The long time necessary for the establishment of steady-state operating conditions is one of the important characteristics of transistorized differential RC-amplifiers. Specifically, this is exemplified by the so-called pulling of the establishment of operating conditions and, consequently, the channel's operating characteristics after the supply is turned on and the electrode branches are switched. While the delay in the establishment of operating conditions after switching on the supply could be accepted, prolonged blocking of the channel after switching the electrode branches (for instance, in recording electrocardiograms) is highly undesirable, since this blocking may last as long as 10 and even 20 sec.

What are the causes of this blocking and how could it be eliminated?

Besides the abrupt changes in the resistance of the signal source (ΔRg), which are most often unequal at the inputs of the differential amplifier's arms (Fig. 1), there are jump-like changes in the polarization at the specimen's surface when the branches are switched in electrophysiological investigations. This is equivalent to supplying to the channel input a step signal with a rather large amplitude, which attains tens of millivolts. Such a surge disrupts the operating conditions of the channel during the establishment of the previous emitter current in each of the stage arms, since it is commensurable with the junction voltage. Figure 1 shows how step signals arise at the input of the differential amplifier stage. It is assumed that the input emitter follower, which is directly connected to the specimen under investigation, transforms the resistance drops ΔRg and reduces them to values which are much lower than the input impedance of the differential stage or, more accurately, to the value ΔRg/β, where β is the transistor's current gain [1].

The step signal amplitudes at the inputs of both arms are defined as U1 = E1 - E2, U2 = E3 - E4. Since, in this case, the voltage gain of the stage does not depend on the current amplification of the transistors, the analysis of the transient response can be "reduced" to the input. We shall use the following system of equations for the antiphase and in-phase signal components in the differential amplifier:

\[
\begin{align*}
I_{in} &= g_{mn} E_{in} - |g_{nc}| E_{ic} \\
I_{ic} &= g_{cc} E_{ic} - |g_{cn}| E_{in}
\end{align*}
\]

where \(g_{nn}\) and \(g_{cc}\) are the input conductances of the balanced differential stage for the antiphase and the in-phase signals, \(g_{cn}\) and \(g_{nc}\) are the mutual conductances of transmission of the antiphase signal to the in-phase signal, and vice versa, at the input of the unbalanced differential stage, the physical interpretation of which was given by Middlebrook [1], and \(I_{in}\) and \(I_{ic}\) are the input currents produced by the antiphase \(E_{in} = (U_1 - U_2)/2 - I \cdot g_{mn}/c\) and the in-phase \(E_{ic} = (U_1 + U_2)/c - I \cdot g_{cc}/c\) components of the input signal, respectively.

After substituting these values in the system of equations (1), we obtain

\[
\begin{align*}
I_{in} &= g_{nn} \cdot \frac{U_1 - U_2}{2} - I \cdot \frac{\tan \theta}{c} - |g_{nc}| \cdot \frac{U_1 + U_2}{2} - I \cdot \frac{\tan \theta}{c} \\
I_{ic} &= g_{cc} \cdot \frac{U_1 + U_2}{2} - I \cdot \frac{\tan \theta}{c} - |g_{cn}| \cdot \frac{U_1 - U_2}{2} - I \cdot \frac{\tan \theta}{c}
\end{align*}
\]

These equations describe the current behavior in the stage arms after a step-like perturbation is applied to the input. The operating conditions are established when \(I_{in} \to 0\) and \(I_{ic} \to 0\).
The transient response at the output of the differential stage is fully defined by the transient responses of the two currents: $I_{IC} + I_{IN}$ and $I_{IC} - I_{IN}$. This means that the transient response of the voltage difference (the antiphase signal) at the output is determined by the first equation of system (1a). The second equation of this system describes the establishment of the mean value of the output potentials of the arms (the in-phase signal).

In the absence of unbalance ($g_{nc} = g_{cn} = 0$), the time in which steady-state operating conditions are established depends on the amplitude of the perturbation signal and the time constants $c/g_{nn}$ and $c/g_{cc}$. Since $g_{cc}/c < g_{nn}/c$, there is considerable pulling of the establishment of the mean output potential level. Therefore, in a system containing only a single capacitive junction ahead of the first differential amplifier stage, it is advisable to maintain a symmetric structure up to the channel output.

Thus, we must distinguish between two exponential transient responses, one for the in-phase, and the other for the antiphase signal in the case of a balanced differential stage. The time constants of these exponentials are vastly different from each other. The establishment of the potential difference at the stage output is of basic importance in practice. It is obvious from the first equation of system (1a) that, since the current amplitude of the antiphase perturbation signal is equal to $g_{nn}(U_1 - U_2)$ for $t = 0$, the time in which the potential difference between the arms is established is somewhat longer than the time necessary for the establishment of the potential of a single arm (by a factor of about 1.2).

The numerical value of the ratio of these times can be obtained in the following manner. Denoting the steady-state amplitude value by $x$, we can write the following system of equations:

$$\begin{align*}
x &= a \cdot \frac{3\tau}{\tau}, \\
x &= 2a \cdot \frac{k\tau}{\tau},
\end{align*}$$

where $a$ is the perturbation amplitude, and $\tau$ is the time constant of the RC circuit.

By solving this system of equations with respect to $k$, we obtain $k = \ln 2 + 3$, and, since the establishment time is equal to $3\tau$ in the first equation and $k\tau$ in the second, we obtain $k\tau/3\tau = (\ln 2 + 3)/3 \approx 1.2$.

Figure 2 shows the transient responses of a balanced differential stage for the antiphase and the in-phase signals. It is obvious from Fig. 2 that, if the in-phase component of the perturbation signal is large, there is considerable delay in the establishment of each arm's potential (curve 2). However, if only the antiphase step signal is supplied to the input of a balanced differential stage, the establishment of steady-state conditions has the same character as in the case of a nonsymmetric stage. The time constants of the exponentials are, in both cases, determined by the product $h_{11}c$, where $h_{11}$ is the stage parameter [1].

A totally different pattern is observed in the case of an unbalanced differential stage ($g_{nc} \neq 0$, $g_{cn} \neq 0$). An analysis of the system of equations (1a) indicates that, in the case of considerable unbalances and a large amplitude of the in-phase component of the step signal, the transient response of the in-phase signal varies exponentially with the time constant $c/g_{cc}$ after the term $g_{cn}(U_1 - U_2/2)\cdot t^{-g_{nn}/c}$ vanishes, i.e., approximately after the time $3\cdot(c/g_{nn})$ (Fig. 3). Under these conditions, the transient response of the antiphase signal resembles the transient response of a two-stage RC-amplifier, the inverse transform of which is given by

$$f(t) = l \cdot \frac{1}{\tau_1} - l \cdot \frac{1}{\tau_2}.$$

The difference consists in the fact that, in the case of short time intervals, the transient response of an unbalanced differential stage is damped more rapidly, and in the case of long time intervals, more slowly, than would be indicated by Eq. (2).