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ELECTRONIC 4-WHEEL DRIVE CONTROL DEVICE

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16. Abstract  This invention discusses a drive control device which controls the excess torque arising from the difference in revolutions between the front and rear wheels generated by the turning motion of a vehicle. The invention specifically relates to an electronic 4-wheel drive control device. This invention reduces the internal rotation torque generated during operation of the 4WD vehicle.					
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ELECTRONIC 4-WHEEL DRIVE CONTROL DEVICE

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(54) Electronic 4-Wheel Drive Control Device

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**Detailed Description:**

**Subject of Invention: Electronic 4-Wheel Drive Control Device**

**Scope of Patent Request**

1. The front wheel drive shaft is directly coupled to the rear drive shaft by means of a gear.

An electronic 4-wheel drive control device whose clutch is attached to one part of the aforementioned rear-wheel drive shaft is provided with: a Torque Sensor #1 which senses the drive torque associated with the aforementioned front-wheel drive shaft; a Torque Sensor #2 which senses the drive torque associated with the aforementioned rear wheel drive shaft; a Revolution Count Sensor (RPM Sensor) #1 which senses the revolution count of the aforementioned front-wheel drive shaft, and a Revolution Count Sensor that senses the revolution count of the aforementioned rear-wheel drive shaft.

An electronic 4-wheel drive control device which has the unique feature that enables it, by means of a microcomputer, to change the engagement of the aforementioned clutch to insure that the ratio of the aforementioned torque sensors remains constant.

**Detailed Explanation of the Invention**

This invention deals with a drive control device which controls the excess torque arising from the difference in revolution between the front and rear wheels generated by the turning motion of the vehicle. The invention specifically relates to an electronic 4-wheel drive control device that controls the excess torque arising from differences in revolution between front and rear wheels of a 4-wheel drive.

In recent years, the use to which automobiles are being put has broadened considerably. Along with this, the trend has been for

the varieties of automobiles to proliferate, with the result that numerous types of vehicles are being made today. The 4-wheel drive (abbreviated henceforth as 4WD) is one example of this trend. The 4WD is basking in the limelight in foreign countries.

Generally, the 4WD can be divided into two types: the directly coupled 4WD and the "full-time" 4WD. In particular, the directly coupled 4WD is being widely used because of its superior mobility over road conditions which make driving slippery, such as irregular surfaces, snow covered roads, and quagmire; and its powerful drivability over extremely poor roads and rocky areas. However, the directly coupled 4WD has disadvantages as follows: In a 4WD vehicle turn, a difference in revolution is generated between the front and rear wheels during the vehicle's turning motion, causing excessive torque in the power transmission system. This leads to forced slip of the front and rear tires; or causes abnormal friction wear of the tires, and/or overloads on the drive system, and/or deterioration of stability in high speed driving, oversteering (snaking), abnormal braking upon the vehicle body, and the so-called "tight corner braking" phenomenon.

Furthermore, since the 4WD vehicle is now being used as multi-purpose vehicles, it has become absolutely necessary not only to improve uneven road surfaces, but upgrade the ordinary paved surfaces. Further, there is increasing demand for improved fuel economy. /138

In general, the turning radius of the wheels of any vehicle during a turn can be expressed as shown in Figure 1. Designating the vehicle's wheelbase as  $L$ , tread (sic) as  $t$ , and turn radius as  $R$ , the turn radius of each wheel can be represented by the following equations:

Right front wheel turn radius 20:	$\sqrt{R^2 + L^2}$
Left front wheel turn radius 21:	$\sqrt{(R+t)^2 + L^2}$
Right rear wheel turn radius 22:	$R$
Left rear wheel turn radius 23:	$R + L$

ORIGINAL TEXT  
OF POOR QUALITY

Taking the turn angle of the vehicle as  $\theta$ , the travel distance of each of the wheels can be expressed by the following equations:

$$\begin{aligned} \sqrt{R^2 + L^2 \sin^2 \theta} \cdot \theta \\ \sqrt{R^2 + L^2 \cos^2 \theta} \cdot \theta \\ R \cdot \theta \\ (R \pm L \sin \theta) \cdot \theta \end{aligned}$$

Thus, each of the wheels travels a different distance.

During the turn, the front wheel axle makes an angular turn of  $\sqrt{(R \pm \frac{L}{2} \sin \theta)^2 + L^2 \cos^2 \theta} \cdot \theta$  and the rear wheel axle  $\sqrt{(R \pm \frac{L}{2} \cos \theta)^2 + L^2 \sin^2 \theta} \cdot \theta$ . However, since in reality the front wheel axis and the rear wheel axis are coupled, the resulting difference in the number of revolutions causes a torsion of the drive system and an internal torque is generated. This torque is termed "internal rotation".

Designating the engine torque as  $T$ , and speed reduction ratio of the gear box as  $i$ , the gear box torque is expressed as

$$T_g = iT \quad (1)$$

On the other hand, designating the distribution ratio of the power to the front and rear wheels as  $k$ , the front wheel torque  $T_f$ , and the rear wheel torque  $T_r$  are expressed as:

$$T_f = kT_g = k iT \quad (2)$$

$$T_r = (1-k)T_g = (1-k) iT \quad (3)$$

This is the ideal torque distribution for a 4WD; but if a revolution count difference occurs between the front and rear wheels by whatever reason as discussed above, a torque is generated between the front and rear wheels. Now, if we relate the torque change, or the internal rotation, resulting from the difference in the revolution count between the front and rear wheels, Equations (2) and (3) become:

$$\begin{aligned} T_f' &= k iT_g + T_i = (k iT_g + T_i) \\ T_r' &= (1-k) iT_g - T_i = ((1-k) iT_g - T_i) \end{aligned} \quad (4)$$

$$(5)$$

where (illegible) represents the loss torque, based on tire slippage. As shown in Figure 2, a tendency is seen toward a simple increase with respect to the input torque from the tire(s).

Since normally the revolution count of the rear wheel is small compared with the front wheel, Equations (4) and (5) become:

$$T_1 = k(T_1 + T_2) \quad (6)$$

(6)

$$T_1 = (1-k) T_1 + T_2 = (1-k) T_1 + T_2 \quad (7)$$

(7)

Therefore, the 4WD that in this fashion allows an internal rotation torque to be generated is characterized by disadvantages such as adverse effects on the engine operation, loss of torque, and declining fuel efficiency.

The objective of this invention is to provide a 4 WD control device capable of reducing the internal rotation torque which is produced during operation of a 4WD vehicle.

Below is explained an example of implementing this invention.

Figure 3 describes one implementation example of this invention. In the figure, the numbers indicate components as follows:

101--engine; 102--gearbox; 103--gear; 104--gear coupling front and rear wheels; 105--electromagnetic clutch; 106--revolution count sensor; 107--torque sensor; 108--front wheel drive shaft; 109--differential device; 110--control device; 111--torque sensor; 112--revolution count sensor; 113--rear wheel drive shaft; 114--differential device; 116--transmission case; 117--front wheels; 118--rear wheels.

At this moment, the output power of the engine 101 is reduced by the gear box 102, transmitted by gear 103 to the front wheel drive shaft 108; thence, through the differential device 109 (abbreviated henceforth as diff) and drives the front wheels 117 and 117a. The aforementioned front wheel drive shaft 108 is coupled to the rear wheel drive shaft 113 by the front-rear coupling gear 104; therefore, one portion of the engine torque transmitted to the



aforementioned front wheel drive shaft 108 is transmitted to the aforementioned rear wheel drive shaft 113, and drives the rear wheels 118 and 118a via the diff 114.

Furthermore, the electromagnetic clutch 105 is attached to the aforementioned rear wheel drive shaft 113. This clutch 105 receives the electrical current supplied by the control circuit 110, makes the proper engagement, and controls the torque that is added to the aforementioned rear wheel drive shaft.

The aforementioned control circuit 110 is structured to receive the power output signal from the revolution count sensor 106 and torque sensor 107 that senses the revolution count and torque of the aforementioned front wheel drive shaft 108. It is further structured to receive the output signal from the revolution count sensor 112 and torque sensor 111 that senses the revolution count and torque of the aforementioned rear wheel drive shaft 113.

Figure 4 provides details of the control circuit 110 shown schematically in Figure 3.

As shown in Figure 4, a Terminal A and a Terminal B are established at the I/O board 148, and processing circuits 144, 145, 146, and 147 are established. The system is structured to receive outputs on the brake signal from Terminal A and clutch temperature signal from Terminal B. There are also established a Terminal C to processing circuit 144, a Terminal D to circuit 145, a Terminal E to circuit 146 and a Terminal F to circuit 147. The terminals are structured to accommodate inputs as follows:

- Terminal C, front wheel revolution count signals
- Terminal D, rear wheel revolution count signals
- Terminal E, front wheel torque signals
- Terminal F, rear wheel torque signals.

To the I/O board, 148 are connected MPU 141, ROM 142 and RAM 143 by means of buslines. To the I/O board, 148 is also attached to a clutch drive circuit 150.

Since it is structured in this way, the front wheel revolution count signal is converted to collateral data via the processing circuits 144, 145, 146, and 147, respectively.

The collateral data, converted, is then input to the I/O board (2 PIA) 148. Other than this, a brake signal that discerns whether or not the vehicle driver is stepping on the brake pedal, and a clutch temperature signal that notifies any temperature rise from heating of the aforementioned electromagnetic clutch 105 are input to the I/O board 148 from Terminal A and Terminal B.

The MPU 141, ROM 142 and RAM 143 are connected to the I/O board 148 via a data busline. This I/O 148 contains 2 PIA. To Terminal PA of PIA 1 are input the aforementioned front wheel revolution count signal which has been collaterally signal processed; similarly, to Terminal PB of PIA (sic) is input the aforementioned rear wheel revolution count signal; to the Terinal PA of PIA 2 is input the aforementioned front wheel torque signal; and to the Terminal PB of PIA 2 is input the aforementioned rear wheel torque signal.

Also to Terminal PB7 of PIA 2 is connected a clutch drive circuit 150 which drives the clutch by output from Terminal PB7 of PIA 2. Also to the Terminals CA1 and CA2 of PIA 1 are input the brake signal and the clutch temperature signal.

Figures 5(A) and (B) show the control flow chart from the diagram of the control circuit 110 shown in Figure 4. In other words, what is shown is the flow chart of the exciter current from the coil of the ele-tromagnetic clutch 105 conducted in the control circuit 110.

Figure 5(A) shows the MAIN ROUTINE. In Step 200, the I/O board 148's PIA 1 and PIA 2 INITIALIZE takes place. By performing the INITIALIZE, the following are made possible: the break-in processing of the brake signal and clutch temperature signal; the input of the front wheel revolution count signal, rear wheel revolution count

signal, front wheel torque signal, and rear wheel torque signal; and the output to clutch drive circuit 150.

By performing INITIALIZE, the subroutine is implemented in Step 201. In other words, in the subroutine READ pia, the processing takes place as shown in Figure 5(B). In Step 300, the aforementioned front wheel revolution count signal is input by loading PIA 1 ORB to AccB. Next, in Step 302, the front-rear wheel difference, in other words, the values of AccA, AccB are obtained, and this difference value is taken as the value of AccA. In Step 303, it is determined whether or not this value of AccA exceeds the fixed value MAR. The difference is obtained and the decision is made in Step 304. If the decision is that the fixed value has been exceeded, then in Step 305, the value that determines the ON-DUTY spread of the clutch drive pulse takes the memory value as the maximum value (#FF), and assuming the ON-DUTY of the pulse of the clutch drive electrical current to be 100%, the clutch is completely engaged.

Normally, the (illegible) of the revolution count of the four tire wheels practically never appear, but when the vehicle is making a tight corner turn, a difference in revolution count is generated in all wheels (the front drive shaft and rear drive shaft). This difference in the revolution count of the front and rear wheels increases with smaller vehicle turn radius, but since there is a limit to the least turn radius of the vehicle, there is also a limit to the difference in the revolution count of the front and rear wheels. In other words, as long as the vehicle is running under normal conditions, the difference in revolution count of the front and rear wheels will remain within fixed bounds.

On the other hand, when the 4-wheel drive vehicle is run over sandy soil, snow cover or quagmire, there are occasions when one or more of the wheels may lose its drive power and spin freely.

In these cases, the drive power of the entire vehicle is disturbed, and the vehicle will lose the powerful drive power which is the unique feature of the 4WD vehicle.

That which detects this type of condition is in fact the difference derived from the aforementioned revolution count, and is the value of the aforementioned MAR, in other words, when the revolution count difference exceeds a pre-specified count (e.g., 50 rpm) (sic), and the ON-DUTY pulse of the aforementioned electromagnetic clutch drive current is taken as 100%; the electromagnetic clutch is completely engaged; and the aforementioned front and rear drive shafts 108 and 103 are completely coupled, the single wheel spinning is prevented.

If the AccA from Step 302 is less than the MAR, in other words, if the difference of the revolution count between the front and rear wheels falls within pre-determined fixed bounds (values), we proceed to Step 304 where the next calculation is performed.

Here, the front wheel torque (the torque load on the aforementioned front wheel drive shaft 108), and the rear wheel torque (the torque load on the aforementioned rear wheel drive shaft 113) generated by the previously shown internal rotation torque are expressed as in Equations (6) and (7). If at this time we fix the ratio of the aforementioned front wheel torque  $T'_f$  to the rear wheel torque,  $T'_r$ , the equations become:

$$T'_f : T'_r = K : (1 - K) \quad (8)$$

and aligned with (6) and (7), becomes:

$$T_t = 0$$

Therefore, it becomes clear that by maintaining a fixed ratio between the aforementioned front wheel torque  $T'_f$  and the rear wheel torque  $T'_r$ , the internal rotation torque can be obliterated.

We now assume that the aforementioned engine torque allocation ratio to be 1:2, and attempt to transmit equivalent torques to the front and rear wheels. Thence, by setting  $T'_f = T'_r$ , the internal rotation torque can be obliterated.

In Figure 5(b)'s Steps 306, 307 and 308, the difference between the front wheel torque and the rear wheel torque is computed. Thus, in Step 306, the aforementioned front wheel torque signal is input by loading PIA 2 ORA into AccA. In Step 307, the aforementioned rear wheel torque signal is input by loading PIA 2 ORB into AccB. Thence, in Step 308, the difference between the front wheel and rear wheel torques is computed through the front-rear wheel torque difference AccA - AccB operational instruction; then in Step 309 we determine whether or not the difference exceeds (0).

If in Step 309 it is determined that the front wheel torque and the rear wheel torque are equal, the operation is stopped and will proceed to RETURN. If, on the other hand, in Step 309, it is determined that the torques are not equal, we proceed to Step 310. We will establish the value of SEQ that will change the ON-DUTY spread of the pulse that controls the aforementioned electromagnetic clutch drive electrical current.

In case the rear wheel torque is greater than the front wheel torque, SEQ will assume a plus (greater than zero) value; and if the front wheel torque is greater than the rear wheel torque, SEQ will assume a minus less than zero value, but their absolute values increase as the difference between the front and rear wheel torques increases.

After the above PROGRAM is completed, we RETURN to MAIN ROUTINE. We next proceed to Step 202 where we output a 1 to the PIA 2 ORA 7 bit, and put the aforementioned electromagnetic clutch drive circuit 150 on ON. In Step 203, by routing into loop only the value established at SEQ, determine the ON-DUTY time duration. The revolution count that was routed into LOOP is stored in AccA. Further in Step 204, the aforementioned electromagnetic clutch drive circuit 150 is placed on OFF by making the PIA 2 ORA 7 bit a 0. In Step 205,

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the time duration of DUTY OFF is determined by routing the (FF-(SEQ)) loop.

In this fashion, as all the PROGRAM is completed, we return to Step 201, and start the PROGRAM again.

The subroutine TIMER at Step 203 and Step 205 are timers utilized in the software.

Figure 5(c) shows the INTERRUPT processing. When an INTERRUPT signal is input to the aforementioned PIA 1 CA 1 and PIA 1 CA 2, in other words, when the aforementioned brake signal and the aforementioned clutch temperature signal shifts from an "H" condition to an "L" condition, the INTERRUPT processing is done. Since under the conditions when the INTERRUPT signal is input, the aforementioned electromagnetic clutch 105 must be completely engaged, the aforementioned electromagnetic clutch drive circuit 210 must be on the ON condition. It follows that the aforementioned electromagnetic clutch drive circuit 210 is placed on ON through Step 401. In Step 402, the internal condition which underwent change by INTERRUPT is returned, and placed on RETURN; then INTERRUPT is restored.

In the program followed in the above manner, as shown in Figure 6, the clutch drive circuit input electrical signal is made to change.

Figure 7 shows the (illegible) condition within the transmission case of the electromagnetic clutch 105 used in this invention. That is to say, the torque from the front wheel drive shaft 266 (108 in Figure 3) is transmitted through the gear 254 and 257 to the OUTER DRIVER 264 and thence to multiple OUTER DISKS.

When the exciter current is supplied to the coil 259, the magnetic flux flows through the YOKE 258, the upper part of the INNER DRIVER 260, the OUTER DISK, the upper part of the INNER DISC, the ARMATURE 261, OUTER DISK 262, the lower part of the INNER DISK 260; the INNER DISK 263 and OUTER DISK 262 are connected, and the power imprinted upon the OUTER DISK is transmitted to the INNER DISK.

The power transmitted to the INNER DISK is further transmitted to the INNER DRIVER SPLINE 260a and transmitted to the rear wheel drive shaft 255.

According to this implementation example, having this type of structure whereby the internal rotation torque is eliminated, the drivability on a high  $\mu$  road typified by dry paved road conditions, can be improved. Again, according to this implementation example, by restricting the revolution count of the front and rear wheels, the drivability on a low  $\mu$  road, typified by snow cover or sandy soil (the unique feature of the 4 wheel drive vehicle) can be improved. Also by improving these drivability characteristics, according to this implementation example, the operation of 4WD has been simplified, allowing any person to drive easily.

As explained above, this invention enables the reduction of internal rotation torque generated during operation of the 4WD vehicle.

#### Simple Explanation of the Figures.

Figure 1 shows the turn radius for each of the wheels during turning motion of the vehicle.

Figure 2 shows the characteristics of the loss torque input torque.

Figure 3 is a system diagram showing the implementation example for this investigation.

Figure 4 is the control circuit diagram for the system shown in Figure 3.

Figure 5 (A) shows the main processing flow chart of the control circuit shown in Figure 4.

Figure 5B shows the subroutines for Figure 5(A)

Figure 5(C) shows the INTERRUPT processing flow.

Figure 6 is the clutch drive circuit input voltage  
(illegible) diagram .

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Figure 7 is the detailed diagram of the electromagnetic  
clutch diagram of Figure 3.

105 is the electromagnetic clutch; 106 is the revolution count  
sensor; 107 is the torque sensor.

Representative: Attorney TAKAHASHI Akio /SEAL/



A- Figure 1

### B- Direction of Turn

C- Figure 2

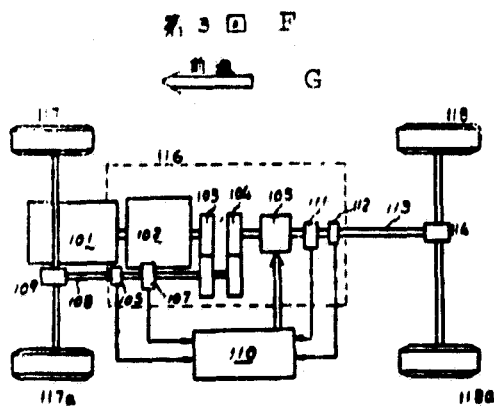
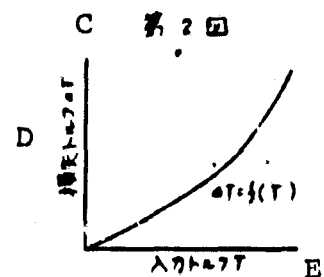
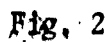
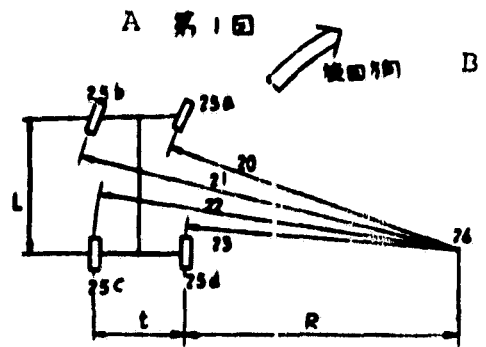
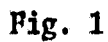
D- Loss Torque

### E- Input Torque

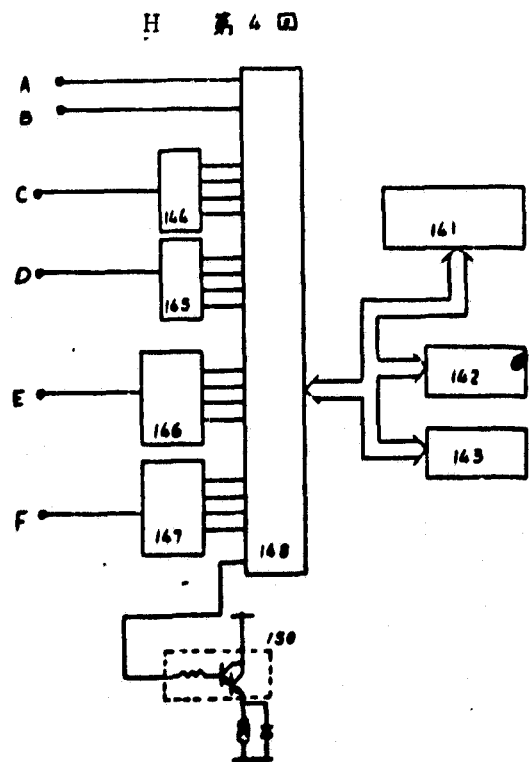
F- Figure 3

G- Forward Motion

**E** Figure 4



**Fig. 3**



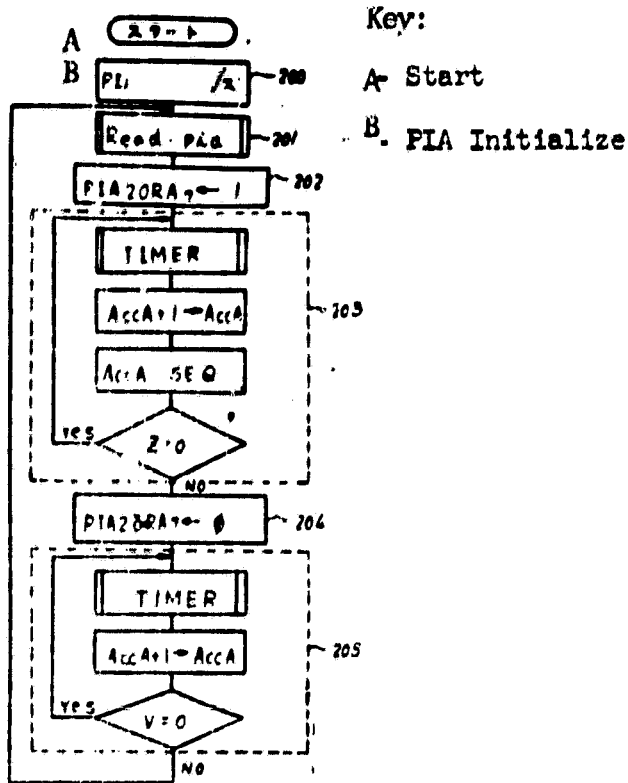


Fig. 5(A)

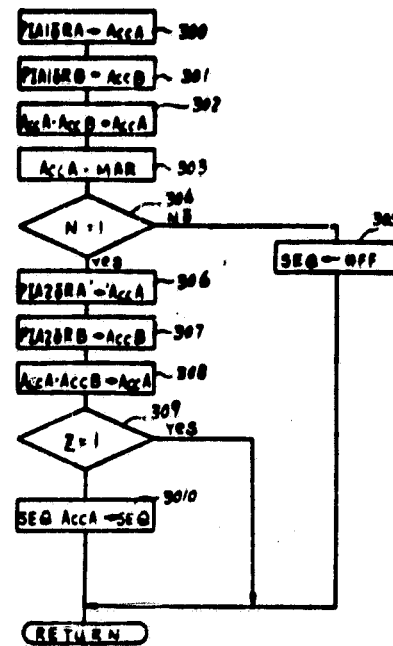


Fig. 5(B)

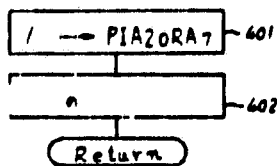


Fig. 5(C)

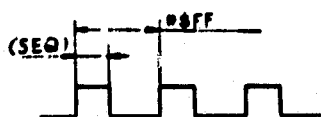


Fig. 6

F- PIA Internal Processor

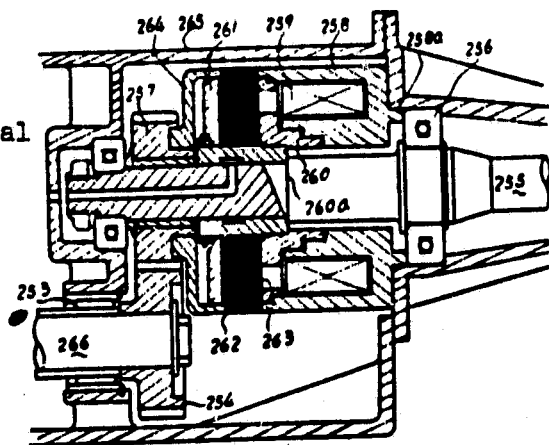


Fig. 7