Multichannel Potentio-/ Galvanostat topologies

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1 Multichannel Potentio-/Galvanostat topologies

There is a multitude of scenarios that demand more than one channel of a potentio-/galvanostat. The reasons vary greatly – just to name a few typical settings:

- automating sequential multi-sensor probing over
- the need of scaling up experiments to more throughput via parallel experiments
- complex multi-electrode arrangements with need for specific synchronized control
- simultaneous comparison of a single or a set of test targets/sensors to a single or a group of reference sensors

As diverse as the reasons for using multichannel arrangements are the choices for solutions. In general, there are four basic approaches:

- multiple single-channel potentio-/galvanostats
- multiplexing
- multi-potentio-/galvanostat
- poly-potentiostat

1.1 Using multiple instruments together

Using multiple single-channel instruments comes with many strings attached and is not acceptable in most situations. Typical downsides include:

- large footprint and complexity of the overall setup due to individual enclosures
- cost intensive
- additional complexity in controlling/programming the overall setup
- in most cases unobtainable synchronization between the instruments

While this might work for adding a second measurement station in a laboratory environment, this approach loses feasibility with higher channel counts.

1.2 Multiplexing

The simple and most often least expensive way is to use a single channel instrument to a multi-channel setting by adding a multiplexer. A multiplexer is basically a set of switches that can be used to switch the measurement ports of the instrument towards several targets. Each port of the instrument needs its own multiplexer/switching components to be multiplexable. There are also scenarios of just switching one of the ports of the instrument and leave the other ports statically connected, e.g. using the same counter and reference electrode but switching between several working electrodes.

There are several points to remember when using multiplexers.

- Measurements must be carried out sequentially leading to time delay between the measurements on each channel.

- Potentio-/Galvanostat-Frontends` main functionality is controlling the cell voltage/current. In a multiplexed setting, only these electrodes that are currently addressed by the multiplexer are “active” and therefore can be regulated. The other ports/electrodes will be left floating during this time.
- Switching means that the potentio-/galvanostat circuitry have to settle again and again with every switch event. Even neglecting parasitic effects this will at least diminish the quality of both setpoint and measurement value. This can of course be countered by extensive delays after switching to wait for the instrument to reach a fully settled state – this settling time depends largely on bandwidth of the instrument in close relation to the overall impedance of the cell/device under test connected to the instrument.
- No switch is ideal, but rather comes with a range of parasitic properties.
- Having more channels connected to one channel adds up the parasitics of the switch components that are connected jointly at one point.

None of these points can be evaluated without looking at the specific applications requirements and the specific technical parameters of the multiplexer/switches. The most important parameters for multiplexers potentio-/ galvanostat and impedance spectroscopy instruments are:

- On-Resistance: The series resistance the switch introduces to the signal path while the switch is turned on. This resistance leads to voltage drops in the current carrying paths and thus takes a current dependent piece out of the available compliance voltage range.
- Input impedance: Electrical impedance parallel to input (typically to a reference point in the circuitry like ground or PCB/enclosure). The resistive component contributes to offset errors and added leakage currents (the lower the resistance the worse the effect). The capacitive component adds to loading both cell/device under test and the instrument itself and limits the bandwidth of the measurements. Measuring impedance, the input impedance especially at reference and working sense ports directly limits the dynamic range of the measurements and put an upper limit to the measurement range in the order of the input impedance.
- Off-Isolation: The capability of the switch of blocking electrical signals (typically at AC) when the switch is turned off. This is either given as isolation in dB (signal damping ratio, typically specified for 50 Ohm source and termination) or isolation impedance.
- Leakage current: currents flowing in/out of the switch terminals through other paths than the primary signal path from in to out. These currents can also flow when the switch is turned off and or when the output is connected to a high impedance (e.g. reference electrode input). In floating or high impedance situations, these currents will also lead to charging the terminal which can potentially lead added charge injection during the next switch event or to voltage build up – both potentially harmful to sensitive sensors.
- Charge injection: The amount of charge inserted into the system at a switch event. If too high this may alter reaction kinetics or lead to additional time for resettling circuitry.

There are several types of switches that can be used for these purposes. Semiconductor switches are very affordable have low power consumption and small footprints. On the downside they have relatively bad parasitic characteristics with leakage currents typically between several pA up to a few nA and input capacitance of a few to several hundred pF. A much better choice in terms of parasitics are relays, better yet reed relays. High quality reed switches will offer several TΩ and <1pF off isolation, extremely low parasitic capacitance < 0.7 pF (close to no cell loading), mΩ On-Resistance, zero leakage current in on state and close to zero charge injection. On the downside they are much more expensive, very large and require lots of power to operate when compared to semiconductor switches.

No matter what type is chosen, feasibility of a specific switch/multiplexer must be carefully evaluated for each application. In some cases the parasitics and timing constraints won´t matter at all, in some they decrease quality and in some they might even end up breaking the sensors.

1.3 Multi-Potentio-/galvanostats

Multi-Potentio-/galvanostats ("multipot") are basically several potentio-/galvanostat-frontends joint in one system. Due to the independent channels operating in true parallel, full parallelization of experiments can be achieved. This results in all the power of having several instruments including independent control without the major drawbacks:

- Smaller footprints due to shared hardware between the channels
- Cost savings compared to several individual instruments
- Easy setup of multichannel arrangements
- Synchronization between channels through internal hard-/firmware

While there are exceptions, typical multipots will not have galvanically isolated channels. This means their channels are not electrically independent. Practically speaking: Current flow between the channels is possible and thus the regulation in one channel can interfere with another channel. So in most applications each channel should be used on an galvanically isolated/electrically independent cell/device under test. Special care must be taken if a multipot is to be used in a non-isolated multichannel setup (e.g. multiple electrodes in the same solution).

1.3.1 Fully Parallel Sampling Multipots

The default case of a multipot will have all components of one channel again for each channel. This also means that not only the regulation of cell voltage/current, but also all the measurements will be taken fully parallel. This type of multipot will basically perform the same as actually having several independent instruments. For most multichannel applications, this is the "go to" solution and will cover almost all possible requirements.

1.3.2 Sequential Measurement Multipots

In this less typical case of multipots the actual measurements (digitization of measured data) is not done fully parallel. Since it is still a multipot, the actual frontend components (all the amplifiers, set point generator and other components making up the potentio-/galvanostat) will still be there for each channel. This means the regulation of cell voltage/current is done independently and fully parallel. But in contrast to the default case all or a set of the channels will be sampled (meaning the analog-to-digital-conversion of the current state of cell voltage/current) sequentially. This eliminates the need of having fully parallel sampling ADCs with the advantages of massive reduction in: control/synchronization effort, hardware footprint, cost and power consumption.

If the timing demands of the application allows for it, this specific topology offers great savings in space, power and cost over conventional multipots. Especially for handheld, point-of-care or other cost-sensitive applications this might be a good choice.

1.4 Poly-Potentiostats

Poly-Potentiostats ("polypot") consist of a single potentiostat with one counter and one reference port, but with several working electrode ports. One of these working electrodes will be distinguished from the others in the sense that this is the electrode against which the regulation of the potentiostat is performed.

In theory also galvanostat mode is possible for this topology with current into the distinguished working electrode is controlled, but since the potential measurement will only be performed against a single reference electrode this mode is generally not used.

Measurement of currents into the working electrodes can be either fully parallel or sequential. While parallel measurement offers a fully synchronous view of kinetics at all working electrodes, sequential measurement offers advantages in terms of size, cost and power consumption.

Even in sequential measurement mode the regulation will naturally be synchronous since there is only one regulation circuitry for all working electrodes. Thus e.g. if a CV is applied this will happen fully synchronously for all channels.

Since all working electrodes belong to the same regulator circuitry they must be electrically coupled (as opposed to galvanically isolated). Typical scenarios will have all electrodes in the same cell/solution. This also means that special attention must be paid to the dependencies between the channels. The current of all working electrodes will be seen as combined load for the counter electrode. This introduces some pitfalls:

- Compliance current must match the combined maximum current
- Current carrying capabilities must match the combined maximum current
- Current density distribution might be inhomogeneous resulting in offset effects

Also there is the problem of cross leakage: Currents flowing from one working electrode to the other might arise from potential differences between the working electrodes. Even without actively offsetting the working electrode potentials there are still the effects of unwanted input offset voltages and input leakage currents.

Optionally the polypot-topology can be extended with independent offsetting on each working electrode. This again increases footprint, cost and power consumption compared to a standard, but also adds new possibilities. Introducing one independent offset generator per working electrode each working electrode's potential can be offset against that of the distinguished working electrode. Even additional dynamic modes of operation could be performed e.g. with one electrode remaining quasi-static while another being exposed to a cyclic voltammetry ramp.

The true power of this topology comes from the enormous savings in circuitry compared to multipot architecture. Power consumption, size and cost will be greatly reduced at the expense of independent control. In settings where experiments are to be fully parallel, independency of electrodes and experiments is not required and cost/size/power are of issue a polypot might be the best available choice.

1.5 Combinations

All these topologies can be combined to match more complex application requirements. For example each channel of a multi-potentio-/galvanostat can be extended with a multiplexer. Also more sophisticated combinations of multi- and poly-potentiostat-topologies (several poly-potentiostats with several working electrodes each combined in one “multi-polypot”) are feasible.

1.6 What we can do for you

Sciospec’s extensive modular platform covers all these topologies and is flexible enough to combine almost any potentio-/galvanostat-requirement with any of them. Apart from our standard solutions the technology platform enables us to create cost effective fully custom solutions. Massive multichannel capabilities and extensive scalability are at the heart of our technology portfolio so whether you need just a few channels in a compact handheld form factor, want to address a newer before seen sensor topology with complex control demands or need to massively scale up a process to several thousand channels – Sciospec is up to the task.

If you have more questions or want to find out how to address your application´s requirements feel free to contact us.