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NEW TELEMETERING DEVICE F SERIES

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I. GENERAL DESCRIPTION

Described in this paper are the new devices for converting various electric quantities to a dc voltage of 0~5 volts (called FV converter), a dc current of 0.15~3 ma (called FA converter) and a pulse-frequency of 12~24 cps (called FP converter).

FV converter for power measurement utilizes the new time-division multiplier, which is able to produce a high-level dc output. FV converter for ac rms voltage measurement utilizes the new root-mean-square circuit, the dc output of which is accurately proportional to the rms value of ac voltage, even if the wave-form is distorted by harmonic waves.

FA converter consists of FV converter and a differential transistor amplifier.

FP converter consists of FV converter and a voltage-controlled linear oscillator. This new oscillator is an astable multivibrator whose discharging current is proportional to the control voltage.

These converters are of great use for both telemetering through physical circuits or carrier channels and analog- or digital-instrumentation.

Advantages of these converters are high-level output (in case of FV converter), high reliability (of course all-solid state), good accuracy, perfect electrical strength, fast response, small power consumption, small size, low cost, etc.

II. FV CONVERTER

1. Use

As shown in *Table 1*, various electric quantities are converted proportionally to a dc voltage of 0~5 volts.

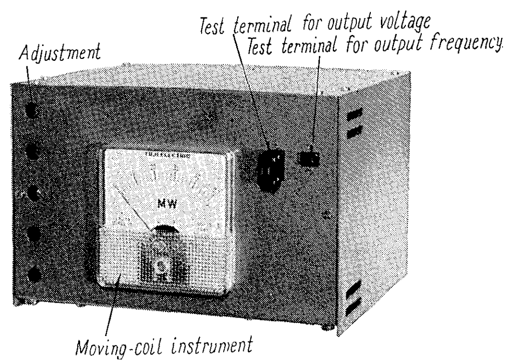


Fig. 1 Outside view of FP converter

Table 1 **Ratings of FV, FA and FP converters**

Input	Ratings volts amp	Measuring range	Output: FV converter	Output: FA converter	Output: FP converter	Supply Dimensions Error
Three-phase power	110...5	0~1 kw −1~0~1 kw	Dc 0~5 volts Internal resistance : ≦ 500 ohms	Dc 0.15~3 ma Load resistance : 0~2000 ohms	Pulse frequency 12~24 cps or 20~30 cps Level : ≧ 2.5 volts Impedance : 600 ohms Polarity : bipolar or unipolar	Supply voltage : any one of 100, 110 volts ac 200 volts ac 24 volts dc Outer dimensions : H 132 mm W 200 mm D 188 mm Limit of intrinsic error : ± 0.5% (* ± 1.0%)
Three-phase reactive power	110...5	0~1 kvar −1~0~1 kvar				
Ac voltage (true rms value)	110	70~140 volts 90~120 volts				
Ac voltage*	110	0~150 volts 70~140 volts 90~120 volts				
Ac current*	5	0~5 amp				
Resistance		by conference				
Dc millivolt		≧ 0~30 mv				
Dc voltage		0~5 volts 10~50 ma				

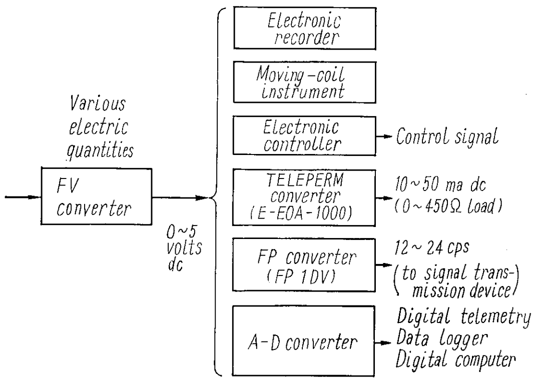


Fig. 2 Application examples of FV converter for analog and digital measurement and control

Examples of applications are shown in *Fig. 2*.

Because of the high-level dc output of FV converter, it can be connected to a moving-coil instrument and an analog-to-digital converter, eliminating the need for a dc amplifier.

2. Three-phase Power (Reactive Power) to Dc Voltage Conversion Circuit

A new time-division multiplier is utilized, which is able to produce a hundred times as high output voltage as a conventional thermal converter or Hall-effect multiplier.

This multiplier is based on the sampling theorem and the pulse-width-difference modulation.

In *Fig. 3*, v_s or i_s is proportional to the input instantaneous voltage v or current i, and V_b is a constant bias voltage. $(V_b - v_s)$ and $(V_b + v_s)$ are impressed on a unique linear oscillator, shown in *Fig. 4*. The discharging current of capacitor C_1 or C_2 is proportional to the base voltage of transistor Q_3 or Q_4, and is independent on the discharging time. Therefore, the time duration T_1 or T_2, within which transistor Q_1 or Q_2 is conducted alternately, becomes as follows.

$$T_1 = V C_2 R_4/(V_b - v_s), \quad T_2 = V C_1 R_3/(V_b + v_s) \ldots (1)$$

Now C_1 is equal to C_2, and R_3 is equal to R_4, the following relation is introduced.

$$(T_1 - T_2)/T = v_s / V_b \propto v \qquad (T = T_1 + T_2) \ldots\ldots (2)$$

Then, the collector voltages of Q_1, Q_2 drive the solid switching circuit in *Fig. 3*.

The current i_s flows through ① side during T_1 and through ② side during T_2. Therefore, the voltage drop e on resistor R_0 becomes the pulse train, shown in *Fig. 5*. The average value of e during T, T', T''..., respectively shown as a point in *Fig. 5*, becomes as follows.

$$i_s \ (T_1 - T_2)/T \propto v i = p \ \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Thus the average value of e is proportional to the input instantaneous power p.

Further, a low-path filter eliminates the sampling frequency components and the twice frequency component of input voltage. Thus, the dc output voltage E is proportional to the input average power P.

Above illustrated is the time-division multiplier for single-phase power measurement. As for three-phase power (reactive power) measurement, the two multiplier shown in *Fig. 3* are utilized according to Blondel's theorem.

The conversion circuit also includes an adequate temperature-compensation circuit and a voltage-stabilizing circuit. In order to protect the circuit against the abnomal phenomena, which might occur in the power line, electric-shielding plates connected with an earth terminal are inserted between primary and secondary windings of auxiliary PT and CT, and

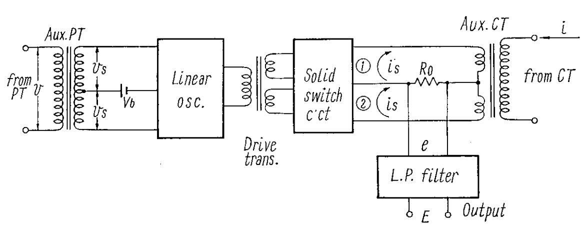


Fig. 3 Block diagram of time-division multiplier

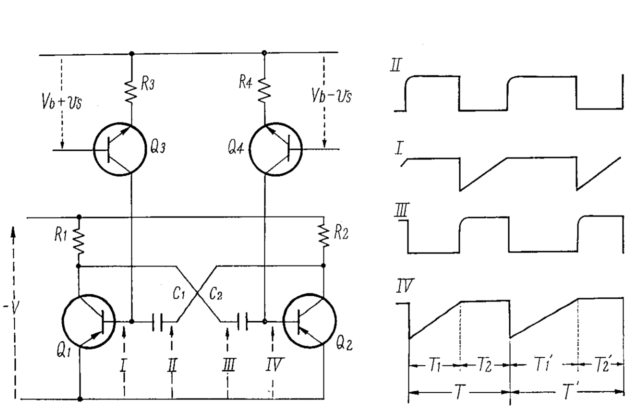


Fig. 4 Basic circuit and wave forms of linear oscillator

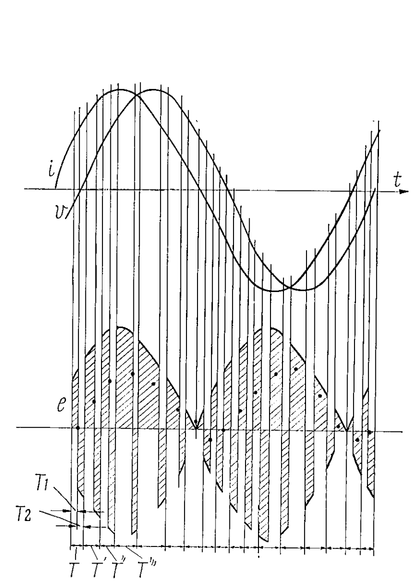


Fig. 5 Wave forms in multiplier of *Fig. 3*

the silicon symmetrical switches are connected parallel to the secondary windings of auxiliary CT.

Technical data:

Linearity .... $\leqq \pm 0.2\%$ of the measuring range
Effect of temperature ... $\leqq 0.2\%/10$ deg, $0.5\%/20$ deg
Effect of supply voltage... $\leqq 0.05\%/20\%$, $0.5\%/-30\%$
Effect of input voltage... $\leqq 0.1\%/10\%$
Effcct of frequency negligible/5%
Effect of power factor ... $\leqq 0.2\%$/lead, lag 0.5
Response time ....0.3 sec (95% response)
Output ripple ....negligible in case of balanced three-phase (0.5%, even if one phase current is zero)
Overload capacity ....
CT c'ct. ......40 × rated current, 1 sec
PT c'ct. ...... 2 × rated voltage, 5 sec
Test voltage (PT, CT and supply c'ct.) ......
.........50 or 60 cps, 2 kv, 1 min
impulse wave (40 μs) 5 kv
Power consumption ......PT c'ct. ...0.1 va each line
CT c'ct. ...1.2 va each phase
Supply c'ct. ...8 va

3. Ac Rms Voltage to Dc Voltage Conversion Circuit

The rms value V_{rms} of ac voltage is defined as follows.

$$V_{rms}=\sqrt{\frac{1}{T}\int_0^T v^2\,dt} \quad \cdots\cdots (4)$$

v: instantaneous voltage, T: period

Fig. 6 shows a newly developped circuit, which is able to accurately measure V_{rms} of equation (4) and provide a linear output. Two routing ($\sqrt{\ }$) circuits are the function generators consisting of diode-limiters, as shown in the right side of *Fig. 6*. The voltage drop of $\sqrt{\ }$ circuit is proportional to the square root of passing current. In the squaring circuit, feedback voltage v_f is proportional to the square root of output current i_1 of the amplifier, so i_1 becomes proportional to the square of input voltage v. The ac components of i_1 are filterd, and the residual dc component i_2 is passed through the $\sqrt{\ }$ circuit, so its voltage drop v_2 becomes proportional to V_{rms} itself.

The voltage v_2 is suppressed and amplified, so that an ac rms voltage of 70~140 or 90~120 volts corresponds with a dc output of 0~5 volts.

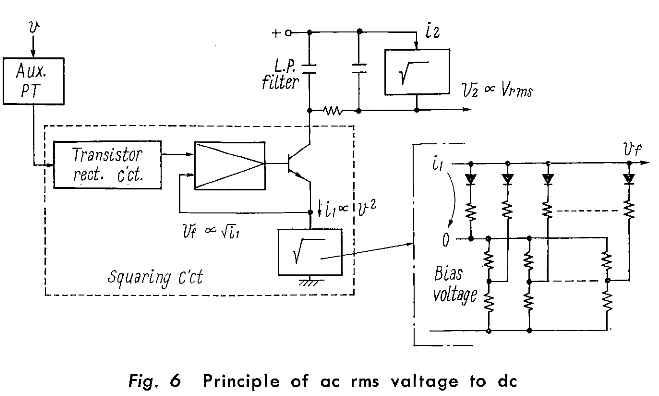


Fig. 6 Principle of ac rms valtage to dc voltage conversion

Conventional rectifying devices measure intrinsically the average value of ac voltage and, therefore, are susceptible to the influence of harmonic distortion. For example, if the third harmonic content is 6%, the output varies within −2~+2% range depending on the harmonic phase. However the new device shown in *Fig. 6* is able to accurately measure the rms value of ac voltage, even if the third harmonic content reaches to 15%.

The effect of temperature is enough less than 0.5%/20 deg.

In order to protect the circuit against an impulse wave (1 × 40 μs) of 5 kv, an electric-shielding plate is inserted between primary and secondary winding of auxiliary PT, and is connected with an earth terminal.

4. Ac Voltage (Current) to Dc Voltage Conversion Circuit

A conventional rectifying circuit is utilized (*Fig. 7*). This circuit, unlike the circuit shown in *Fig. 6*, is susceptible to the influence of harmonic distortion, but is inexpensive.

5. Resistance to Dc Voltage Conversion Circuit

A conventional bridge-circuit is utilized (*Fig. 8*). For example, this circuit is used to connect with a potentiometer in a water-level transmitter.

6. Dc Millivolt to Dc Voltage Conversion Circuit

A conventional modulated dc amplifier is utilized (*Fig 9.*)

This circuit is used to connect with a pre-converter, which has an output of lower than 5 volts.

III. FA CONVERTER

1. Use

As shown in *Table 1*, the various electric quantities

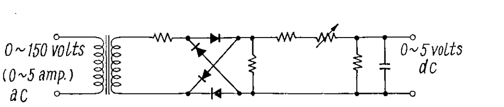


Fig. 7 Ac voltage (current) to dc voltage conversion circuit

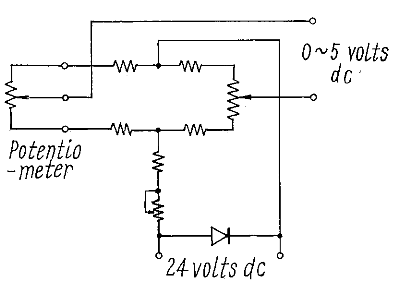


Fig. 8 Resistance to dc voltage conversion circuit

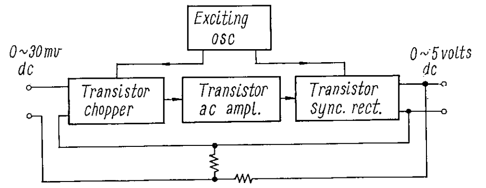


Fig. 9 Dc millivolt to dc voltage conversion circuit

are converted proportionally to a dc current of 0.15 ~3 ma.

The use of FA converter is similar to that of FA converter (*Fig. 2*). The differences between the two are as follows.

	Output	Impedance of receiver	Connection of receivers
FA	current	low	serial
FV	voltage	high	parallel

The load-resistance (sum of transmission lines and receivers) may be within a 0~2000 ohms range. Therefore, it is easy to connect several moving-coil instruments to one converter.

The suppressed zero of 5% is of service to distinguish between life zero and dead zero.

2. Dc Voltage to Dc Current Conversion Circuit

FA converter consists of FV converter and a dc amplifier housed in a single case. Because of the high-level output of FV converter, it is permitted to utilize a simple dc amplifier. Then, a differential transister amplifier is utilized. The output current is independent of the load-resistance, because the feedback voltage is proportional to the output current (*Fig. 10*).

IV. FP CONVERTER

1. Use and Organization

With FP sending converter, as shown in *Table 1*, the various electric quantities are converted proportionally to a pulse-frequency of 12~24 cps or 20~30 cps.

For example, a conventional three-phase power to pulse-frequency converter has been organized as shown in *Fig. 11* (*b*). Namely, in addition to a primary converter, a secondary converter consisting of four printed plates, which should be inserted in a standard communication rack, has been needful. In contrast with (*b*), the new converter is organized as shown in

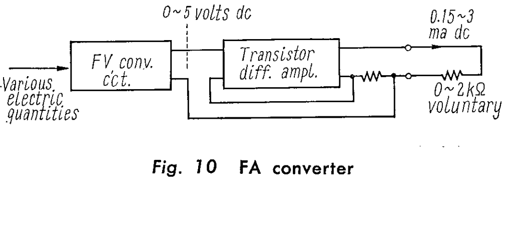


Fig. 10 FA converter

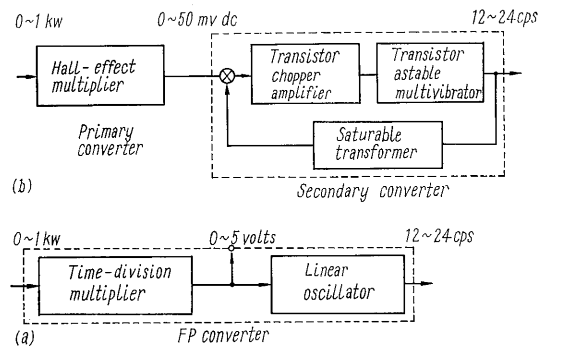


Fig. 11 New (a) and conventional (b) devices; which convert three-phase power to pulse-frequency

Fig. 11 (*a*), and united in the same case as the conventional primary convertor. Therefore, the space necessary for installation becomes about one half. Simplification of circuit also contributes to improvement of reliability and reduction of cost.

Fig. 12 shows an example of FP sending converter, the outside view of which was already shown in *Fig. 1*.

Next, with FP receiving converter the pulse-frequency of 12~24 cps or 20~30 cps is converted pro-

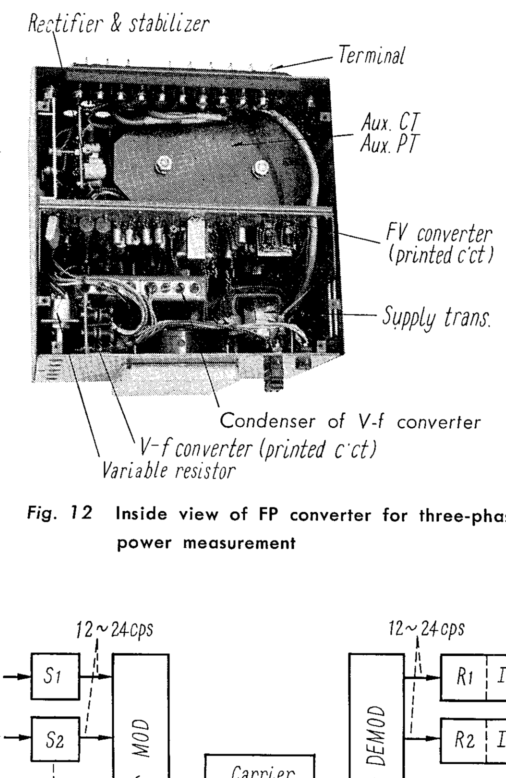
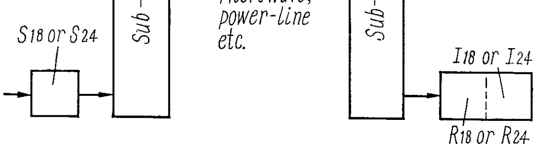


Fig. 12 Inside view of FP converter for three-phase power measurement



S: FP sending converter *R*: FP receiving converter
I: Receiving instrument

Fig. 13 Frequency-division-multiplex telemetering portionally to a dc signal of 0~0.75 ma (load-resistance : 500 ohms) or 0~250 mv. Its permissible error is ±0.5% of the measuring range.

FP receiving converter is either constructed as a printed plate, which is to be inserted in the standard communication rack, or included in the receiving recorder or indicator.

Generally, as shown in *Fig. 13*, FP sending and receiving converter are used for frequency-division-multiplex telemetering by means of carrier channels, such as power-line and microwave, with subcarrier MOD- and DEMOD-devices, the technical data of which are common to that for telegraphic communication.

2. Dc Voltage to Pulse-frequency Conversion Circuit

As shown in *Fig. 14*, voltage E (input voltage E_a plus constant bias voltage E_b) is impressed on a linear oscillator. Similarly to *Fig. 4*, transistor Q_1 and Q_2 are conducted alternately. Oscillating frequency f is as follows.

$$f=E/2VCR \quad (C_1=C_2=C, \quad R_3=R_4=R) \quad \ldots\ldots(5)$$

Now, V, C and R are constant, thus f becomes proportional to E. Then, a switching circuit is driven by collector voltage of Q_1, and produces a pulse train with regular conditions as an output.

Transistor Q_5 is used in the bias voltage circuit to compensate the temperature influence of Q_3 and Q_4. Diodes D_1 and D_2 prevent the influence of leakage current passing the base of cut-off transistor Q_1 or Q_2. The low bias voltage produced by resistance R_7 or R_9 prevents the influence of collector leakage current in cut-off transistor Q_1 or Q_2.

For example, the total characteristics of the three-phase power to pulse-frequency converter are within the same limit as those of the three-phase power to dc voltage converter (Ⅲ. 2). Therefore, it becomes possible to achieve more accurate measurements than possible with a conventional converter.

3. Receiving Conversion Circuit

A received pulse train is shaped to a square wave with enough level, and then applied to a primary winding of a saturable transformer.

As shown in *Fig. 15*, the average value I_a of the pulsed current i is as follows.

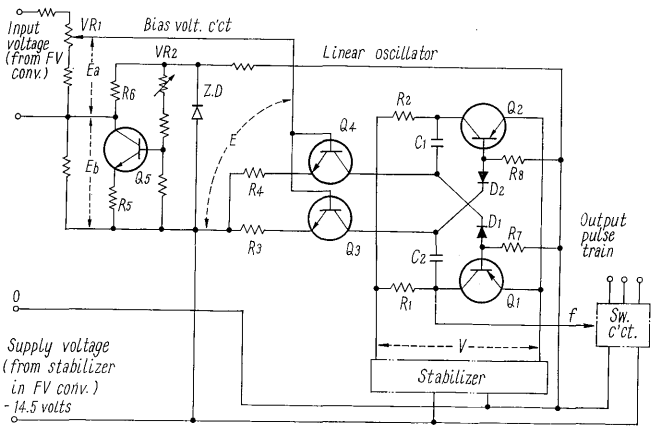


Fig. 14 Dc voltage to pulse-frequency conversion circuit

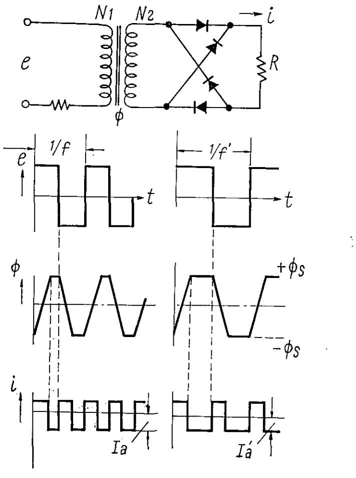


Fig. 15 Principle of receiving conversion circuit

$$I_a=4\,\Phi_s N_2 f / R$$

Now saturated flux Φ_s, number of turns on secondary winding N_2 and load resistance R are constant, then I_a becomes proportional to pulse frequency f.

Current corresponding to base frequency is subtracted by constant voltage issued from an internal voltage stabilizer.

Because of its relatively high-level output, this converter can be connected directly to a moving-coil instrument. Because of its relatively short saturation time, the distortion of mark-to-space ratio of upto 58% is permissible.