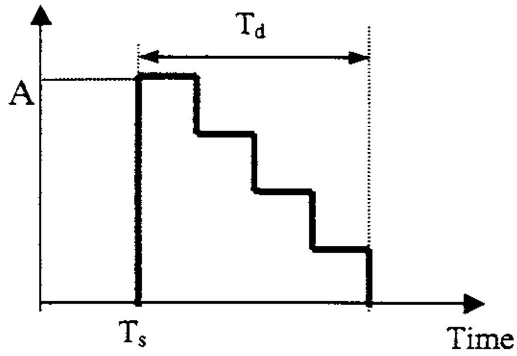

Fig.14b Stair-down waveform

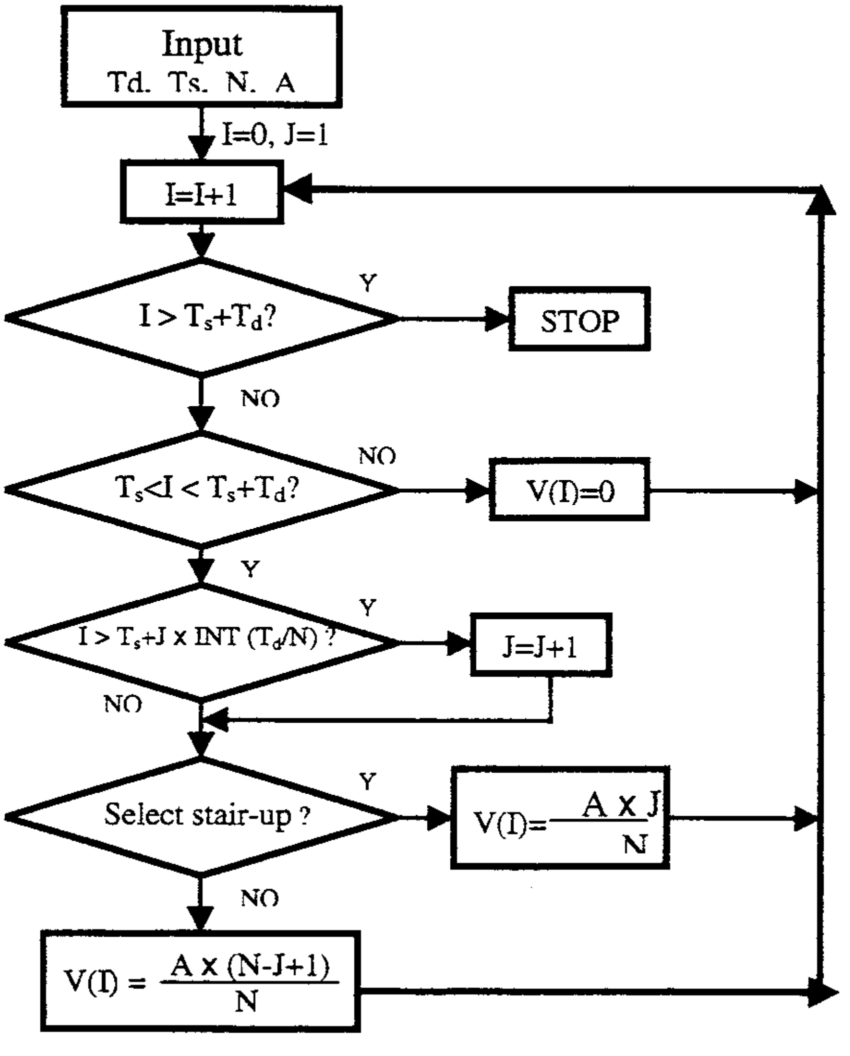

Fig.15 Stair waveform programming logic diagram

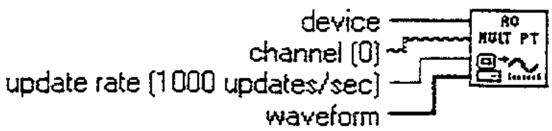

Fig.16 AO Function

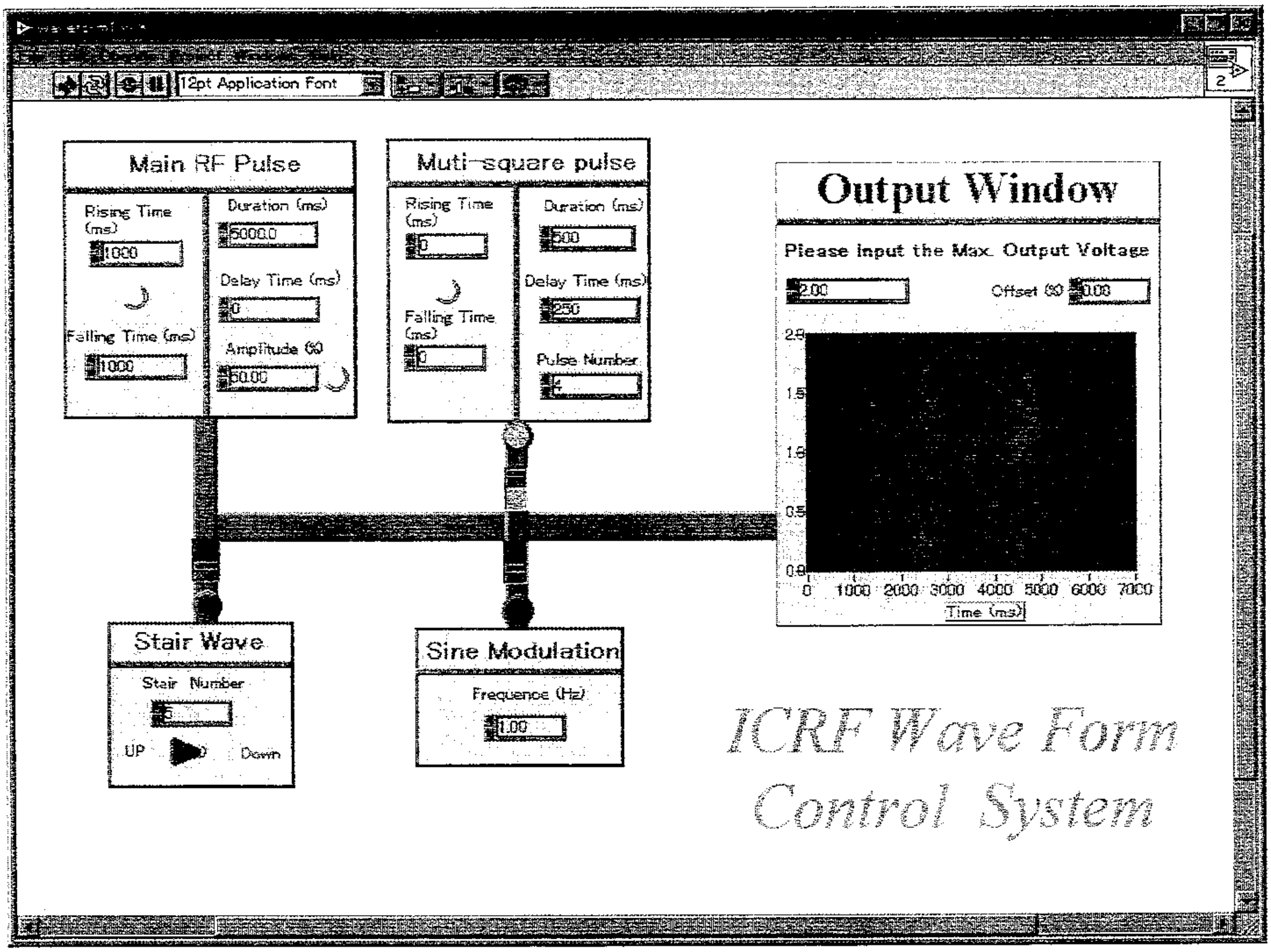

Fig.17 User GDI

waveform1.vi
E:¥WINNT¥Profiles¥Administrator¥Personal¥装置関連¥modulation¥waveform1.vi
Last modified on 99/11/08 at 午後 05:24
Printed on 99/11/24 at 午後 01:42

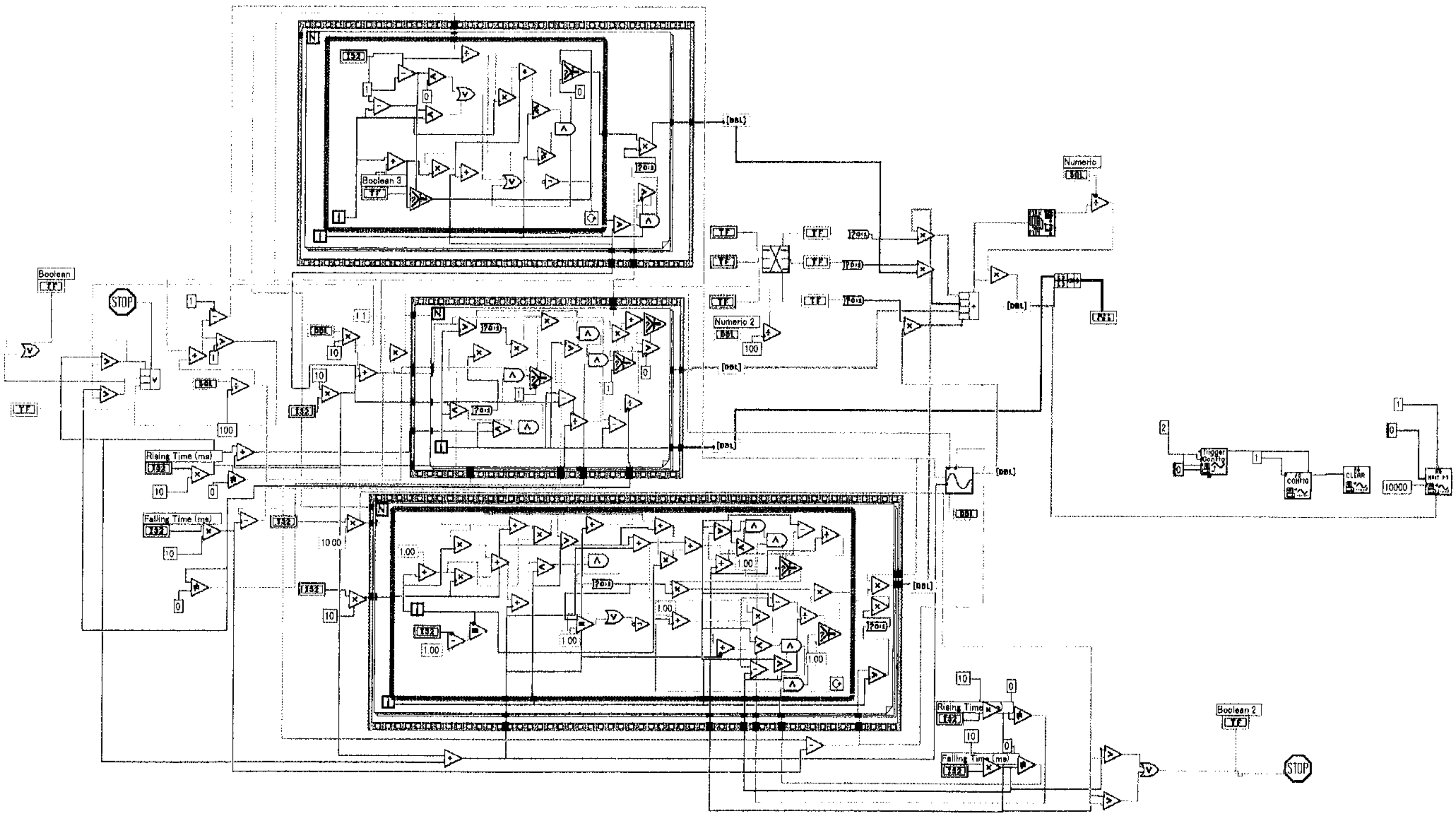

Fig.18 Labview Program

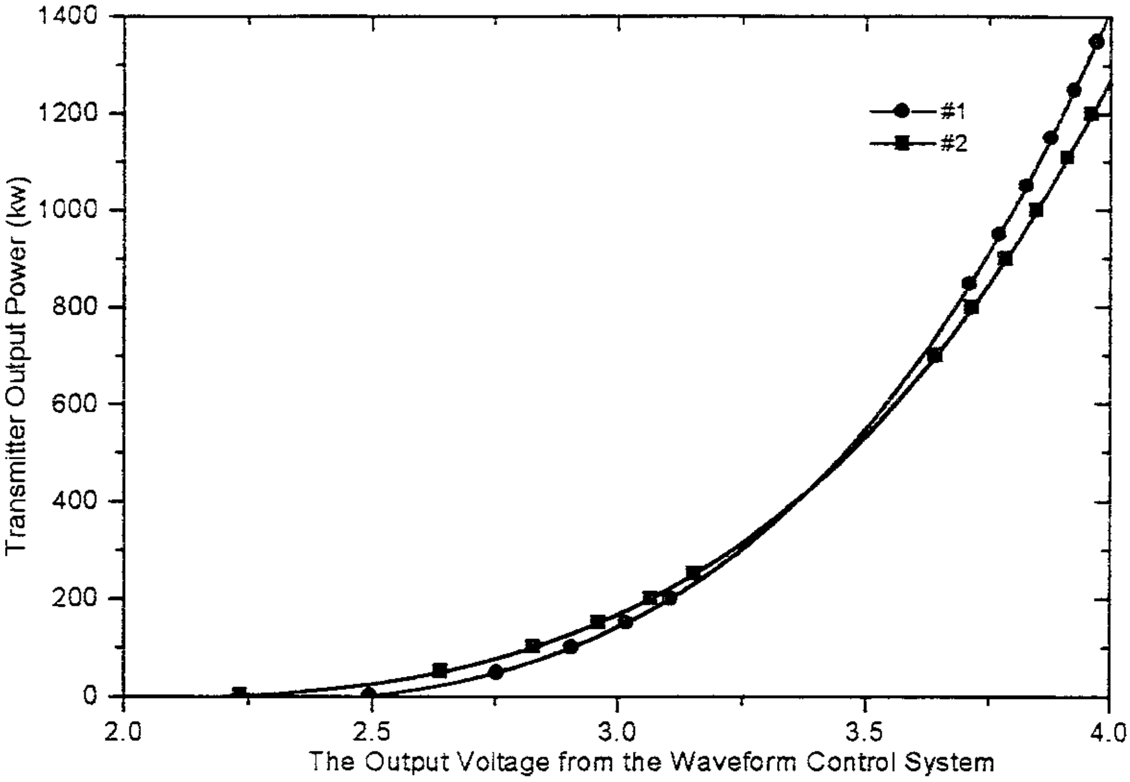

Fig.19

Table I

Generator No.	A_0	A_1	A_2	A_3	A_4
#1	12.81791	-145.20803	267.83440	-165.59278	32.41671
#2	9.41341	-89.15414	173.25242	-113.95412	23.99531

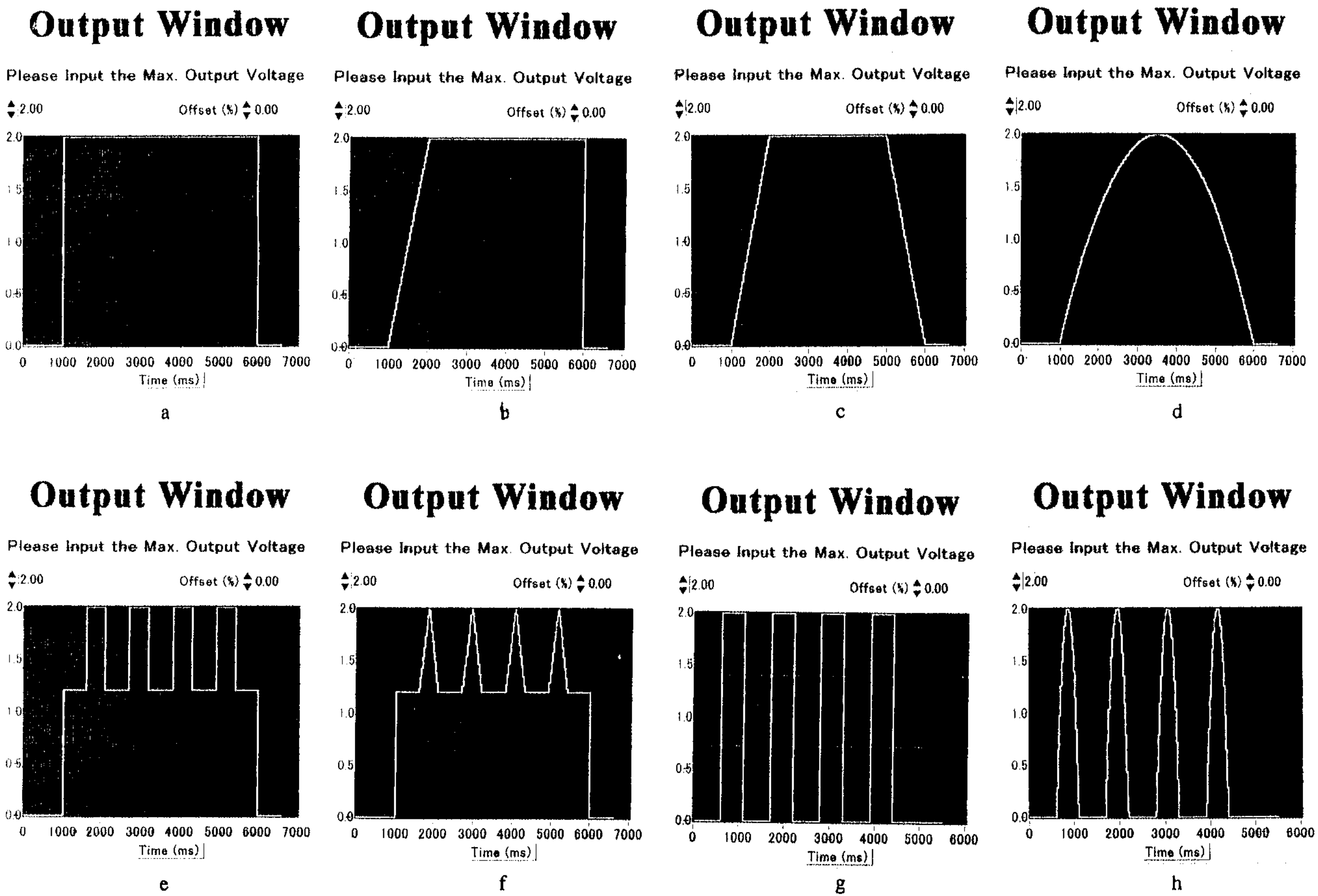

Fig.27 The Output Waveforms

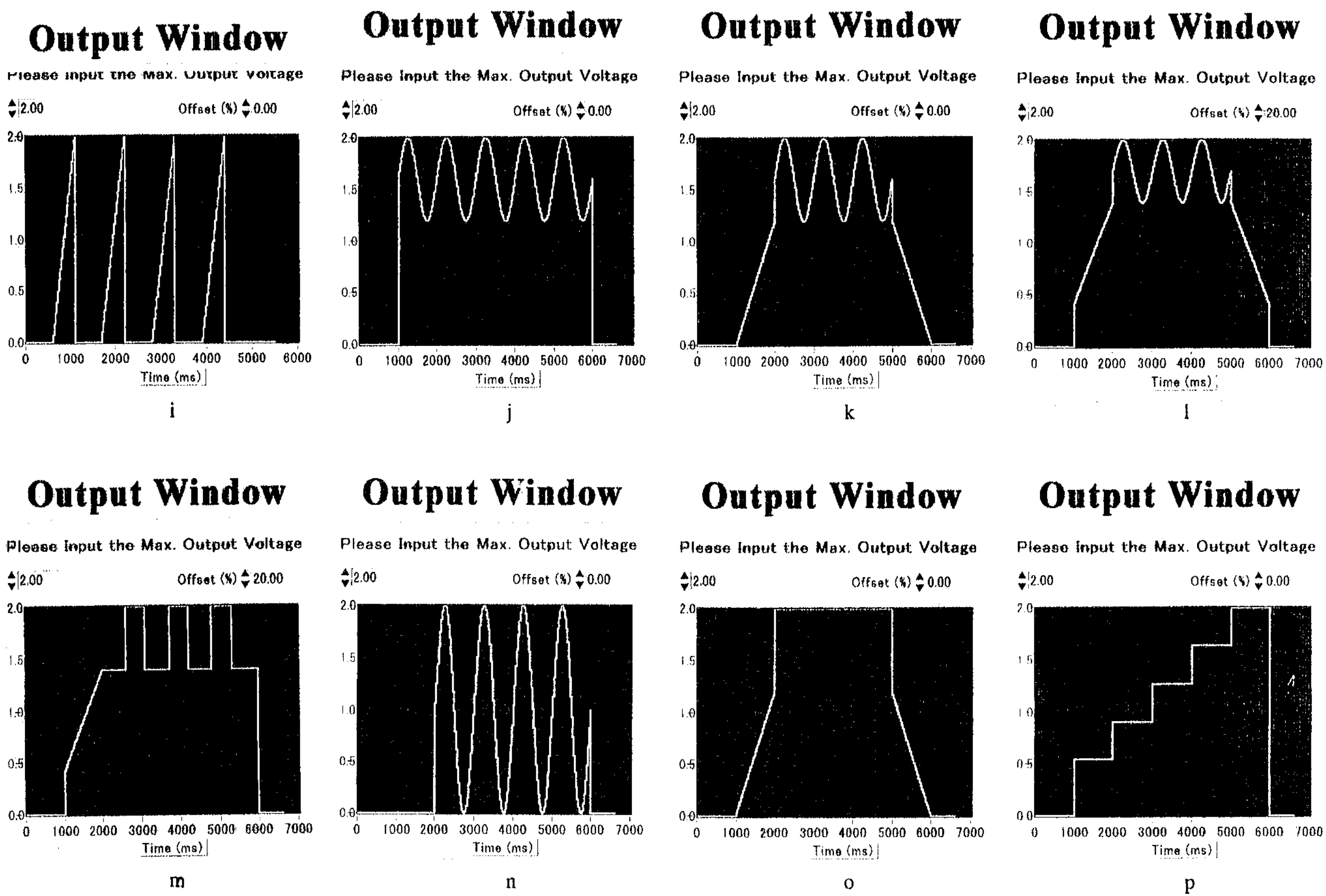

Fig.27 The Output Waveforms (continued)

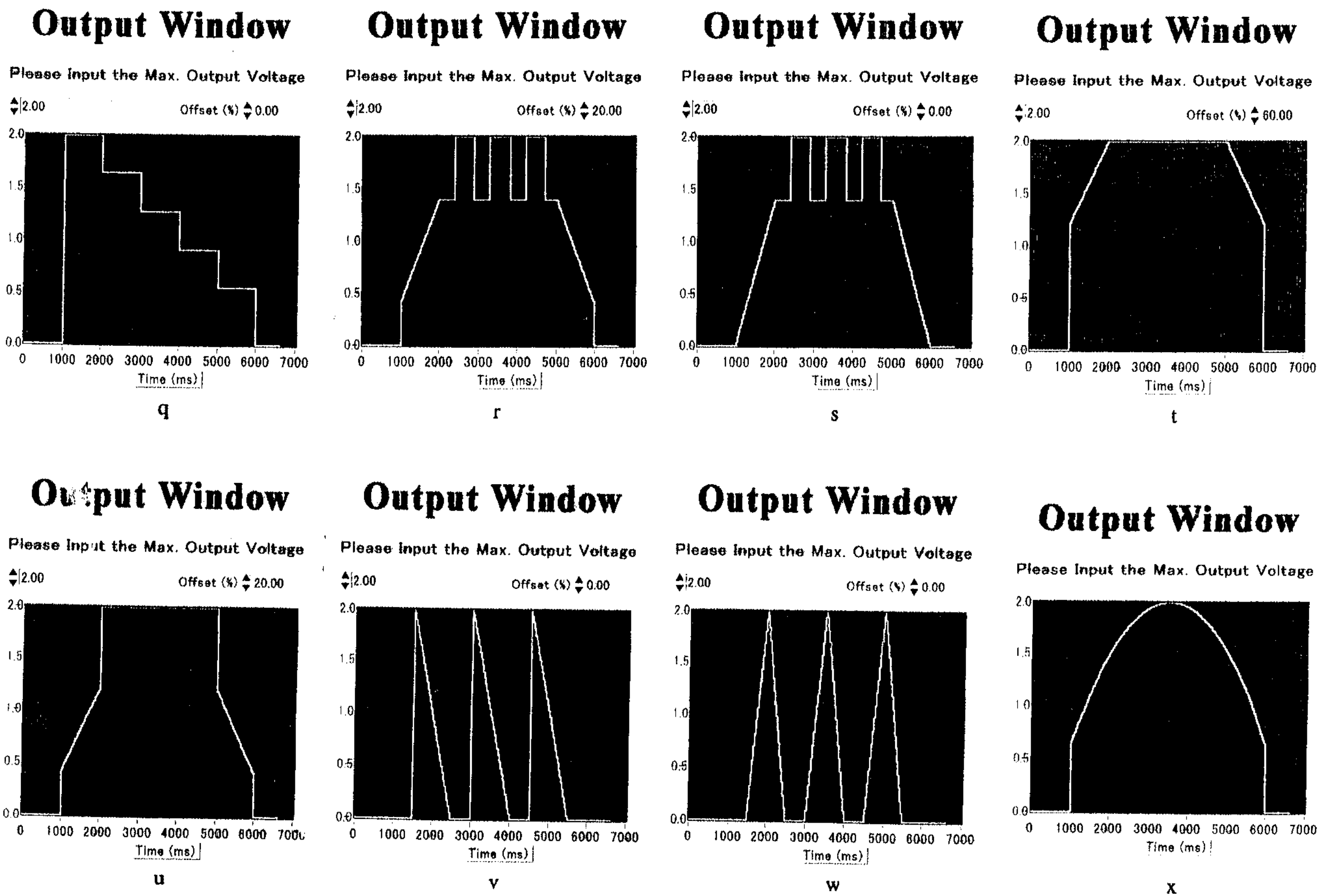

Fig.27 The Output Waveforms (continued)

Table 2.

Figure Name	Parameters for RF waveforms														
	Main RF Pulse					Multi-square Pulse					Stair Wave		Sine Modulation	Output Window
	Rising time (ms)	Falling time (ms)	Duration (ms)	Delay time (ms)	Amplitude (%)	Rising time (ms)	Falling time (ms)	Duration (ms)	Interval time (ms)	Pulse No.	Stair No.	Selector	Frequence (Hz)	Offset (%)
Fig.27a	0	0	5,000	1,000	100									0
Fig.27b	1,000	0	5,000	1,000	100									0
Fig.27c	1,000	1,000	5,000	1,000	100									0
Fig27d	5,000	5,000	5,000	1,000	100									0
Fig27e	0	0	5,000	1,000	60	0	0	500	600	4				0
Fig27f	0	0	5,000	1,000	60	250	250	500	600	4				0
Fig27g	0	0	5,000	0	0	0	0	500	600	4				0
Fig27h	0	0	5,000	0	0	500	500	500	600	4				0
Fig27i	0	0	5,000	0	0	500	0	500	600	4				0
Fig27j	0	0	5,000	1,000	60								1.0	0
Fig27k	1,000	1,000	5,000	1,000	60								1.0	0
Fig27l	1,000	1,000	5,000	1,000	50								1.0	20
Fig27m	1,000	0	5,000	1,000	50	0	0	500	600	3				20
Fig27n	1,000	0	5,000	1,000	0								1.0	0
Fig27o	1,000	1,000	5,000	1,000	60	0	0	3000	0	1				0
Fig27p	0	0	5,000	1,000							5	UP		0
Fig27q	0	0	5,000	1,000							5	Down		0
Fig27r	1,000	1,000	5,000	1,000	50	0	0	500	400	3				20
Fig27s	1,000	1,000	5,000	1,000	70	0	0	500	400	3				0
Fig27t	1,000	1,000	5,000	1,000	40									60
Fig27u	1,000	1,000	5,000	1,000	40	0	0	3,000	0	1				20
Fig27v	0	0	5,000	1,000	0	0	1,000	1,000	500	3				0
Fig27w	0	0	5,000	1,000	0	500	500	1,000	500	3				0
Fig27x	5,000	5,000	5,000	1,000	90									10

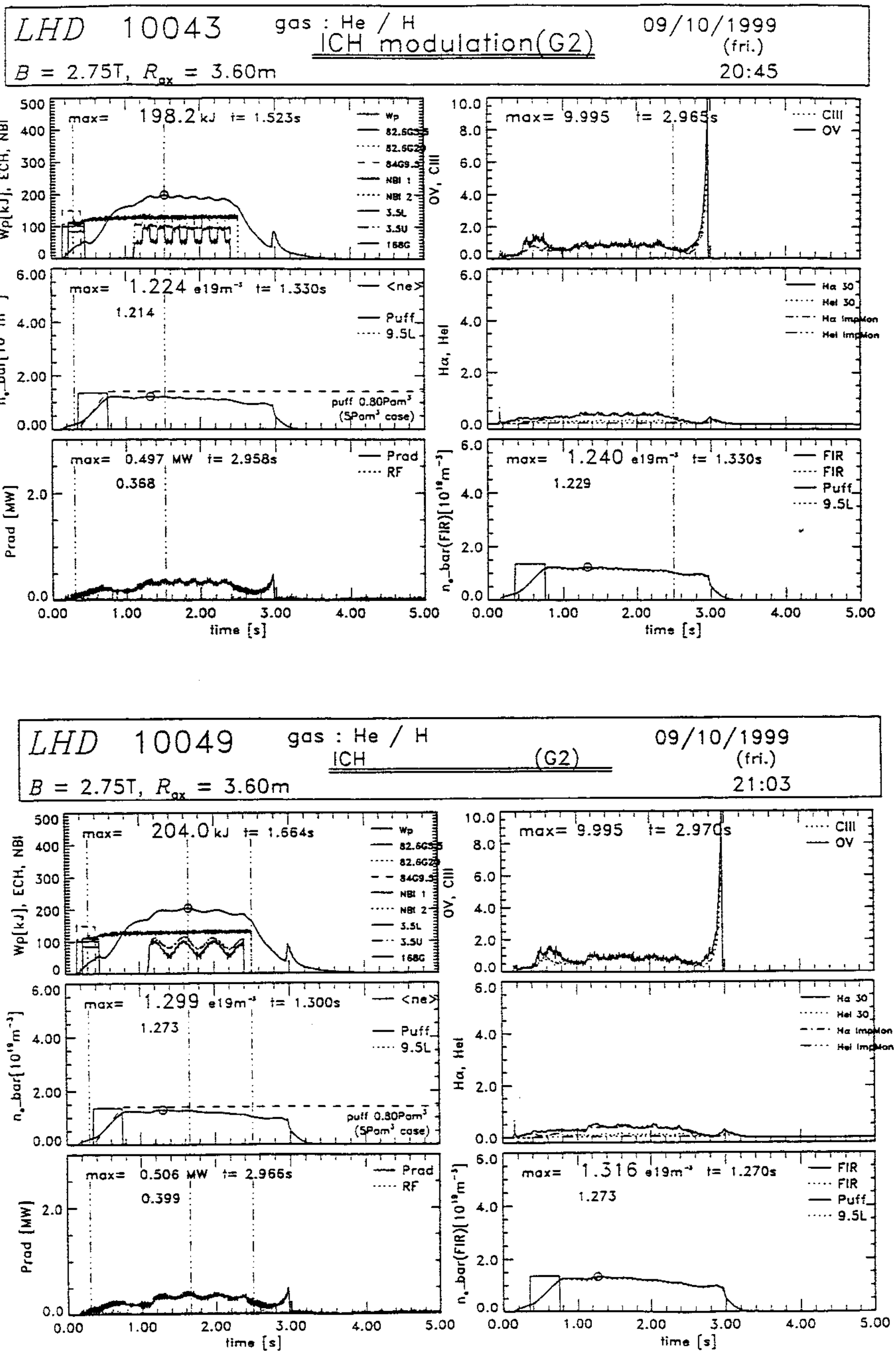
LHD 10043
gas : He / H
ICH modulation(G2)
09/10/1999
(fri.)
20:45
B = 2.75T, Rax = 3.60m
max= 198.2 kJ t= 1.523s
Wp[kJ], ECH, NBI
max= 9.995 t= 2.965s
CIII
OV
OV, CIII
max= 1.224 e19m-3 t= 1.330s
1.214
<ne>
Puff
9.5L
puff 0.80Pam3
(5Pam3 case)
ne_bar[10^19 m^-3]
Hα 30
HeI 30
Hα ImpMon
HeI ImpMon
Hα, HeI
max= 0.497 MW t= 2.958s
0.368
Prad
RF
Prad [MW]
max= 1.240 e19m-3 t= 1.330s
1.229
FIR
FIR
Puff
9.5L
ne_bar(FIR)[10^19 m^-3]
time [s]
time [s]
LHD 10049
gas : He / H
ICH (G2)
09/10/1999
(fri.)
21:03
B = 2.75T, Rax = 3.60m
max= 204.0 kJ t= 1.664s
Wp[kJ], ECH, NBI
max= 9.995 t= 2.970s
CIII
OV
OV, CIII
max= 1.299 e19m-3 t= 1.300s
1.273
<ne>
Puff
9.5L
puff 0.80Pam3
(5Pam3 case)
ne_bar[10^19 m^-3]
Hα 30
HeI 30
Hα ImpMon
HeI ImpMon
Hα, HeI
max= 0.506 MW t= 2.966s
0.399
Prad
RF
Prad [MW]
max= 1.316 e19m-3 t= 1.270s
1.273
FIR
FIR
Puff
9.5L
ne_bar(FIR)[10^19 m^-3]
time [s]
time [s]

Fig.28

Publication List of NIFS-TECH Series

NIFS-TECH-1 H. Bolt and A. Miyahara,
Runaway–Electron –Materials Interaction Studies ; Mar. 1990

NIFS-TECH-2 S. Tanahashi and S. Yamada,
Dynamic Analysis of Compact Helical System Power Supply and Designs of Its Upgrade; Sep. 1991

NIFS-TECH-3 J. Fujita, K. Kawahata, S. Okajima, A. Mase, T. Suzuki, R. Kuwano, K. Mizuno, T. Nozokido, J.J.Chang and C.M.Mann,
Development of High Performance Schottky Barrier Diode and its Application to Plasma Diagnostics; Oct. 1993 (in Japanese)

NIFS-TECH-4 K.V. Khlopenkov, S. Sudo, V.Yu. Sergeev,
Operation of the Lithium Pellet Injector; May 1996

NIFS-TECH-5 Nakanishi, H., Kojima, M. and Hidekuma, S.,
Distributed Processing and Network of Data Acquisition and Diagnostics Control for Large Helical Device (LHD); Nov. 1997

NIFS-TECH-6 Kojima, M., Nakanishi, H. and Hidekuma, S.,
Object-Oriented Design for LHD Data Acquisition Using Client-Server Model; Nov. 1997

NIFS-TECH-7 B.N. Wan, M. Goto and S. Morita,
Analysis of Visisble Spectral Lines in LHD Helium Discharge;June 1999

NIFS-TECH-8 Y. Zhao, Y. Torii, T. Mutoh, R. Kumazawa, F. Shimpo, T. Seki, K. Saito, G. Nomura and T. Watari,
ICRF Waveform Controlling; Dec. 1999