The SCP signal diagram in BioExplorer: A manual

Module 1: Source Signal Module (SSM)

INPUTS: raw EEG/EOG data from the libjwa dll.

Data import

The SSM picks up source signals from the libjwa dll.

ExG ch 2 (EEG): an EEG signal is imported into BioExplorer.
ExG ch 1 (EOG): an EOG signal is imported into BioExplorer.

Data processing

A measure of ExG signal quality is extracted.

EEG bp filter: the EEG signal is 45-55 Hz bandpass filtered.
EOG bp filter: the EOG signal is 45-55 Hz bandpass filtered.

Most importantly, the SSM outputs the signal on which feedback is given. This could be any signal that is generated from the sources.

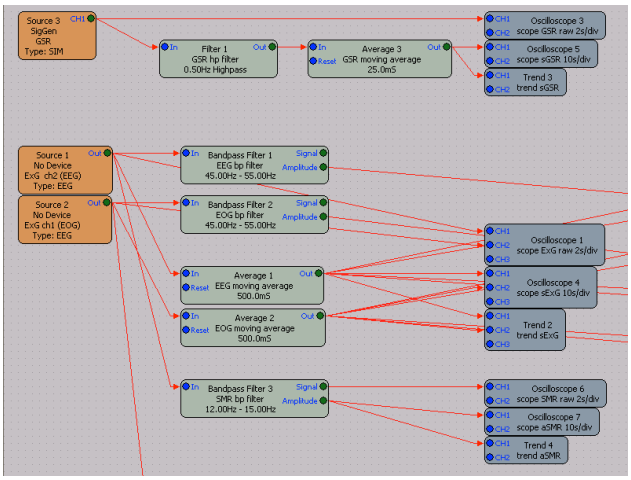
EEG moving average: a slow wave EEG signal (SCP) is generated by a moving average of the EEG over 500 ms (updated every sample).
EOG moving average: a slow wave EOG signal (sEOG) is generated by a moving average of the EOG over 500 ms (updated every sample) for the purpose of correcting for eye-movements.

Data visualization

The SSM displays the raw and filtered data on the operator window.

scope ExG raw 2s/div: displays the raw EEG/EOG signals.
scope sExG 10s/div: displays the SCP/sEOG signals.
trend sExG: displays the SCP/sEOG signals.

OUTPUTS: signals for feedback, correction and rejection (SCP/sEOGsignals, 45-55 Hz ExG amplitudes) and the raw EOG signal (on which the trial sequence generation is based).



Figuur 0-1. The signal diagram: Source Signal Module.

Module 2: Trial Sequence Module (TSM)

INPUTS: the raw EOG signal

Introduction

The trial sequence is generated using the sampling frequency of the device that measures the feedback variable. There was a need to do this because we found discrepancies between time series of the multiple devices when BioExplorers playback function was used.
To be able to reconstruct the data that we recorded we could not use the internal clock of BioExplorer (the one the BioExplorer signal generator uses).
This method yielded good results for the reproducability of the data. However, it introduced another problem. The GSR device has a sampling frequency of 9.89 Hz, where it should be 10 Hz. Thus, with the above method in mind (generating trial sequence in the GSR condition with a 9.89 Hz samplerate, whereas it was 200 Hz in the SCP condition) it becomes clear that in the GSR condition trials take slightly longer.

Trial sequence generation

The trial sequence is built from a sine wave with a frequency that is determined by the sampling frequency of the input data. The sine wave is converted to a block signal. The block signal period functions as the smallest time unit for trial sequence generation. The periods of the block signal are counted, resulting in a discretized ramp function that is reset after every trial (discretized sawtooth function with a period equal to trial duration + ITI).

sample counter: counts the number of samples that appear on the input.
sine wave generator: generates a sine wave of 2 Hz (but output is zero for the first 0.5 seconds).
block signal generator: converts the sine wave to a block signal with the same frequency (time high ≡ time low).
pacer: the output increments by one at rising edges of the input block signal: every 0.5 s
reset pacer: resets the pacer after 19, 20, 21 or 22 counts, which is conditional on the ITI that was set for that trial (see below).

The sawtooth function is manipulated such that the time window that is to be the active feedback phase of the trial is set to a unique constant; and the ITI period is set to a different unique constant. The ITI is variable, in the sense that -for each trial- it is one of a predefined number of ITI's. The resulting signal is a semi-periodic signal (though in a periodic signal) with unique constant values for 1) preparation phase; 2) baseline phase; 3) active phase; 4) ITI. The semi-period is counted as an indicator of the trial number.

trial shaper I: sets the feedback phase (*pacer* object counts 2-15 ≡ 7 seconds) of a trial to the value of 2.
trial shaper II: sets the ITI (*pacer* object counts 16-19/16-20/16-21/16-22 ≡ 1.5/2.0/2.5/3.0 seconds) to a value of 3.
trial counter: counts trials at the start of the preparation phase.

Next, trial conditions are determined. This consists of tagging every trial with a label 'positivity' or 'negativity' by adding a sign to the trial sequence signal, indicating that the feedback signal should be manipulated in a positive/negative direction.
Also, in this step, the differentiation between the preparation phase and baseline phase is cancelled, both receiving the same constant value. Thus, trial sequence is coded as: -a/a in the preparation phase; -b/b in the active phase (b>a) and 0 in the ITI.

trial counter reset: resets the trial counter after a predefined number of trials.
ITI 1-4: defines the trials that are followed with ITI 1, ITI 2, ITI 3 (by trial number specification) or ITI 4 (by not being specified in *ITI 1-3* objects); ITI durations are determined by the *reset pacer* object.

positivity trials: defines the trials that are to be positivity trials (by trial number specification)
negativity trials: defines the trials that are to be negativity trials (by not being specified in the *positivity trials* object).
positivity preparation phase: sets the preparation phase in positivity trials (incl. the baseline phase) to a constant positive value (=0.2).
positivity active phase: sets the active phase in positivity trials to a constant positive value (=1).
negativity preparation phase: sets the preparation phase in negativity trials (incl. the baseline phase) to a constant negative value (=-0.2).
negativity active phase: sets the active phase in negativity trials to a constant negative value (=-1).
trial sequence: combines the four '*phase*' objects to yield a trial sequence signal: -0.2/0.2 in the preparation phase; -1/1 in the active phase and 0 in the ITI.

Furthermore, this module includes an output object that spikes at trial start and trial end.

trial start & end indicator: spikes at trial start and trial end.

Trial sequence indication

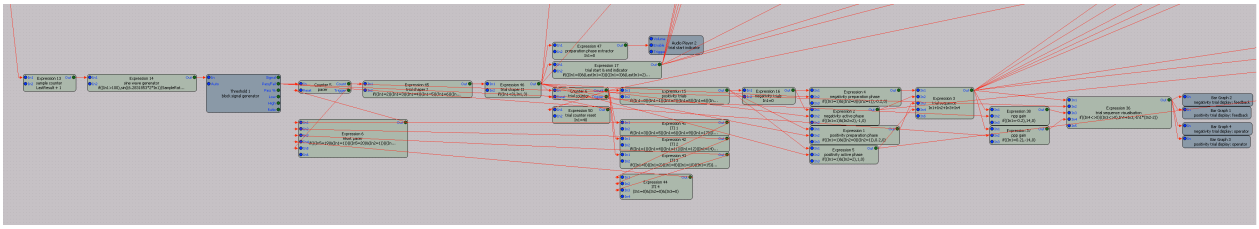
The trial sequence is presented to the subject and operator visually in bar graphs. In the preparation phase of positivity/negativity trials the complete positivity/negativity trial sequence presentation bar graph switches colour to attend subjects on the condition of the trial. At the start of the active phase the bar will return to the original (non-activated) colour, whereafter it will stepwise fill with the (activated) colour, indicating the time left in the active phase.
This is achieved by generating a signal that is alternately high and low in the preparation phase and is a discretized ramp function in the active phase with the highest/lowest value equal to the high value in the preparation phase and the range of the bar graphs.

ppp gain: converts the positive trial sequence code for the positivity preparation phase to a negative constant equal to the *pacer* object count at the end of the active phase minus one (=-14).
npp gain: converts the negative trial sequence code for the positivity preparation phase to a positive constant equal to the *pacer* object count at the end of the active phase minus one (=14).
trial sequence visualization: switches output between prepartion phase (=14/-14) and active phase (=pacer count-2/-(pacer count-2)).
positivity trial display: feedback: displays the trial sequence on the feedback window for positivity trials.
negativity trial display: feedback: displays the trial sequence on the feedback window for negativity trials.
positivity trial display: operator: displays the trial sequence on the operator window for positivity trials.
negativity trial display: operator: displays the trial sequence on the operator window for negativity trials.

Furthermore, the start of a trial is indicated auditorily.

preparation phase extractor: the output is high in the first 0.5 seconds of a trial.
trial start indicator: plays a sound at trial start.

OUTPUTS:



Figuur 0-1. The signal diagram: Trial Sequence Module.

Module 3. Trial Rejection Module (TRM)

INPUTS:

SCP measurements are very artefact sensitive. Therefore, one needs to reject trials that are contaminated with uncorrigable artefacts (EOG is corrected for, see Module 4).
These artefacts include bad signal quality and movement artefacts.

Impedance rejection

The impedance of the connection between electrode and scalp determines signal quality. If the connection is bad, impedance is high and signal quality is low. A measure of impedance is the amount of 50 Hz noise that is picked up by the electrodes. Therefore, if the amplitude of the 45-55 Hz bandpass filtered EEG or EOG signal exceeds a predetermined value (depending on your demands), the signal can be characterized as of too poor quality. To avoid rejection of trials when the criterion is met for just a very short period of time, only trials are rejected that have too high impedance in the baseline period (which is the most critical period).

EEG impedance threshold: output is high/low when the 45-55 Hz amplitude is smaller/larger than 20 uV.
EOG impedance threshold: output is high/low when the 45-55 Hz amplitude is smaller/larger than 20 uV.
baseline impedance: output is high when EEG or EOG impedance threshold object output is low during the baseline period.

Movement rejection

Only a small range of variation is to be expected in the SCP/sEOG. If a certain range of the SCP/sEOG is exceeded in a trial, it is likely that the trial is contaminated by an artefact.

SCP minimum: holds the minimum value of the SCP between resets (at trial start and end).
SCP maximum: holds the maximum value of the SCP between resets (at trial start and end).
EOG minimum: holds the minimum value of the sEOG between resets (at trial start and end).
SCP maximum: holds the maximum value of the sEOG between resets (at trial start and end).
SCP range: output is high when the range of the SCP is larger than 200 uV in a trial.
s*EOG range:* output is high when the range of the sEOG is larger than 800 uV in a trial.

Three reject criteria have been characterized by a high output of three different objects. These are combined to form one reject signal. This signal is 'held' untill the end of the trial once one of the criteria is met in the trial.

trial reject: combines *baseline impedance*, *SCP range* and s*EOG range* objects to yield a reject signal that is high when any of the reject criteria met.
reset trial rejection: increments when reject criterion is met and is reset at trial start and end (output is high wether criterion is met once or multiple times).
reject hold: holds the high output of the *trial reject* object untill the end of the trial.

OUTPUTS:

Module 4. EOG Correction Module (ECM)

INPUTS:

The SCP is contaminated by eye-blinks and eye-movements. Horizontal eye-movements are corrected for by using linked mastoids and measuring from midline. Vertical eye movements (mainly eye blinks) are propagated over the scalp and are picked up attenuated by EEG electrodes. Because the frequency components of these vertical eye movements are close too and overlap the frequency components of the signal of interest these cannot be filtered out. Therefore, the SCP has to be corrected for vertical eye movements. For this purpose, the procedure of Kotchoubey et al. was used (see below).

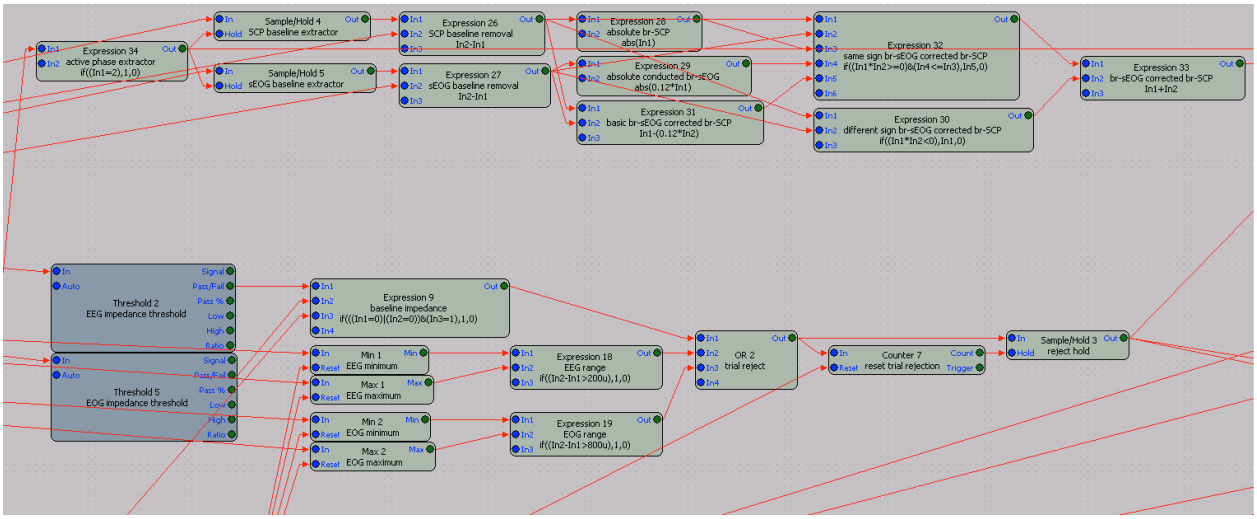
First, SCP/sEOG baselines have to be determined. The baselines are taken as the average over the last 500 ms before the active phase. The baselines are subtracted from the ongoing SCP/sEOG to result in baseline-removed SCP/sEOG (br-SCP/br-sEOG). Then, 1) the absolute value of the SCP is calculated; 2) the absolute value of the conducted sEOG is calculated by multiplication of the sEOG with a conduction factor; 3) the sEOG corrected SCP is calculated by subtracting the conducted sEOG from the SCP.

active phase extractor: the output is high in the active phase of a trial and low otherwise.
SCP/sEOG baseline extractor: holds the value of the SCP/sEOG slow wave at the start of the active phase throughout the active phase.
SCP/sEOG baseline removal: subtracts the SCP/sEOG baseline from the ongoing SCP/sEOG to result in the baseline-removed SCP/sEOG.
absolute SCP: calculates the absolute value of the br-SCP.
absolute conducted sEOG: calculates the absolute value of the conducted br-sEOG (= 0.12 * br-sEOG).
basic br-sEOG corrected br-SCP: calculates the br-SCP corrected for the conducted br-sEOG

As stated above, not in all situations the EOG correction needs to be applied. Three cases are distinguished: formules en motivatie!!!!

1) *different sign br-sEOG corrected br-SCP:* when the br-SCP and the br-sEOG have the different signs, the output is the (non-corrected) br-SCP.
2) *same sign br-sEOG corrected br-SCP:* when the br-SCP and the br-sEOG have the same sign and the absolute value of the conducted br-sEOG is smaller than or equal to the absolute value of the br-SCP, the output is the br-sEOG corrected br-SCP.
3) *br-sEOG corrected br-SCP:* when the br-SCP and the br-sEOG have the same sign and the absolute value of the conducted br-sEOG is larger than the absolute value of the br-SCP, the output is zero; otherwise it is the equal to the summed output of the *different/same sign br-sEOG corrected br-SCP* objects.

OUTPUTS:



Figuur 0-1.The signal diagram: Trial Rejection Module and Eye-movement Correction Module.

Module 5. Feedback Signal Module (FSM)

INPUTS:

A very important issue in biofeedback is what feedback is applied; and when (real-time or delayed, after a trial) and how it is applied (visually, auditorily, continuous, discrete). The feedback signal module handles all aspects related to the feedback.

The first issue is how we should handle the conditions. In SCP feedback, the most intuitive way of presenting the feedback is 'negative up'. This is because a negative SCP is associated with arousel, which, in turn, is associated with 'up'. Therefore, the br-SCP signal should be inverted.

signal invertor: inverts the br-SCP signal.

Then, feedback should only be provided when the trial is in the active phase. Additionally, the feedback should be terminated when the trial is rejected. The resulting signal is what is called the feedback signal.

feedback inhibitor: creates the feedback signal by setting the inverted br-sEOG corrected br-SCP to zero in the ITI's and preparation phases and when a reject was issued in a trial (otherwise -when all is okay- the output is the inverted br-sEOG corrected br-SCP).

The feedback signal is to be displayed to the subject in the form of a bar of which the heigth is proportional to the feedback signal. Furthermore, values should be set as succes criteria. These values include threshold values the feedback signal has to exceed in order to receive a visual reinforment and threshold values and durations the feedback signal has to exceed in order to receive a auditory reinforment.

A graphical display of the feedback signal and the (trial sequence signal) is provided to the operator in order to keep track of the history of the feedback signal.

negativity/positivity feedback threshold: operator: sets the threshold for the sound reinforcement in negativity/positivity trials and displays the feedback signal on the operator window when it is negative/positive.

negativity/positivity feedback threshold: feedback: sets the threshold for the smiley reinforcement in negativity/positivity trials and displays the feedback signal on the feedback window when it is negative/positivity.

scope FB/TS 10s/div: displays the feedback signal and trial sequence on the operator window (in a graph). - NB 500ms/div

Because two threshold are set that can both be activated in a trial -and only one should be activated depending on trial condition- inhibits are needed that cancel the one threshold not belonging to the current condition.

negativity/positivity success inhibit: inhibits the success signal when the positivity/negativity threshold was reached in a negativity/positivity trial.

negativity/positivity smiley inhibit: inhibits the smiley reinforment when the positivity/negativity threshold was reached in a negativity/positivity trial.

A sound reward should only a given once, irrespective of the number of times success is achieved???. Therefore, once the success criterion is met, the signal that indicates success should be held untill the end of the trial after which it should be reset.

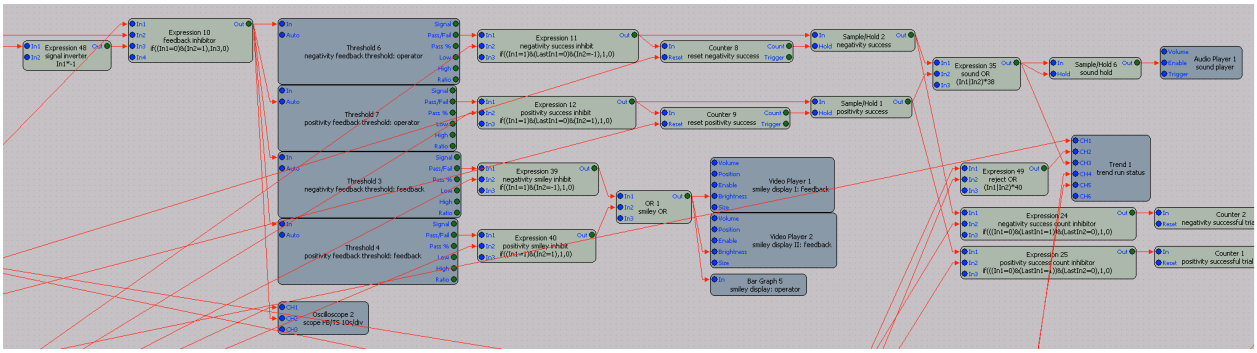
reset negativity/positivity success: reacts to the success signal with a high output when negativity/positivity success is reached (at least once) and is reset at trial start (and end).

negativity/positivity success: holds a negativity/positivity success indication to the end of a trial.

The same sound should be played and smileys should be displayed irrespective of meeting the criteria in negativity or positivity trials. Therefore, the signals are combined to signals that indicate the meeting of the criterion for negativity as well as positivity trials. The smiley reinforcement will than be displayed for the period of time the criterion is met. A sound reinforcement, however, will be inhibited by constant high output once it was already given in a trial. The sound reinforcement signal is held high even after the trial to circumvent the problem of only playing half the sound reinforcement when success is achieved in the last second of a trial.

sound OR: combines negativity and positivity successes to yield a high signal during a trial from whenever success is reached (the output is multiplied by 38 for display purposes).
smiley OR: combines negativity and positivity smiley reinforcement signals to yield a high signal during a trial from whenever smiley reinforcement should be provided.
sound hold: holds the success signal untill one second after the trial to ensure the playing of the entire sound (duration < 1 second) when success is reached in the last second of a trial.
sound player: plays a sound file when success is achieved.
smiley display I: feedback: displays the upper smiley on the feedback window.
smiley display I: feedback: displays the lower smiley on the feedback window.
smiley display: operator: displays a smiley indicator on the feedback window.

OUTPUTS:



Figuur 0-1. The signal diagram: Feedback Signal Module.

Module 6. Trial Counter Module (TCM)

INPUTS:

One way of quanitifying progress of discrete neurofeedback is the learning curve. This is a curve that displays the percentage of successful trials over sessions. To keep track of the percentage of successful trials the count of should rejected trials, valid trials and successful trials should be recorded. This is the function of the TCM.

To calculate the percentage of successful trials, the number of successful and valid trials need to be counted. The number of valid trials are uniquely defined by subtracting the number of rejected trials from the total number of trials.

negativity/positivity trial reject: reacts to a reject signal in a negativity/positivity trial with a high output.
negativity/positivity invalid trial counter: counts the number of rejected negativity/positivity trials.
negativity/positivity trial counter: counts the negativity/positivity trials at the end of the trials.
negativity/positivity valid trial counter: calculates the number of non-rejected negativity/positivity trials.

The feedback protocol with direct feedback when success is achieved has many advantages. One disadvantage, however, is that there is a possibility that after when success is achieved the trial is rejected. Therefore, -to avoid trials are counted is successful and invalid- an inhibit should be applied before counting successful trials. After that, the percentage of successful trials can be calculated by the quotient of the successful trials and the valid trials multiplied by 100.

negativity/positivity success count inhibitor: inhibits the success count when a trial is rejected after it was regarded a successful trial.
negativity/positivity successful trial counter: counts the successful negativity/positivity trials.
negativity/positivity success percentage: calculates the percentage of successful trials in negativity/positivity trials.

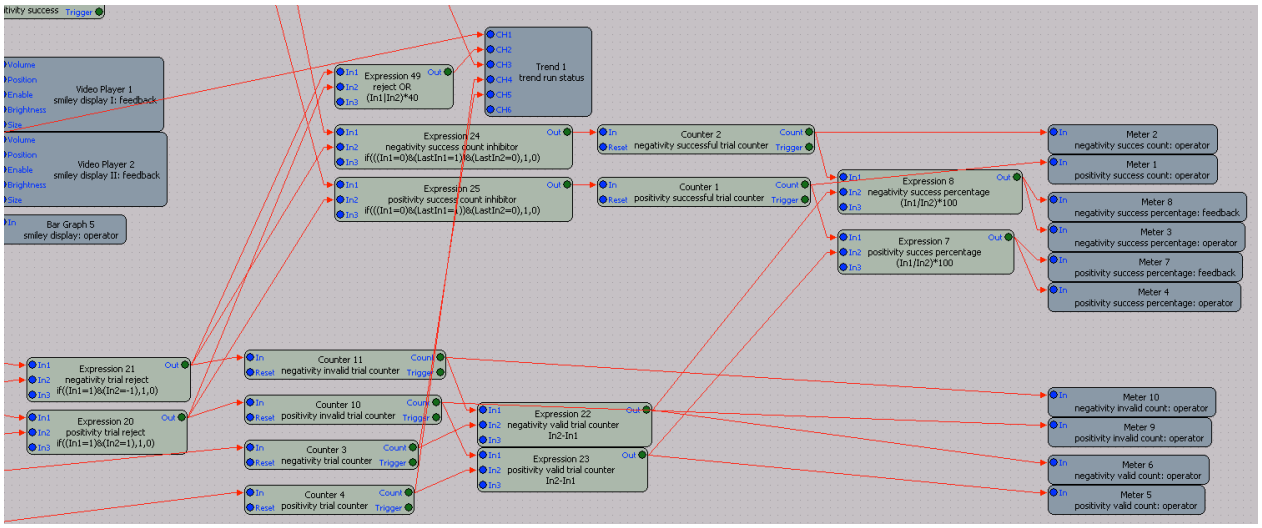
The percentage of successful negativity and positivity trials is fed back to the subject visually and is updated after each trial. The counts of invalid, valid, successful trials and the percentage of successful trials are displayed on the operator window.

negativity/positivity success count: operator: displays the number of successful negativity/positivity trials on the operator window.
negativity/positivity success percentage: operator: displays the percentage of successful negativity/positivity trials on the operator window.
negativity/positivity success percentage: feedback: displays the percentage of successful negativity/positivity trials on the feedback window.
negativity/positivity valid count: operator: displays the number of non-rejected negativity/positivity trials on the operator window.
negativity/positivity invalid count: operator: displays the number of rejected negativity/positivity trials on the operator window.

To inform the operator about the status of the run, a visual display is added to the operator window that indicates which trials are invalid, successful, and if a trial is a positivity or negativity trial.

reject OR: combines the negativity and positivity reject signal (the output is multiplied by 40 for display purposes).
trend run status: displays the status of a run on the operator window; this includes indication of which trials were negativity/positivity trials, invalid trials and/or successful trials.

INPUTS:



Figuur 0-2. The signal diagram: Trial Counter Module.