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DIGITAL TELEMETERING EQUIPMENT FOR WATER FILTRATION STATIONS

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I. INTRODUCTION

Telemetering has been developed and utilized in the fields of commercial power, gas, and water supply.

Telemetering systems used for water supply facilities were comparatively smaller than those for power supply systems because the amount of data handled in this field was small and a one-to-one configuration was suitable for data related to the water sources (dams or reservoirs) and the various data concerning the water distribution system transmitted to a central water supply station. Consequently, the pulse frequency system, one of the analog frequency division systems, in this transmission system amply satisfied objectives.

However, with the recent high concentration of population in urban areas the water supply system has become more and more complicated and the need for rapid and accurate bulk data transmission has risen due to the necessity of complete linking among network stations and control.

The digital telemetering system is an effective means to attain these objectives. The purpose of the digital telmetering equipment delivered to the Tamagawa Network of the Tokyo Metropolitan Waterworks Bureau is to perform effective control over the water supply network, and is attracting much attention as being a new method to control water supply networks.

An outline of this system is described in the following because the authors believe that a great number of such systems will be employed in the future.

II. OUTLINE

The digital telemetering equipment installed for this water supply system supervises and controls data from the five water filtration stations of the Tokyo Metropolitan Waterworks Bureaus Tamagawa Network by connecting them to the main bureau through a repeating station located at one of the individual filtration stations. The data obtained at each transmitting station is sent to the repeating station in instantaneous value 3-digit and 6-digit integrated flow data through the private 0.9 ϕ 1p communications line of the Waterworks Bureau.

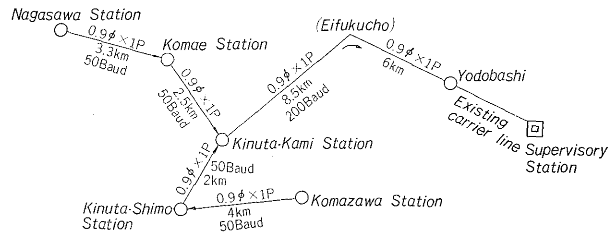
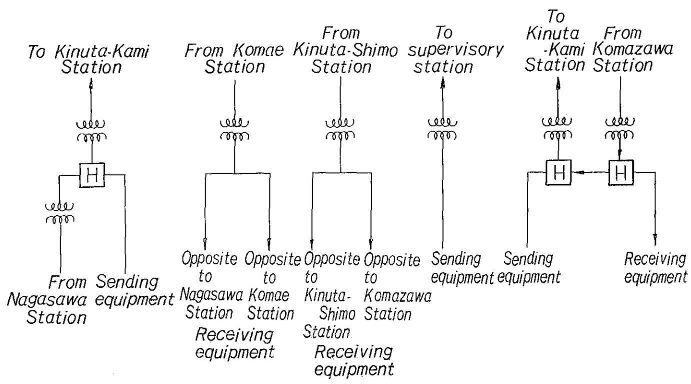


Fig. 1 Data transmission diagram



(a) Komae Station (b) Kinuta-Kami Station (c) Kinuta-Shimo Station

Fig. 2 Construction of repeating stations

The repeating station displays the transmitted digital data together with its own analog measurement data, on the meter panel. The simultaneous rearrangement of the received data measured at each station is then sent to the main bureau through the above private line.

The repeating systems used at the repeating station are the ac repeating system, which branches the FS modulated wave by hybrid coil, and the dc repeating system, in which the FS modulated wave is received, decoded, and then used as the input for the transmitting equipment. *Fig. 1* shows the entire system and *Fig. 2* the transmission composition at each repeating station.

This telemetering equipment (Type DTM-20) normally cyclically transmits a total of 18 different items of data (including eight integrated data items), such as water distribution quantity, integrated water distribution quantity, water level if distribution pool, etc.

One item of data is composed of 15 bits: 12 data bits, 2 flag bits, and 1 parity bit.

Frame synchronization is employed to increase transmission efficiency. Transmission speed is 50 bauds up to the end repeating station and 200 bauds, because of the increased amount of data from the repeating station to the main bureau. One frame length is approximately 6.3 seconds at 50 bauds, and 2.835 seconds (6-digit transmission) at 200 bauds.

The measured amounts obtained at each measuring station convert the current and air pressure signals generated by the transmitter, already existing or newly installed, at each measuring station into input signals for the corresponding telemetering equipment. The instantaneous analog value is treated in such a way that the 0～250 mv range corresponds to 0～999 by converting the current signal into a voltage signal by simultaneous scale factor computation.

This signal is converted into a 3-digit binary coded decimal by the a–d converter built into the telemetering equipment. The integrated amount is displayed by the cyclometer type integrating indicator at the site in the form of current signals from the transmitter. The signal, converted to transmit pulses by the pulse generating device with an integrating indicator, is received by the 6-digit counter in the telemetering equipment.

The complex scale factor calculation is performed by selecting a proper measuring range and pulse frequency. A 3 : 1 frequency divider is also used when the frequency of the voltage pulse is high.

Such scale factor computation nullifies the computation on the receiving side and simplifies the data processing that follows reception.

The integrating pulse counter mentioned above is equipped with a floating charge type power supply independent of the main unit transmitter as a precaution against instantaneous interruptions or complete failure of the main power supply. The batteries used in this independent power supply are smaller in size than conventional alkali batteries. Since there is no danger of generating noxious gases which are harmful to the equipment, betteris are accommodated in the telemeter rack.

In consideration of data processing, a manual integrated account correction device and counter reset device are mounted on the front of the rack.

III. SYSTEM CONFIGURATION

1. System Configuration

The following items must be included when employing a telemetering system.

(1) Transmission system

(2) Tranmission line

There are two kinds of transmission systems, the analog system and the digital system.

The analog pulse frequency system has been mostly used as the conventional network. This system uses the 0.3～3.5 kc audio frequency band divided into 170 cps segments. In other words, this system is a frequency division system in which one line can transmit up to a maximum of 18 channels of data.

Since one datum occupies one channel, this system is capable of continuously transmitting data timewise. However, it has the disadvantage that when the amount of data items to be transmitted is large, the number of transmission lines is increased.

In contrast to this, the digital system, although there is a scanning time delay inherent in the time division system, can increase the transmission efficiency by increasing the transmission speed.

Other features of the digital system are described in the following.

Table 1 **Transmitting Data**

Sending Equipment	Receiving Equipment	Frequency (cps)	Transmission Speed	Sampling Period (sec)	Transmission Quantity	Data Logging Method
Nagasawa Station	Kinuta-Kami Station	1105±35	50 Baud	6.3	3 (1)	
Komae Station	Kinuta-Kami Station	1445±35	50 Baud	6.3	2 (1)	Digital display at Kinuta-Kami Station
Komazawa Station	Kinuta-Kami Station	1105±35	50 Baud	6.3	7 (3)	Digital display at Kinuta-Kami Station
	Kinuta-Shimo Station	1105±35	50 Baud	6.3		Digital display at Kinuta-Shimo Station
Kinuta-Shimo Station	Kinuta-Kami Station	1445±35	50 Baud	6.3	4 (2)	Digital display at Kinuta-Kami Station
Kinuta-Kami Station	Supervisory Station	1200±100	200 Baud	2.835	18 (8)	Type print at supervisory station (including the 2 quantities measured at Kinuta-Kami Station)

Notes: 1) Display tubes are used for digital display at Kinuta-Shimo and Kinuta-Kami Stations.
The number of digits displayed is as follows.
Instanteneous value 3 digits
Integrated value 6 digits

2) In the colum for transmission quantity, the numeral within parentheses denotes integrated quantity contained in the transmission quantity.

1) Accuracy

Higher than the analog system since the data is pulse coded.

2) Line noise

No problems encountered, with respect to noise, since code checks, such as parity checks, are performed.

3) Transmission line

Capable of transmitting a large amount of data by using only one channel of the frequency band. However, scanning time delay is generated in this principle. This scanning time delay can be reduced by increasing the transmission speed.

4) Circuit and data processing

Although the circuit is complex, it is easily connected to other digital equipment.

5) Economy

Generally, the cost is low when the number of items to be transmitted is more than 7～8. However, cost increases when the number of repeating points is increased. The problem of economy must be examined by taking into account the system configuration, contents of the facility to be established in the future, and on-line real time control by a digital computer.

There are two kinds of transmission circuits, the dc system and the carrier system. Dc current transmission is mainly used in the former. This method is effectively used when the transmission distance is short and the amount of data small. The latter is commonly used when the system covers a long distance and the amount of data large.

There are two kinds of carrier systems, wire and radio. The wire system is divided into two: one using the private line of the Waterworks Bureau and the other the private line of the Nippon Telegraph and Telephone Public Corporation. Although the former has freedom in line formation, the latter has limitations, such as the transmission level must be below 0 dbm and the number of channels used must not exceed a certain specified number. The radio system also has limitations in respect to the usable frequency band and the fact that it is almost impossible to use more than one frequency.

Therefore, system configurations limited to the 1:n system to be described later. Moreover, the effect of city noise must be considered in the radio system.

The system configuration is classified into the following four kinds.

(1) 1 : 1 system

(2) 1 : n system

(3) Repeating system

(4) Combination of systems (2) and (3)

The 1 : 1 system consists of one control station and one controlled station.

The 1 : n system is a system in which n controlled stations are located radially around the control station. The control station calls up the controlled stations or receives the signals from the controlled stations by selecting them cyclically in sequence.

The repeating system is the system in which controlled stations are located in a straight line. It is easier for an intermediate station to perform branch reception or ac repeating to the control station if a private line is used.

System (4) is a combination of the 1 : n system and the repeating system.

The amount of data, number and geographical distribution of the filtration stations, past expansion, etc. have been considered in the telemetering equipment at the filtration stations of the Tamagawa Network. A digital transmission system by means of carrier transmission employing the private line of the Waterworks Bureau is used.

The system configuration is such that there is an intermediate repeating station. The transmission speed between the controlled stations and the repeating station is 50 bauds and the transmission speed between the repeating station and the supervisory station is 200 bauds.

2. Branch and Transfer of Data

Various data obtained at each water filtration substation is displayed, recorded or computed at its master station and simultaneously sent to the central configuration to be processed for system control.

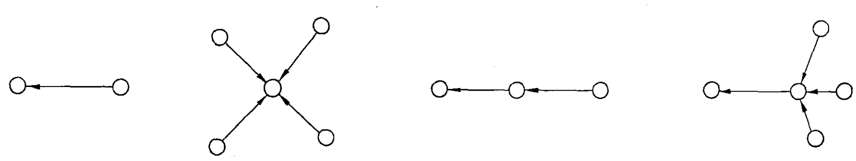
Since, in the future the system control will take a configuration that covers not only the data of its own system but also the data from a related system, the repeating and transfer of data will be more complicated and branched.

In the Tamagawa Network, as shown in the system diagram, data is handled as follows.

(1) The control station types out the data from each water filtration station.

(2) The Kinuta-Shimo station displays the digital data from the Komazawa station.

(3) The Kinuta-Kami station displays the digital data from the Komae, Komazawa, and Kinuta-Shimo stations.



(a) 1 : 1 system (b) 1 : n system (c) Repeating system (d) Combination system

Fig. 3 **System construction**

The data obtained at the Komazawa and Nagasawa stations is transferred to the Kinuta-Kami station by means of hybrid repeating at the Kinuta-Shimo and Komae stations, respectively. Transmission speed is 50 bauds.

On the other hand, the Kinuta-Kami station receives data from the Nagasawa, Komae, Kinuta-Shimo, and Komazawa stations, and digital by displays this data with simultaneous output of binary coded digital codes. These signals are used as the code input of the Kinuta-Kami station transmitter and are sent, together with the data obtained at the Kinuta-Kami station, to the control station. The transmission speed employed between the Kinuta-Kami station and the control station is 200 bauds to prevent the degradation of response caused by the increase in the amount of data.

The data from the Nagasawa, Komae, Komazawa, and Kinuta-Shimo stations is dc repeated at Kinuta-Kami. This system has the following advantages.

(1) Makes data logging at the control station easier.
(2) One direction receiving unit can be used at the control station.
(3) Complicated hybrid network at the Kinuta-Kami station can be omitted.

IV. MEASURING EQUIPMENT

The data measured at each water filtration substation is mainly related to distributed water flow, integrated distributed water flow, and pressure of the distributed water. The measured data is pneumato-electric and current-voltage converted, where there is an existing transmitter in the TELEPERM force balancing system and the ABGRIFF system, into specified signals.

The TELEPERM S-series instrument is used for dial registered display in measuring the integrated data and has pulse oscillating equipment for telemetering.

Moreover, the voltage pulse from the existing integrator is converted into the specified pulse by means of a converter that has a built-in frequency division circuit.

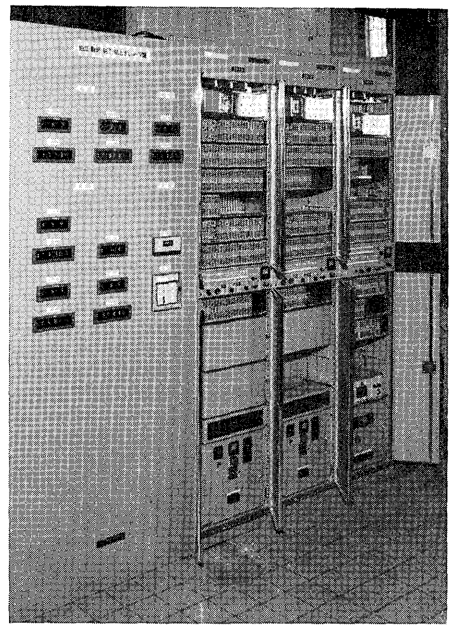


Fig. 5 Front view of panel at Kinuta-Kami Station

The pressure, together with the instantaneous flow of the water supply, is recorded on the two-pen recorder (Type S-ERM-2) at this station. The water supply pressure is measured and is displayed at the meter panel of each water filtration station.

The main specifications of transmitter and converter are as follows,

(1) Water flow transmitter
System: MMF-II TELEPERM balancing system
Accuracy: ±0.5%
Output: Dc 10～50 ma
Power supply: 100 vac, 50 cps

(2) Pressure transmitter, pneumato-electric converter
System: E-PTH (pressure), EPTI (pneumato-electric converter) TELEPERM ABGRIFF system

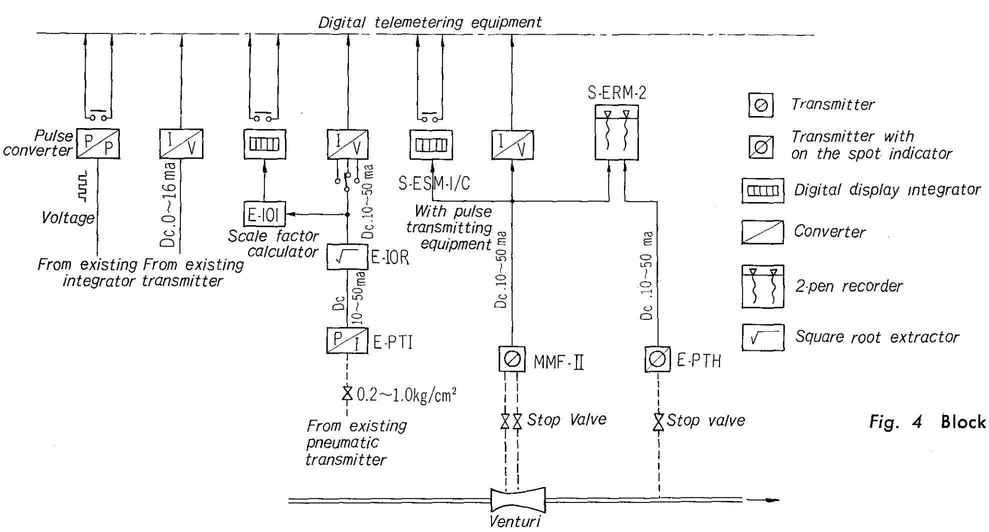


Fig. 4 Block diagram

Accuracy: ±0.5%
Output: Dc 10~50 ma
Power supply: 48 vdc

(3) Scale factor culculator
Input: Dc 10~50 ma or 0~16 ma
Output: Output corresponds to each measured value.

The sacle factor calculator is used to convert the dc signals, ranging from 10ma to 50 ma, into numerics at the rate of 0~250 mv / 0~999 for each measured full scale value.

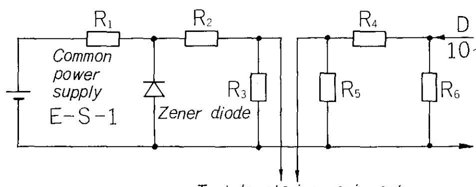


Fig. 6 Calculator of scale factor

(4) Continuous integrator
Type: S-ESM-I/C
Input: Dc 10~50 ma with pulse generator
Output: 100, 200, 250, 300, 400, 500, 600, 800, 1000 pulse/hr
Contact: 1a, ac 100 v, 0.3 amp

This integrator employs the principle of a dc motor whose rpm is proportional to the input voltage. A transistorized oscillator is used for pulse transmission. The pulse signal is generated by the ON-OFF operation of the relay each time the shielding plate, fitted to the integrating mechanism, shields the oscillator coil and stops oscillation and interrupts the flow of oscillating current.

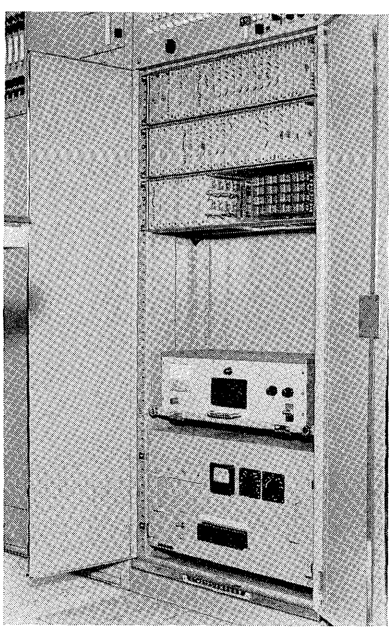


Fig. 7 Floating battery for integrated pulse counter

(5) Power source for power failure of pulse counter
Input: 100 vac, 50 cps
Output: 12 vdc or 24 v
Capacity: 0.5 amp or
once a minute 550 ma for one second
once five minutes 1.1 amp for one second
once an hour 1.65 amp for one second
Battery:
Furukawa column battery, Type S108 and S121
Nominal voltage 1.25 v
Mean capacity S108 5 amp-hr (10 hour rate)
S121 870 ma-hr (5 hour rate)
Dimensions and weight (single unit)
S108 Dimensions: 33.4ϕ × 39
Weight: Approx. 235 g
S121 Dimensions: 31.5ϕ × 28.2
Weight: Approx. 70 g

This battery has, different from the conventional open type battery, a complete closed construction and gas generated during charging is absorbed by the electrode plates. Since the battery is extremely small, it is contained, together with the floating charger, in the telemeter rack.

V. TYPE DTM-20 TELEMETERING EQUIPMENT

1. Kinds of Measured Items

The items required to be measured for information transfer are generally classified into the following forms.

This equipment can handle all.

1) Transmission input
(1) Analog input
Dc voltage given by the primary converters for instantaneous water flow, water level, and pressure.
(2) Code input
Codes given by water level, set values, etc.
(3) Pulse input
Input given in pulse numbers as the integrated water flow.

2) Reception output
(1) Analog output
Drives an indicator, recorder, etc., with dc voltage.
(2) Code output
Either decimal or binary coded decimal. This output is connected to a digital indicator, etc.

2. Code Transmission System

1) Code formation

Each word consists of a total of 15 bits; 12 data bits, 2 flag bits, and 1 parity bit. The number of bits for data is determined by the required accuracy. Usually a 3-digit binary coded decimal number, in other words, 12 bits, is sufficient. When more than 3 digits are needed, as in the case of integrated values, 2 words are used to transmit the data. The flag bits have many uses. For example, they are used

Table 2 **Data Table**

Station	Measured Value		Measuring System
	Kind of measurement	Measured range	
Nagasawa	Water supply quantity	0～20,000 0～16,000 m³/hr 0～14,000	Converts the existing air pressure 0.2～1.0kg/cm² into current, extracts the square root, then calculate the scale factor
	Water supply quantity integration	Switching	Integrator with pulse transmitter
	Water level of distributing pool	0.5～5 m	Pneumato-electric conversion, scale factor calculation
Komae	Water supply quantity	0～2000 m³/hr	Current transmission by flow transmitter of force balancing system, scale factor calculation
	Water supply quantity integration		Integrator with pulse transmitter (200 pulse/hr full scale)
	* Pressure	0～5 kg/cm²	Current transmission by TELEPERM pressure transmitter. Then 2-pen record together with quantity of flow
Komazawa	Water supply quantity 3	{0～8000m³/hr×1set {0～4000m³/hr×2sets	Calculation of the scale factor of the signal from the existing transmitter (dc 0～1 6ma)
	Water supply quantity integration 3		Pulse conversion of the existing pulse transmitting integator (25,600 pulse/hr)
	Water level of water supplying tower	0～20 m	Calculates the scale factor of the signal from the existing current transmitter (dc 0～16 ma)
Kinuta-Shimo	Water supply quantity 2	0～2000 m³/hr 0～4000 m³/hr	Current transmission by flow transmitter of force balancing system. Scale factor calculation.
	Water supply quantity integration 2		Integrator with pulse transmitter (200, 400 pulse/hr full scale)
	* Pressure	0～10 kg/cm²	Current transmission by TELEPERM pressure transmitter. 2-pen record together with quantity of flow
Kinuta-Kami	Water supply qunatity	0～10,000 m³/hr	Wame as the above (100 pulse/hr full scale)
	Water supply quantity integration		
	* Pressure	0～10 kg/cm²	

Note: Those marked ※ denotes analog record of the measuring station.

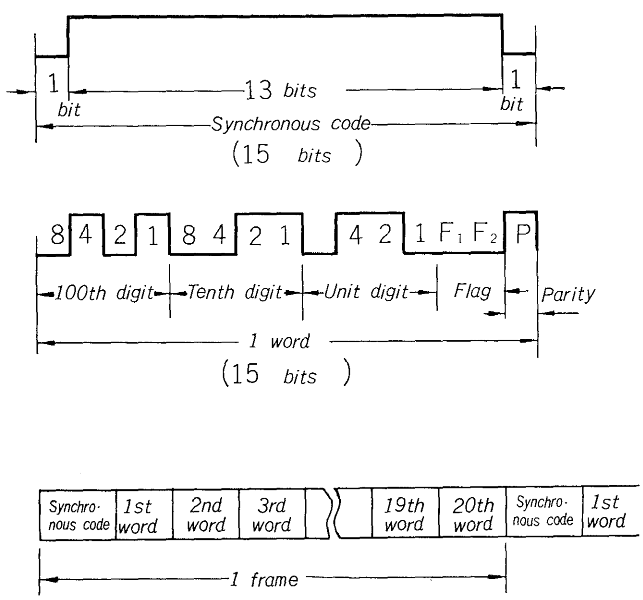


Fig. 8 Code construction

as the BUSY signal at the double brush switching time of the water level meter. One frame consists of 20 such words, and one word-length of the synchronizing signal precedes the frame.

2) Synchronizing system

Generally speaking, there are two synchronizing systems, the word sychronization in which each word has a synchronizing signal and frame synchronization in which one set of synchronizing signals are inserted into one frame.

In word synchronization, the transmission efficiency is decreased since it is necessary to add a synchronizing code and address code to each word.

For this reason the present equipment employs frame synchronization.

A long mark that covers 13 bits and has a space of one bit before and after is added as the synchronizing signal.

The transmission efficiency $E(f)$ of the equipment employing frame synchronization is represented by the following equation.

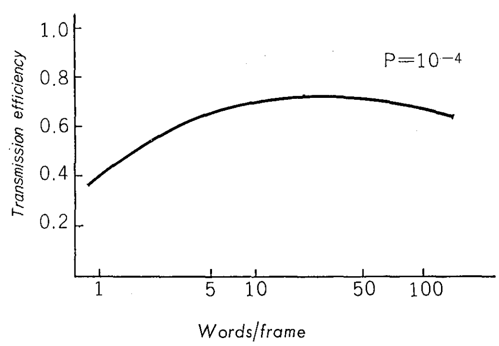


Fig. 9 **Transmission efficiency**

$$E(f)=\frac{T_0}{T}=\frac{\text{Net data transmission time of one frame}}{\text{Mean frame transmission time}}$$

where $T_0=n\cdot m\cdot\alpha$

$T=T_1+[E(x)+E(y)]\,T_1$

$T_1=(m+1)(n+1)\,\alpha$

m: Number of net bits per word

α: Length of one bit

T_1: Length of one frame

$E(x)$: Probability that the data will be lost by erroneous data bit

$E(y)$: Probability that the data will be lost by the loss of synchronizing code

P: Bit error rate

$$\therefore\quad E(f)=\frac{n\cdot m\cdot\alpha}{(m+1)(n+1)\,\alpha\,\{1+2n(m+1)P\}}$$

Fig. 9 shows this relationship. As can be seen in the drawing, the transmission efficiency is highest near the capacity of 20 when $P=10^{-4}$. Therefore, taking into account the installation space of the equipment, the capacity of this equipment is determined to be 20.

Independent synchronization is employed for bit synchronization. Highly accurate 8 kc crystal oscillators are installed in the transmitters and receivers, respectively, in such a way that on the receiving side the bit synchronizing circuit starts after the frame synchronizing code is separated. Thus, bit synchronization is accurately maintained up to the final bit of the frame.

3) Code check system

The contents of data should be transmitted correctly and securely. In practice, however, induction, noise, and instantaneous cutoff of the transmission line often cause the erroneous transmission of contents. To detect such an error, various kinds of code check systems have been devised.

A word by word parity check method is employed in this equipment, since the bit error rate of a line is generally $10^{-4}\sim10^{-6}$ and the data is transmitted cyclically.

4) Transmission speed

Transmission speeds of 50, 200, and 1200 bauds are in general use in various systems. These speeds are determined by the line used, transmission amount, sampling period (response or transmission time), etc. The smaller the sampling period, the better.

However, the amount of information from a measuring point is about 20 in the case of a water filtration station and usually contains no urgent data. However, a minimum time required for data collection and distribution, including the relay time, of less than a few seconds is desirable.

From the aforementioned conditions and the state of the existing transmission line, plus economy, a speed of 200 bauds was employed between the Kinuta-Kami station and the control station and 50 bauds for other lines.

Table 3 shows the relationship of the transmission time to code formation.

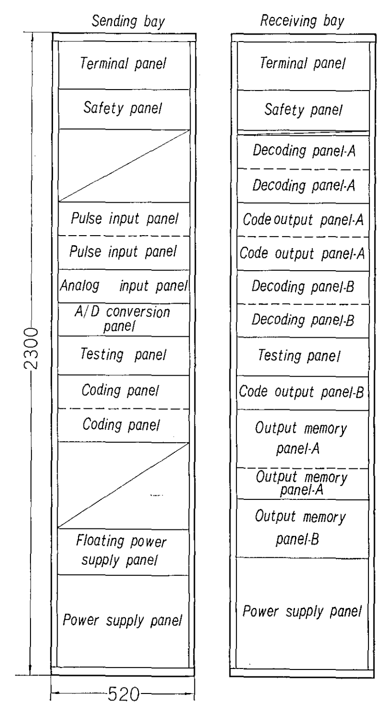


Fig. 10 **Bayface of DTM-20**

Table 3 **Sampling Time (3 number of digits)**

Transmission Quantity \ Transmission Speed	1200 Baud (sec)	600 Baud (sec)	200 Baud (sec)	50 Baud (sec)
20	(0.263)	(0.525)	1.575	6.3
50	0.638	1.275	(3.825)	(15.3)
100	1.263	2.525	(7.575)	(30.3)

3. Equipment Configuration

Both the transmitting and receiving equipment are mounted in standard steel communications racks 2300 mm high, 520 mm wide, and 225 mm deep.

Since the transmitting equipment is moduled into the analog input pannel, a-d conversion panel, code input panel, pulse input panel, and coding panel, these panels can be extended in a building block system according to the kind and capacity of the input. Similarly, the receiving equipment consists of the decoding panel, code output panel, and printer control panel.

Since the power supply panel is of the plug-in type and standardized printed circuit boards are used in the main circuit, maintenance and inspection are easy.

The receiving equipment is so designed that one rack can accommodate two-direction receiver.

4. Outline of Operation

1) Transmitting equipment

(1) Analog input panel and a-d conversion panel

Data, such as instantaneous water flow and water level, which is converted into 0~250 mv analog voltages by the primary converter before feeding to the transmitter, is converted further into digital codes by one a-d converter. For this purpose, a switching circuit is provided to sequentially convert each input into a digital code by means of time division. One shelf can contain up to eight analog input panels. (One shelf is needed for the a-d converter panel.)

(2) Pulse input panel

The pulse input, such as the integrated water supply, is integrated by the counter, and the integrated amount is transmitted. The integrated value is transmitted in two words when it is more than 3-digits.

A lightweight, small size column battery is used as the counter power supply. Since a floating battery system is employed, the contens are not lost even when the power fails. (Two 6-digit counters can be mounted on one shelf.)

(3) Code input panel

This panel transmits the digital inputs (such as the binary coded decimal input), switching them sequentially.

(4) Coding panel

The function of this circuit is to convert the measured value of the selected item by each input panel into a serial code and to sequentially transmit it.

The output of the 8kc oscillator is converted into 200 baud signals having a pulse width of 5ms at the pulse distribution circuit, then applied to the selection gate of the parallel-serial conversion circuit, where it is converted into a serial code bit by bit.

Since 15 pulse bits compose one word, +1 is added to the address distribution circuit every 15 bits and the input selection circuit is switched to the next item. As for the transmitted codes, the synchronizing code is scanned first, then the 1st word, 2nd word, and so on. When the 20th word has been scanned, the next data item is transmitted starting with the new synchronizing code. The transmisson time for one cycle is 20 words and the response is 1.575 ms (in the case of 200 bauds).

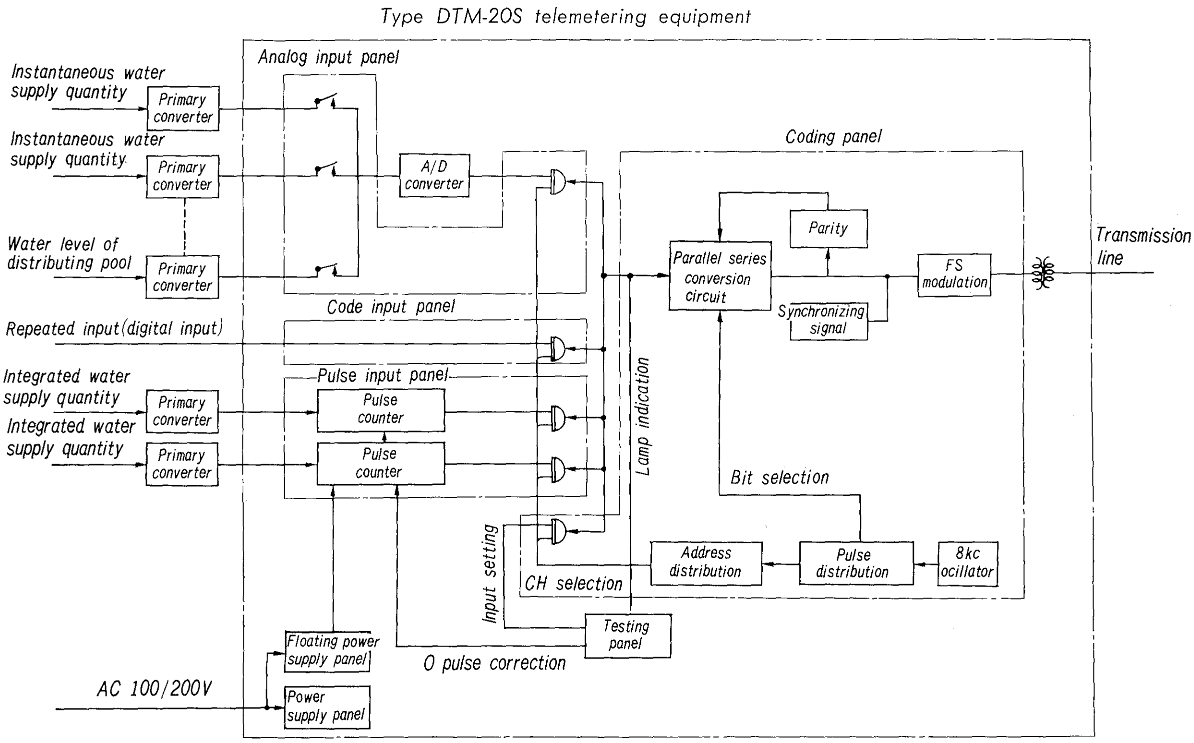


Fig. 11 Block diagram of equipment

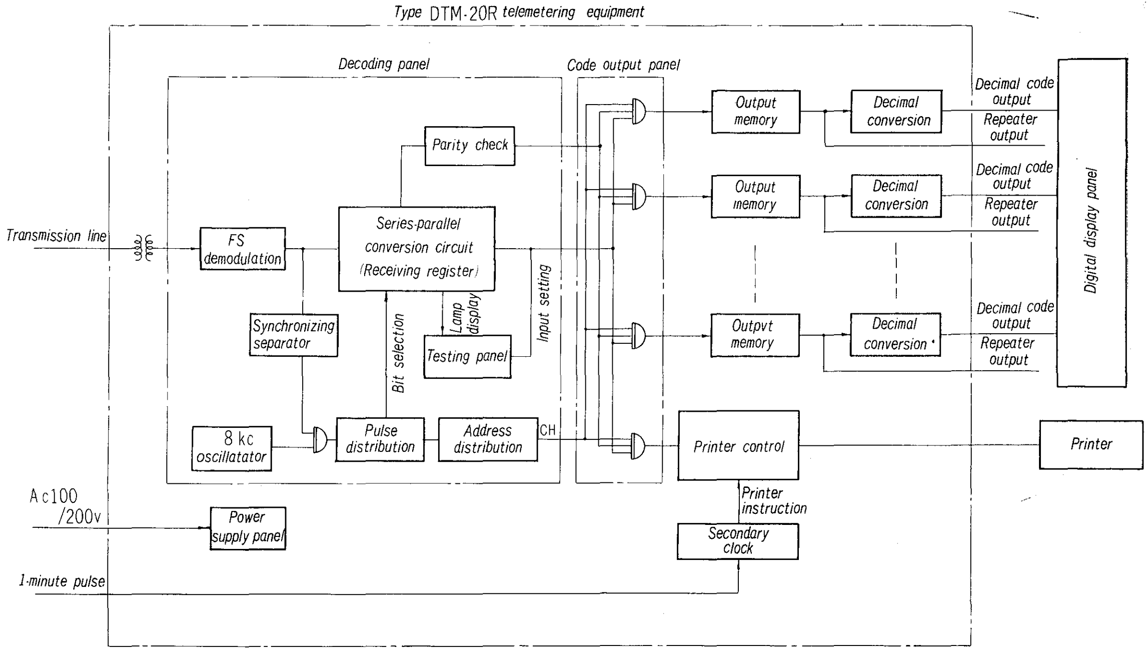


Fig. 12 **Block diagram of receiving equipment**

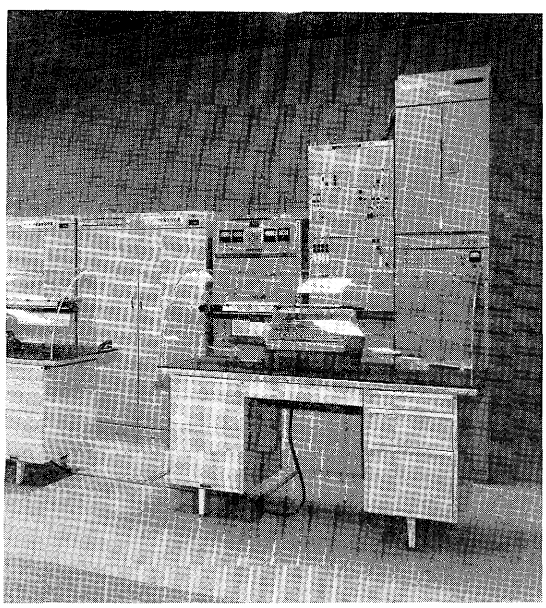


Fig. 13 **Receiving equipment (extreme right) and logging typewriter**

In order to avoid erroneous operation due to line noise, instantaneous cutoff, etc., each word has a parity bit to perform odd parity check.

2) Receiving equipment

(1) Decoder panel

This panel consists of the demodulation circuit that converts the FS signal into a pulse code, synchronizing separation circuit that detects the synchronizing code, each distributor that produces the bit and address codes, and receiving register that memorizes the received codes.

The demodulated code detects the synchronizing code having a pattern (a long mark of 13 bits) specified by the synchronizing separation circuit and starts the decoding circuit so that it will operate in synchronism with the received code. The received codes are written on the register sequentially and, if the result of the code check for one word is favorable, transfer the contents of the register to the output memory specified by the address code. If the result is unfavorable, the data is discarded without being transferred to an output memory, and the register maintains the prereceived contents until the next correct data is received. The decoding panel sends out an alarm signal when the results of successive code checks are unfavorable over a certain specified period.

(2) Code output pannel

This circuit is used to obtain the decimal digital signal in order to drive the display tube, lamps, etc. Two kinds of output memories, electronic memory, are used to memorize the received data in the register. They are selected according to application.

Binary coded decimal code output is produced at the repeating point to facilitate future connection to an electronic computer and transfer to other stations.

(3) Printer control panel

The function of this circuit is to type out the measured amount at a specified time. *Fig. 14* shows a block diagram.

The secondary clock operates on the one-minute pulses and, when the specified time arrives raises the start circuit to turn on the printer power supply. At the same time, it operates the address counter and prints the time and data according to the predetermined format.

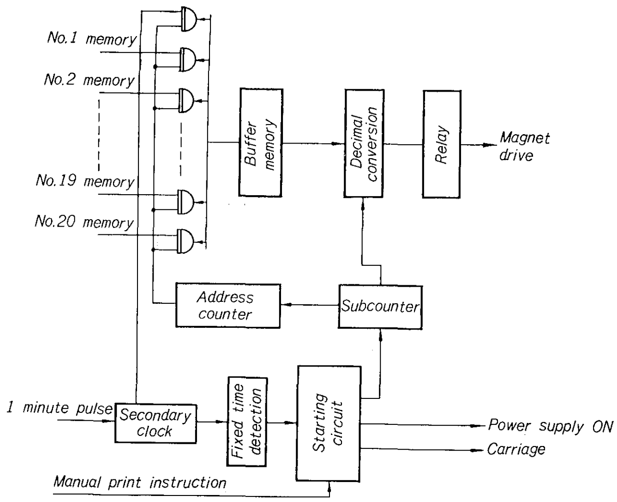


Fig. 14 **Block diagram of printer control**

It is possible to print out at any time by manual operation.

There is one more panel, besides those described above, the analog output panel. Although it has not been added to the receiving equipment at this time, it has the function of transferring the received data in the register to a memory, driving the transistorized switch of the a-d converter, and converting the data into dc voltages ranging from 0 v to +5 v.

3) Testing function

Both the transmitting and receiving equipment have the following test functions to facilitate inspection of circuit operation and maintenance.

(1) Equipped with display lamps capable of displaying each measured value by switching.

(2) Equipped with a setting button capable of writing in the data for each measured item by switching.

(3) Equipped with a built-in meter capable of measuring the analog input/output voltages.

5. A-d Converter

The analog-digital converter is a circuit used to convert the magnitude of the analog input (dc voltage ranging from 0 v to 250 mv) into digital magnitude (3 digit numerics ranging from 000~999). Many conversion systems can be considered, including the counting and the successive comparison types. This equipment is fully transistorized and employs the successive comparison type system.

In the successive comparison type conversion system, the input analog voltage and the voltage proportional to the digital magnitude set in the register are successively compared and the contents of the register changed until both are identical. *Fig. 15* is a block diagram of the a-d converter. The comparator compares the input voltage with the d-a converter output voltage and, when the d-a converter output is higher than the input voltage, generates a reset pulse.

The d-a converter circuit consists of a switch connected to each register, resistors that have a weight equivalent to the value on the register, and a standard battery.

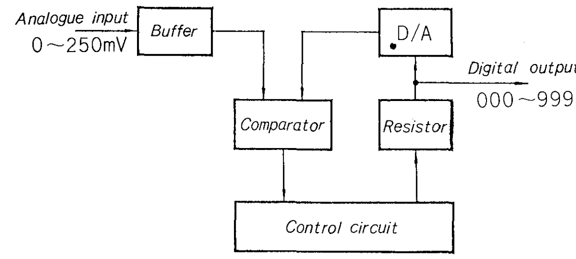


Fig. 15 **Block diagram of a-d converter**

Table 4 **Specifications of a-d conveter**

1	Input voltage	0~+250 mv (one side grounded)
2	Output format	000~999 (binary coded decimal 3 digits)
3	Nominal accuracy	±0.2%
4	Conversion time	14 ms/1 point (including the input switching time)
5	Input resistance	10 MΩ or more (for filter input)
6	Input filter characteristics	Dc component...100% pass (voltage) Ac 50 cps......0.4% pass (voltage)

Its function is to generate a dc voltage proportional to the contents of the register.

The control circuit is programmed so that conversion is completed in a minimum amount of time.

When a start signal arrives, the control circuit resets all the registers, then sets the register for 800. The d-a output becomes an analog voltage equivalent to 800 and is compared with the input votage. When the d-c output is higher than the input voltage, the register for 800 is reset. When the d-a output is lower than the input voltage, the register for 800 remains set. The register for 400 is then set and the d-a output is compared with the input voltage. In this way the d-a output and the input voltage are successively compared in descending order of weight and conversion completed by 12 steps. When comparison is completed the input votage equals the d-a converter output, and the digital numeric of the voltage, at this time, is set on the registers.

6. Miscellaneous

There is another element, the d-a converter which has not been supplied at this time. It will be described in the following for reference.

The digital-analog converter is a circuit which, contrary to the a-d converter, converts a transmitted digital numeric into analog magnitude to move the meter or recorder.

The d-a converter consists of the transistor switch connected to the output memory, resistor that has weight, and a standard voltage. It is designed to

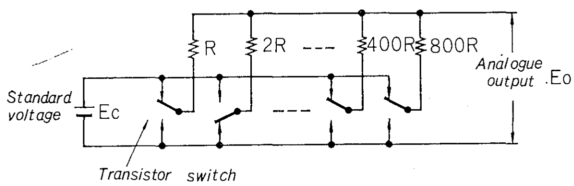


Fig. 16 D-a converter circuit

Table 5 **Specifications of d-a converter**

1	Input code	000~999 (binary coded decimal 3 digits)
2	Output voltage	0~+5 v (one side grounded)
3	Internal resistance	961 Ω
4	Allowable load	0 Ω~∞
5	Nominal accuracy	±0.1%
6	Conversion time	Generally negligible

produce an output voltage proportional to the output memory. Assume that the weighted resistor connected to the upper side by the transistor switch is r_{ui}, and that the resistor connected to the lower side is r_{dj} (*Fig. 16*). Then the output voltage E_0 is given by the following equation.

$$E_0 = E_c \cdot \frac{R_d}{R_u + R_d} = E_c \frac{\sum^{i} \frac{1}{r_{ui}}}{R_0}$$

where

$$\frac{1}{R_u} = \sum^{i} \frac{1}{r_{ui}}$$

$$\frac{1}{R_d} = \sum^{j} \frac{1}{r_{dj}}$$

$$\frac{1}{R_0} = \sum^{i} \frac{1}{r_{ui}} + \sum^{j} \frac{1}{r_{dj}}$$

On the other hand, the output impedance Z_0 becomes

$$Z_0 = \frac{1}{\frac{1}{R_u} + \frac{1}{R_d}} = R_0$$

Since the output impedance is constant all the time and since the output voltage E_0 is proportional to $\sum^{i} \frac{1}{r_{ui}}$, a dc voltage proportional to the memorized numeric can be obtained when a weighted resistor is selected according to the numeric of the output memory.

7. Features

1) Capable of transmitting 200 bauds

Because of the transmission line, transmission quantity, sampling period, etc., data is transmitted at a speed of 50 bauds up to the Kinuta-Kami station; then, because the quantity has increased, at a speed of 200 bauds up to the control station.

2) Capable of mass and multipurpose transmission

This system can transmit up to 20 quantities of analog data (such as the instantaneous flow and water level that has been converted into d-c voltage by the primary converter), digital quantities (code inputs of water level, set value, etc., and pulse input such as the flow integration), and contact signals.

Since the output side is digitized, numeric representation and tabulation by the printer can be directly performed.

Moreover, by connecting this system to a digital computer, such operations as control, supervision, sorting, and summarizing can be easily performed.

3) Employment of frame synchronization

The employment of frame synchronization in which one synchronizing code is inserted into entire words (one frame) increases transmission efficiency, and accelerates response. Independent synchronization is employed for bit synchronization.

4) High accuracy

In the conventional pulse frequency analog telemeter the all-around error, including that originating in the transmission line, reaches approximately 1~2%.

In the digital system, however, error is originated only in the transducer, a-d converter, and d-a converter. This permits the system to carry out highly accurate transmission.

5) Employment of building block system

Since the circuits of this equipment are separately modulized for input/output data and, since the building block system in which these modules are combined properly according to the quantity and kind of data is employed, this equipment is highly versatile.

VI. CONCLUSION

Digital telemetering equipment for water filtration facilities has been adopted in step with the increasing complexity of the water supply system. In addition to this new trend in water filtration facilities, the future should reveal retransmission of data and on-line control (including telecontrol) by electronic computer.

Our thanks go to the many people of the Tokyo Metropolitan Waterworks Bureau who have assisted us in the completion of this equipment.

Reference

(1) Y. Okamoto, H. Muramatsu, and I. Ono: Digital Telemetering Equipment for Electric Power System, *Fuji Electric Journal* Vol. 40, No. 5, (1967).