Note on the instrumentation for measuring electrical process parameters with electro erosion machining

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A description is given of an electronic circuit existing of two differential amplifiers for monitoring voltage and current signals and a high speed and-circuit for producing pulses, which are required if voltage and current are both present at the same time.
A description is given of an electronic circuit existing of two differential amplifiers for monitoring voltage and current signals and a high speed and circuit for producing pulses, which are required if voltage and current are both present at the same time.
The circuit described here, has been designed for easy measurement of voltage and current pulses, and for producing pulses, which are required if voltage and current are both present in the circuit.

Fig. 1 gives the principle of the measurement of voltage \( U_f \) and current \( i_f \) in the process.

The voltage is measured over the sparkgap, while, for measuring the current, a small resistor \( R_{\text{shunt}} \) is mounted in the circuit \( i_f = \frac{U_1}{R_{\text{shunt}}} \).

Because of the complexity of machinery used one is not free to choose the earthing point of the circuit.

In fig. 1 it is seen that the voltages at points 1 and 2 are \( U_1 = U_f + U_i \) and \( U_2 = U_1 \).

So for measuring \( U_i \) one should use a differential amplifier \( U_f = U_1 - U_2 \).

For the measurement of \( U_1 \) one could use an amplifier with a single input, but the logic circuit is only sensitive to one polarity.

So it is convenient to use a differential amplifier too, if polarity has to be changed.

Four possibilities may occur in the circuit:

1. no voltage and no current
2. voltage and no current - sparkgap too large
3. no voltage and current - short circuit
4. voltage and current.

Only the fourth case is important to EDM and should be selected.

The number of times it occurs should be counted.

For the selection the logic has been designed.

The demands for a well-working logic are amongst others high speed, good sensitivity and short delay.

As for a monitor amplifier, linearity is most important. The signals may be weak as well as rather strong.

Therefore the logic function and the monitor function were separated to obtain good results.

It is to be noted that the voltage across the sparkgap may be so high that the signal has to be attenuated; this has been effected by using two 3.9 kΩ resistors (see fig. 2) which have the advantage that despite the adaptation to 75Ω cables the load over the gap is very small.
These 3.9 kΩ resistors have to be placed as near as possible to the sparkgap to ensure minimum capacitive loading.

**Note:** It is clear that for the current channel 75Ω is much more than $R_{\text{shunt}}$, which is of the order of 70 milli-ohms (0.07Ω; see report WT 0184).

Fig. 2 gives a block diagram of the amplifier connected to the measuring object.

**Note:** a and a' - logic amplifiers with differential input for reducing the discharge voltage and amplifying the shunt voltage to levels suitable for the logic circuit.

b - high speed and-circuit.

c - pulse amplifier.

d and d' - monitor amplifiers (with differential input).

Some characteristics:
The voltage across the gap can be 10 to 30 volts (burning) and 400V maximum (ignition); so with 3.9 kΩ resistors the input voltage will vary from approx. 200 mV to 8V. The shunt resistor for the current measurement is about $R_{\text{sh}} = 70$ milli-ohms. The current will vary from 1A up to 100A. So the input voltage will be 100 mV to 10V.
The minimum pulse duration will be 100 ns.

**Monitor amplifier**
The input signal can be rather high, therefore it is first attenuated by a factor two ($R_{1,2,5}$ and 6).

**Note:** In the circuit diagram, $T_1$ may be $T_{11}$ or $T_{21}$, $R_4$ may be $R_{101}$ or $R_{201}$ and so on depending on the part of the circuit.

Then the signal is applied to a differential amplifier with a large controlling area, which is achieved by adding two resistors ($R_3$ and $R_4$) to the emitter circuit of the transistors $T_1$ and $T_2$. Further, these two resistors ensure a stable distribution of the current through $T_1$ and $T_2$, while the sum of currents is kept constant by adding a current source in the common emitter circuit formed by $T_3$, $R_{10}$, $Z_1$ and $R_9$.
The common mode rejection ratio of the first stage is dependent on this current source and the equality of $T_1$ and $T_2$.
But more important is the attenuator.
So one should choose $R_1 \cdot R_5 = R_2 \cdot R_6$ within e.g. 0.25%.
For high frequencies, however, transistor characteristics and parasitic capacitors become more important.

As \( R_1 \cdot R_5 = R_2 \cdot R_6 \), also the 3.9 KΩ resistors before the voltage input are important to the rejection ratio; \( R_{22}, R_{23} \) and the equality of \( V_d \) of \( D_{1,2,3} \) and \( D_4 \) become significant if high common mode signals are supplied to the input. (See note page 5).

This situation will not be reached because the current channel measures against earth and the voltage channel gets the current signal (which is 10 V max.) as common mode signal after it is attenuated to a signal weaker than 200 mV by the 3.9 KΩ resistors in combination with the input impedance.

The second amplifier stage is single ended and is followed by an emitter-follower with an output impedance of approx. 75Ω.

This stage is shortcircuitproof during short times.

The DC level of the monitor output can be made zero by slightly changing \( R_{13} \). A higher value of \( R_{13} \) will force the output to the negative and a lower value to the positive side.

### Counting logic

Both channels start with a Fairchild \( \mu A710 \) high speed differential comparator.

The input is protected to high input signals with four high speed diodes and two resistors \( (R_{22} \text{ and } R_{23}, D_1 \text{ to } D_4) \). See page 5.

To prevent noise and other interfering signals from giving an output, the comparator is forced to negative output by means of \( R_{24} \), which is connected from the non-inverting input to the \(-6V\) supply.

This also includes that weak signals will not give an output (see technical data).

The comparators are followed by a gate \( (D_{15}, D_{25}, R_{301}, R_{302} \text{ and } R_{303}) \) an inverter \( (T_{31}) \) and a threshold formed by \( D_{31}, R_{305} \) and \( R_{306} \) (see fig. 3); this combination is called "b" in fig. 2.

The threshold improves the noise immunity and the speed of the counting logic. The last stage is an emitter-follower like that of the monitor amplifiers.

The output has a positive DC level and the output pulses are of negative polarity.

**Note:** As mentioned at "monitor amplifier" it is important to choose in the voltage channel the 3.9 KΩ resistors and \( R_{20} \) and \( R_{21} \) equal to each other within e.g. 0.25% and \( R_{22} = R_{23} \) within 2% to obtain a good rejection ratio.
When building these circuits one should mount the input and the output plugs isolated from each other to prevent parasitic earth currents. The figures 3, 4 and 5 represent: circuit diagram, list of components and printed circuit board with component location.

Technical data

Monitor amplifier

Attenuation, loaded with 75Ω cable approx. 1.5 meters long, terminated with 75Ω: 5x.
Bandwidth-3dB: 12 MHz.
Delay time for several input voltages: leading edge 20 ns
rear edge 20 ns
Rise time: 20 ns
Fall time: 20 ns
Maximum input voltage for linear operation: 10V (peak)

Common mode rejection ratio: at 1 MHz: 300
at 2.5 MHz: 150
at 5 MHz: 100
at 7.5 MHz: 80
at 10 MHz: 70

Counting logic

Balanced input: input impedance 2x 75Ω
Output impedance: 75Ω
DC level of output (loaded with 75Ω): +3V
Maximum input voltage: 10V
Output pulse (output loaded with 75Ω): 3V
Rise time: 20 ns
Fall time: 20 ns
Delay times measured with a 100 ns input pulse:
input pulse 0.1V to 1V: leading edge 70 ns to 20 ns.
rear edge 40 ns to 90 ns.
input pulse 1V to 10V: leading edge 20 ns.
rear edge 90 ns.

Minimum input pulse (100 ns) to obtain an output pulse of full amplitude:
75 mV (delay time approx. 100 ns).

Minimum input signals (sinusoidal) to obtain an output pulse:
at 1 MHz 50 mV rms' at 5 MHz 70 mV rms' and at 10 MHz 150 mV rms'.
Output signal if no pulse has to appear: Less than 10 mV p-p.
Power supply

Fig. 6 represents the circuit diagram of the power supply which is rather simple but well functioning.

A part of the output voltage is compared with the reference $Z_2$ by means of $T_4$, which controls the booster $T_2$ of the power transistor $T_1$.

To change the output voltage, the value of $R_8$ or $R_7$ can be changed.

A smaller value for $R_8$ or a higher value for $R_7$ gives a lower output voltage. A higher value for $R_8$ or a smaller value for $R_7$ gives a higher output voltage.

For final alignment of the logic it would be convenient to make sure first that the power supply voltages are within some per cent of the indicated values.

A simple current limit has been realised with $T_3$, $R_3$ and $R_4$.

The circuits for +12V and -12V are identical.

The figures 6, 7 and 8 represent: circuit diagram, list of components and printed circuit board with component location.

Technical data

Output voltages: +12V and -12V.

Current limiting at 0.65A.

Line regulation: + or -10% line voltage change will give output changes less than 1 mV (measured with a load current of 250 mA).

Load regulation (DC): a current change of 0.2A gives an output change of less than 12 mV.

Noise and ripple: Less than 15 mV peak to peak.

Note: As mentioned in chapter "Counting logic" the only function of $D_{11}$ to $D_{14}$ and $D_{21}$ to $D_{24}$ is to protect the microcircuits to high voltages.

If high common mode signals ($>V_D$) are applied to the inputs an output signal may occur, because of the different diode voltages (e.g. $V_{D12} > V_{D13}$ or $V_{D14} > V_{D11}$).

Replacing $D_{13}$, $D_{23}$, $D_{11}$ and $D_{21}$ by two diodes (same type) will prevent this situation.

This modification does not change the measuring capabilities of the circuit, since there will be no output in case where the common mode signal is higher than $V_D$, even when the noninverting input (n.i.) is positive with respect to the inverting input.
### Fig. 4 List of components (Counting Logic)

<table>
<thead>
<tr>
<th>R101</th>
<th>R201</th>
<th>R110</th>
<th>R210</th>
<th>75Ω</th>
<th>All resistors 3/8 Watt except:</th>
<th>R116, R216 1/8 W</th>
<th>R109, R311 1/4 W</th>
</tr>
</thead>
<tbody>
<tr>
<td>R102</td>
<td>R202</td>
<td>R111</td>
<td>R211</td>
<td>82Ω</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R103</td>
<td>R203</td>
<td>R112</td>
<td>R212</td>
<td>82Ω</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R104</td>
<td>R204</td>
<td>R113</td>
<td>R213</td>
<td>1kΩ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R105</td>
<td>R205</td>
<td>R114</td>
<td>R214</td>
<td>1kΩ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R106</td>
<td>R206</td>
<td>R115</td>
<td>R215</td>
<td>1kΩ</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>R107</td>
<td>R207</td>
<td>R116</td>
<td>R216</td>
<td>1kΩ</td>
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</tr>
<tr>
<td>R108</td>
<td>R208</td>
<td>R117</td>
<td>R217</td>
<td>1kΩ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R109</td>
<td>R209</td>
<td>R118</td>
<td>R218</td>
<td>1kΩ</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To obtain good rejection ratios for the monitor amplifiers one should choose:

R107 - R207 = R106 - R206
R207 - R208 = R206 - R205

### Capacitors
- C11, C22, C33, C44, C55, C66, C77, C88, C99, C10, C110, C210

0.9 μF (metallized polyester) ±5%

### Diodes
- T1, T11
- T2, T22
- T3, T33
- T4, T44

### Integrated Circuits
- B6Y48
- MPS 6517
- M11/1717 (with cooling clip)

### Other Components
- 11914
- Zener diode 3V
- Zener diode 6V

Printed Circuit Board

"Counting Logic"

Component side

• Hole

× Hole for short circuiting both sides of pc board

Copper layer
**Fig. 6** Power Supply

B₁, B₃ 4 x 1494
B₂, B₄ FWL 600 (Mallory)

PT: Power Transformer
iron core EI 78/86

P₁, P₂ 1460 Wdg's 0.22 mm² 220 V~
S₁-S₆ 122 Wdg's 0.22 mm² 18.5 V~
S₇-S₉ 110 Wdg's 0.5 mm² 16.5 V~
S₁₀-S₁₂ 122 Wdg's 0.22 mm² 18.5 V~
S₁₃-S₁₅ 110 Wdg's 0.5 mm² 16.5 V~

S₁, Shield 1 connected to metal case
S₂, Shield 2 connected to "Signal earth" (zero)

Numbers between () indicate the connections on the P.C. board.
## List of components (Power Supply)

<table>
<thead>
<tr>
<th>R</th>
<th>Value</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>3.2kΩ</td>
<td>1/4W</td>
</tr>
<tr>
<td>R2</td>
<td>680Ω</td>
<td>1/8W</td>
</tr>
<tr>
<td>R3</td>
<td>100Ω</td>
<td>1/8W</td>
</tr>
<tr>
<td>R4</td>
<td>1.0Ω</td>
<td>1/4W</td>
</tr>
<tr>
<td>R5</td>
<td>560Ω</td>
<td>1/8W</td>
</tr>
<tr>
<td>R6</td>
<td>3.3kΩ</td>
<td>1/8W</td>
</tr>
<tr>
<td>R7</td>
<td>6.0kΩ</td>
<td>1/8W</td>
</tr>
<tr>
<td>R8</td>
<td>8.2kΩ</td>
<td>1/8W</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C</th>
<th>Value</th>
<th>Voltage</th>
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</thead>
<tbody>
<tr>
<td>C11</td>
<td>640μF</td>
<td>40V</td>
</tr>
<tr>
<td>C12</td>
<td>250μF</td>
<td>30V</td>
</tr>
<tr>
<td>C13</td>
<td>47μF</td>
<td>250V</td>
</tr>
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<table>
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<tr>
<th>T</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>T1</td>
<td>2N3054 with cooler WA357-9 Schaffner</td>
</tr>
<tr>
<td>T2</td>
<td>BC107</td>
</tr>
<tr>
<td>T3</td>
<td>BC107</td>
</tr>
<tr>
<td>T4</td>
<td>BC107</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Z</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>Z11</td>
<td>Zenerdiode 5V</td>
</tr>
<tr>
<td>Z12</td>
<td>Zenerdiode 7V</td>
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</table>

<table>
<thead>
<tr>
<th>B</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>4 x 110914</td>
</tr>
<tr>
<td>B2</td>
<td>FWL 600 (Mallory)</td>
</tr>
</tbody>
</table>