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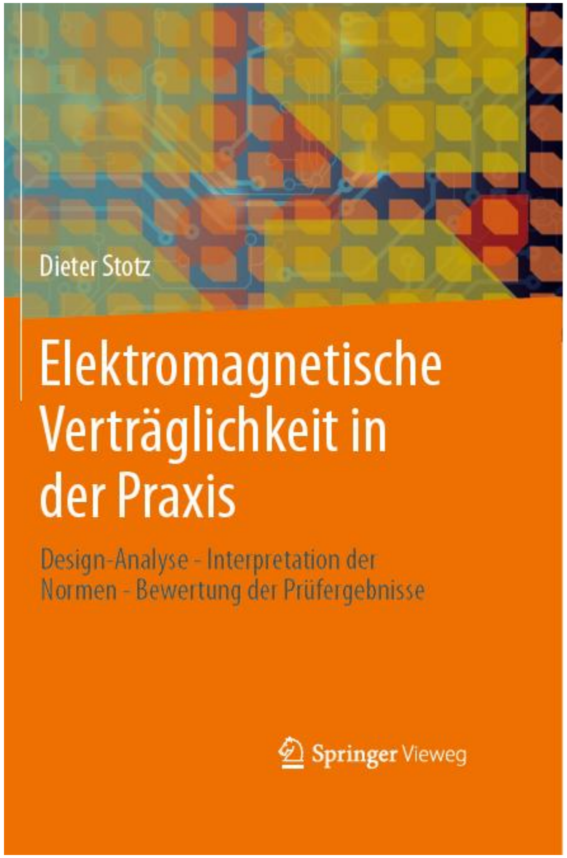
Books by Dieter Stotz



Measuring Liquid Levels with QuickField

Level measurement on liquids – Extensions (special cases in the field) with the following themes:

- **Conical vessel shapes**
- **Temperature gradient and inhomogeneous conductivity**
- **Measurement systems with finite internal impedances**
- **Poor conductivity and AC measurement**
- **Very high conductivity, similar to metal**
- **Effects by foam generating media**
- **Effects by build-up**

The first part explained the theory and the use of QuickField for analyzing. This is the second part, which will take focus on special circumstances of the parameters and geometry.
While we assumed cylindrical vessels in the first webinar part, we want to have a look at a vessel, which is of a conical shape.
In the field, you never would have ideal homogenous media. Especially there is most often a temperature gradient, and thus a gradient of conductivity. Our focus will be on linearity effects caused by this.
The measurement system provides just finite impedances. What happens, when the medium's impedance comes in scales of the one of the measurement system? We will analyze that.
A similar theme is media with poor conductivity like distilled water or WFI (Water for Injection), which does not provide sufficient conductivity, but still enough electrical permittivity. What happens, when we are using higher frequencies?
The opposite is a medium with very high conductivity, like alkaline or acid solution could constitute. Which kind of nonlinearity do we have to expect?
Some applications (especially in dairy or brewing industries) do have foaming media. Are we able to estimate the behavior of our level measure method then?
Last but not least, some media can produce a so called build-up, that means remaining medium between the rod and the vessel's wall, which can have influence to the measurement.

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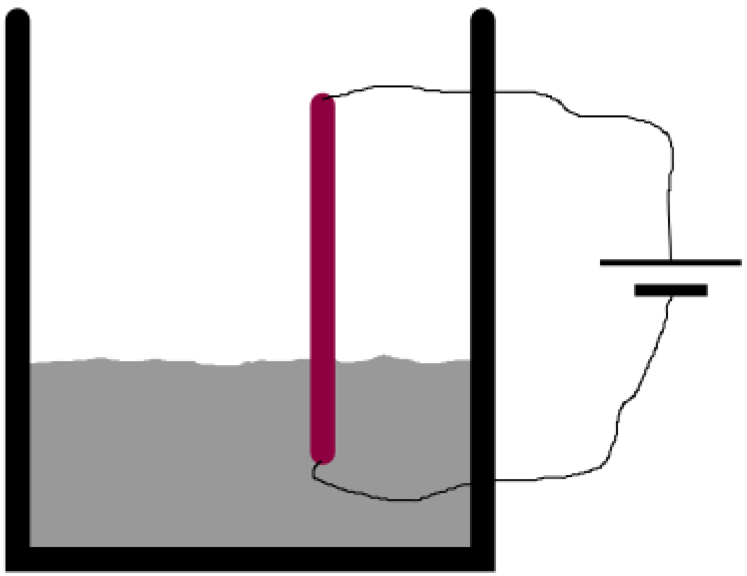
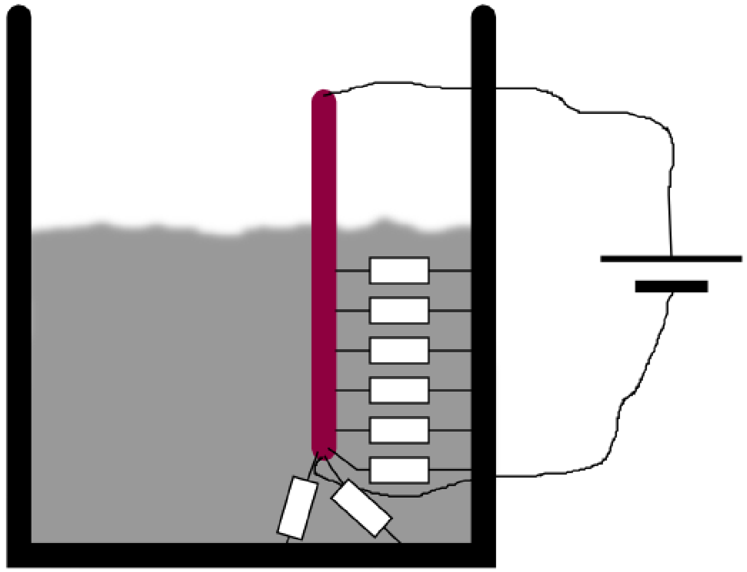


- Potential difference between rod‘s ends
- Current through rod
- Medium with conductivity
- Conductive vessel
- Wires and rod isolated

First of all, we should repeat the explanation for the principle shortly.
The most important thing is a potentially free metallic rod, which has to be energized by an electric current.

Measuring Liquid Levels with QuickField



- Distributed resistors caused by the medium
- Conductivity to the vessels bottom

As long as the medium provides some conductivity, it is like distributed resistors all along the vessel. I have to mention , that there is also a certain conductivity against the bottom side, which will cause special effects discussed later on.

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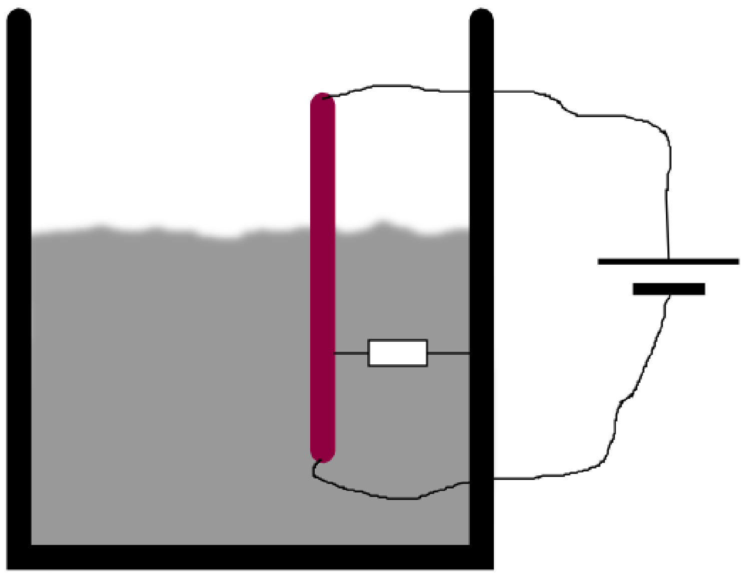
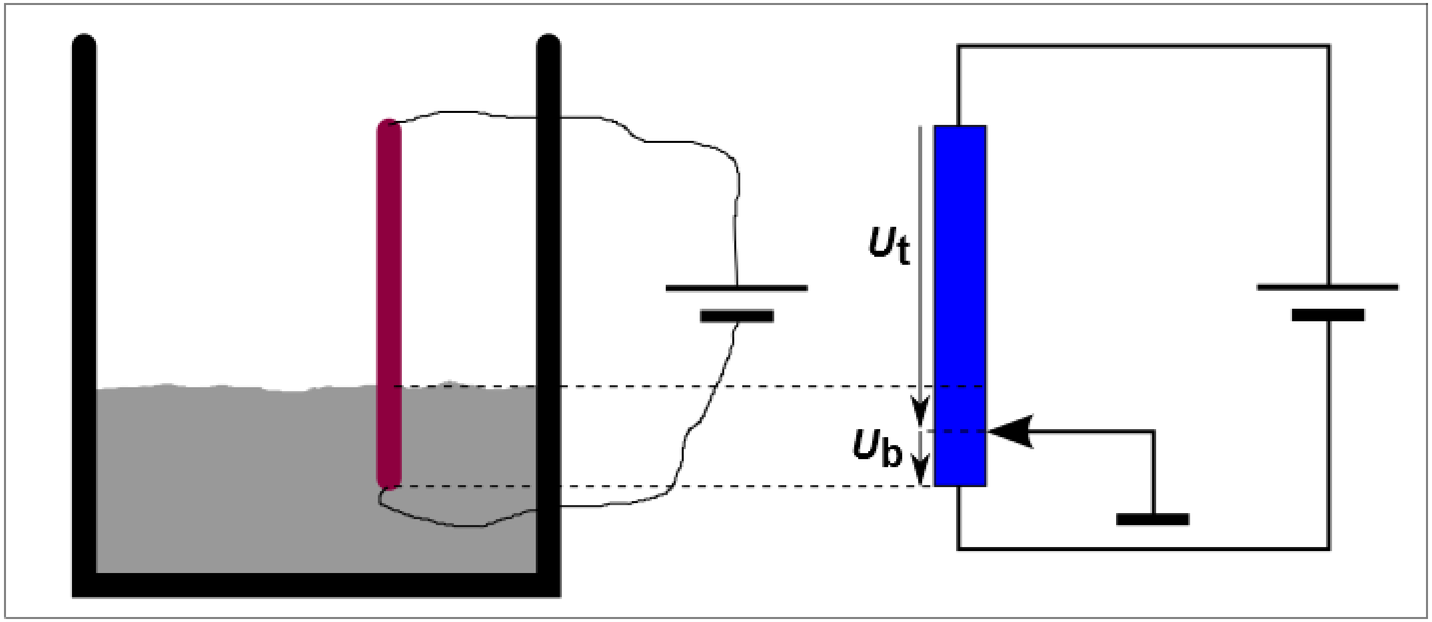


- Reducing to a central resistor
- Emphasis of the conductivity
- Half height between rod‘s bottom and liquid‘s surface

All these discrete resistors could be imagined as a single one, which is then positioned in the middle of the whole covering level, better said at the emphasis of conductivity.

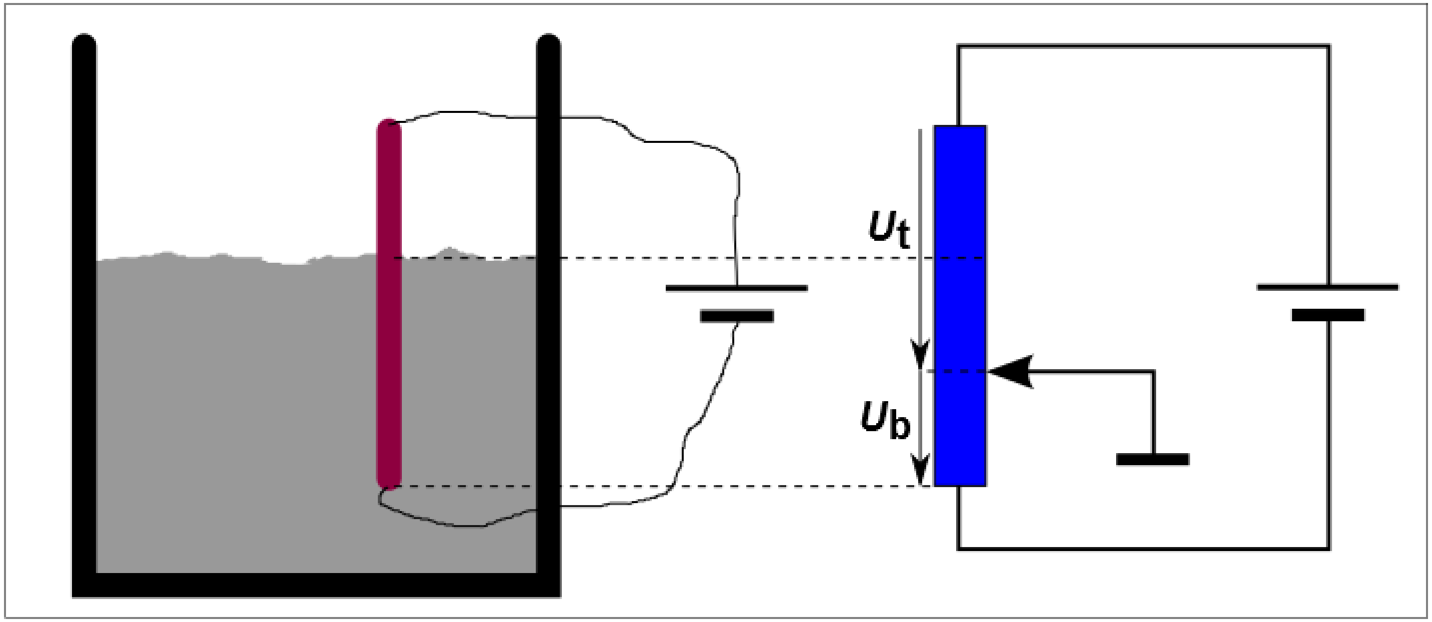
Measuring Liquid Levels with QuickField



- Potentiometer equivalent circuit
- Partial voltages

Let's have a look at the equivalent circuitry: The metallic rod is the potentiometer's track, the wiper is the liquid itself. The partial voltages are the measure of the filling level.

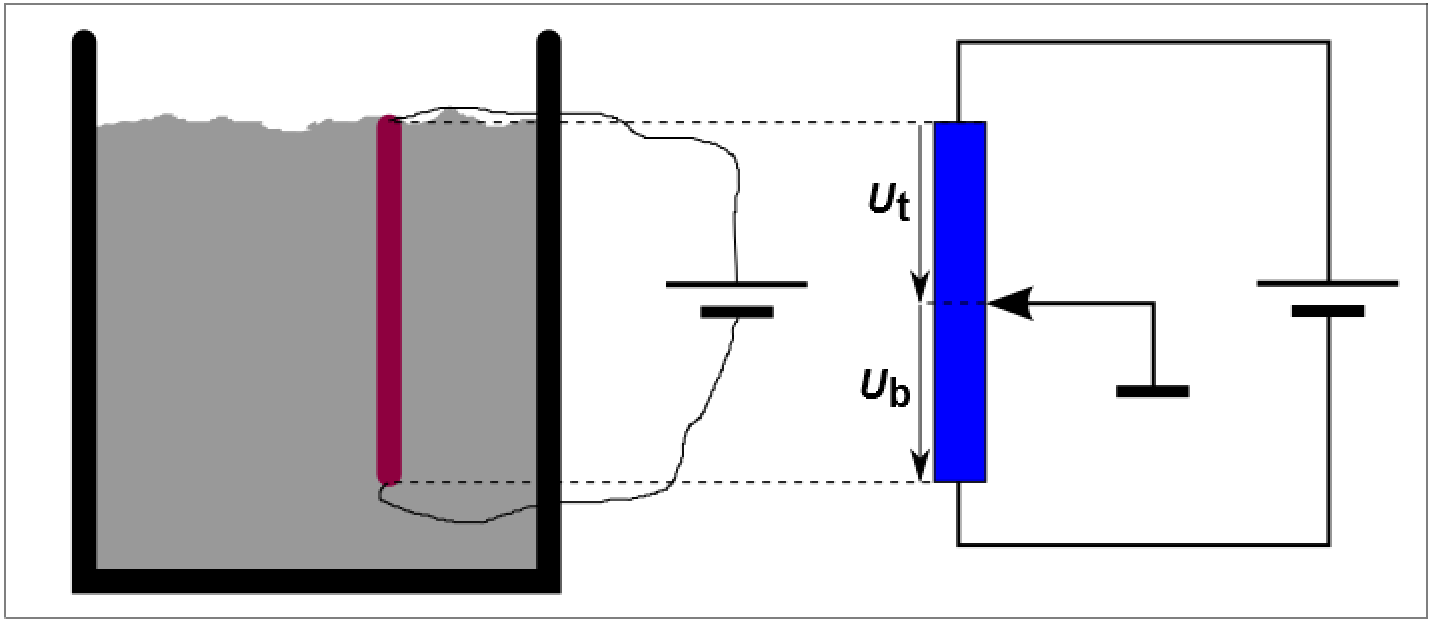
Measuring Liquid Levels with QuickField



- Increasing Liquid Level

.. and this changes, when filling height varies.

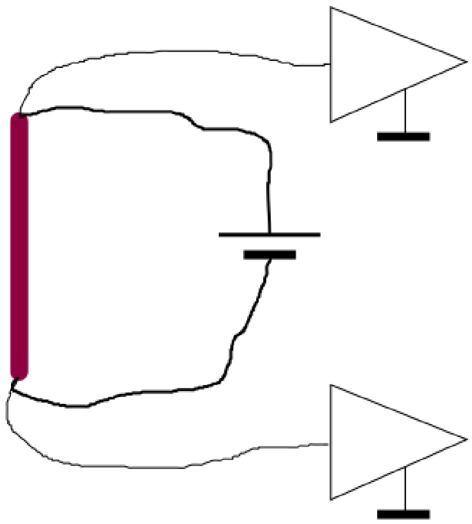
Measuring Liquid Levels with QuickField



- Increasing Liquid Level
- $2\,\frac{U_b}{U_b+U_t}$

.. and once more increasing level. A simple expression provides the relative level.

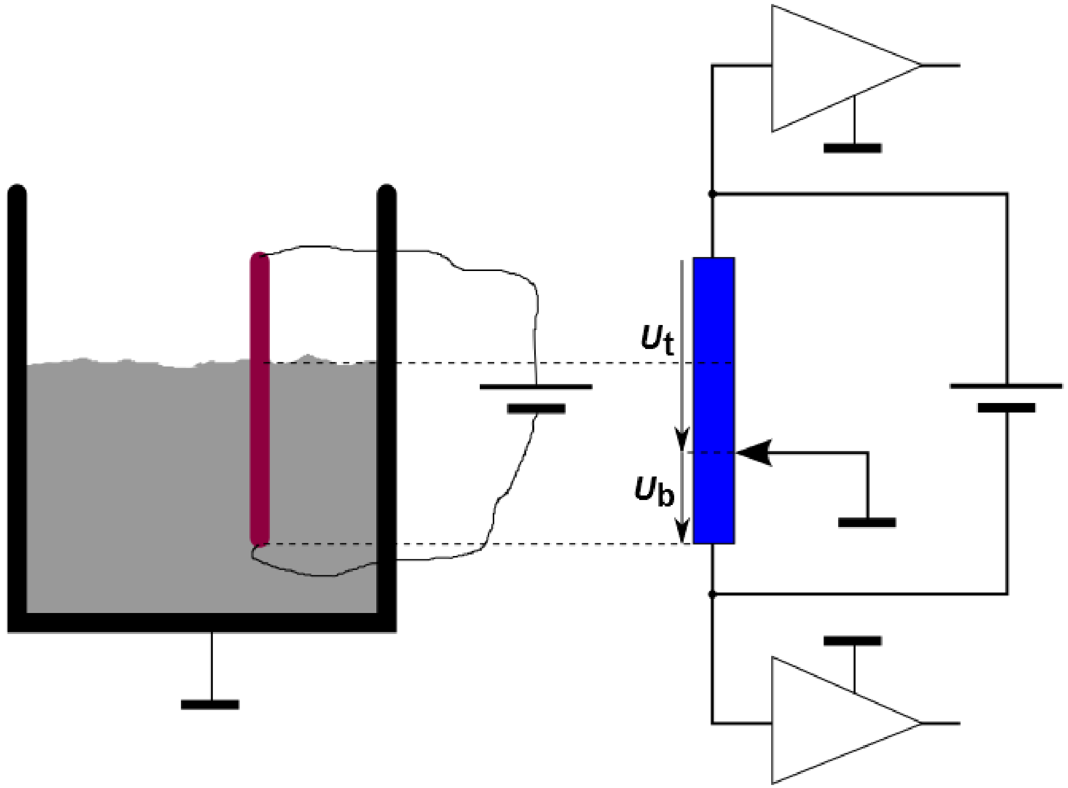
Measuring Liquid Levels with QuickField



- Four wire measurement
- High impedance of the system
- Potential freedom of the rod
- Technology of the rod (internal wires in a hollow hose)

In praxi there is a four-wire-measurement required with a very high-impedance amplifier system. Once again: The rod has to be isolated from the vessel, the only connection is via medium. The leading of the wires can be a technological challenge as well as the electronics.

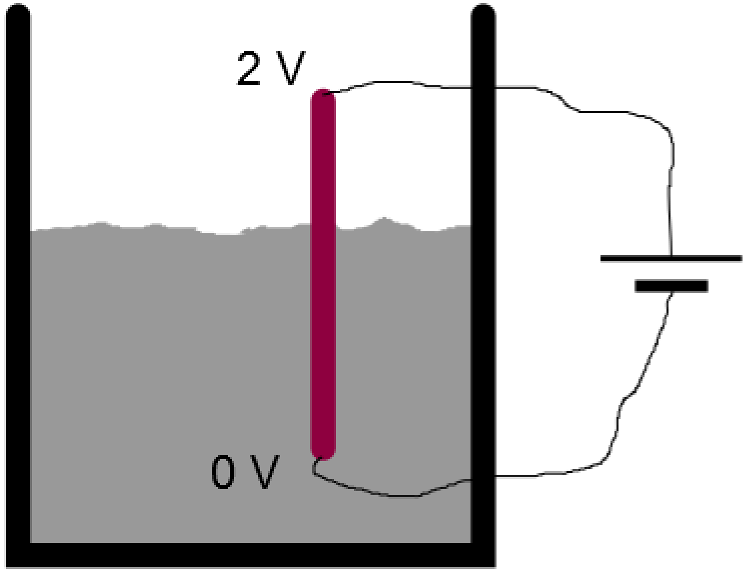
Measuring Liquid Levels with QuickField



Here it is shown the whole principle once more. To avoid electrolytic effects and to enhance the signal processing it is needless to say, that the rod is energized by AC. Other than in this figure, where the vessel is naturally grounded and all other voltages refer to this …

- Principle of the measurement
- AC energizing

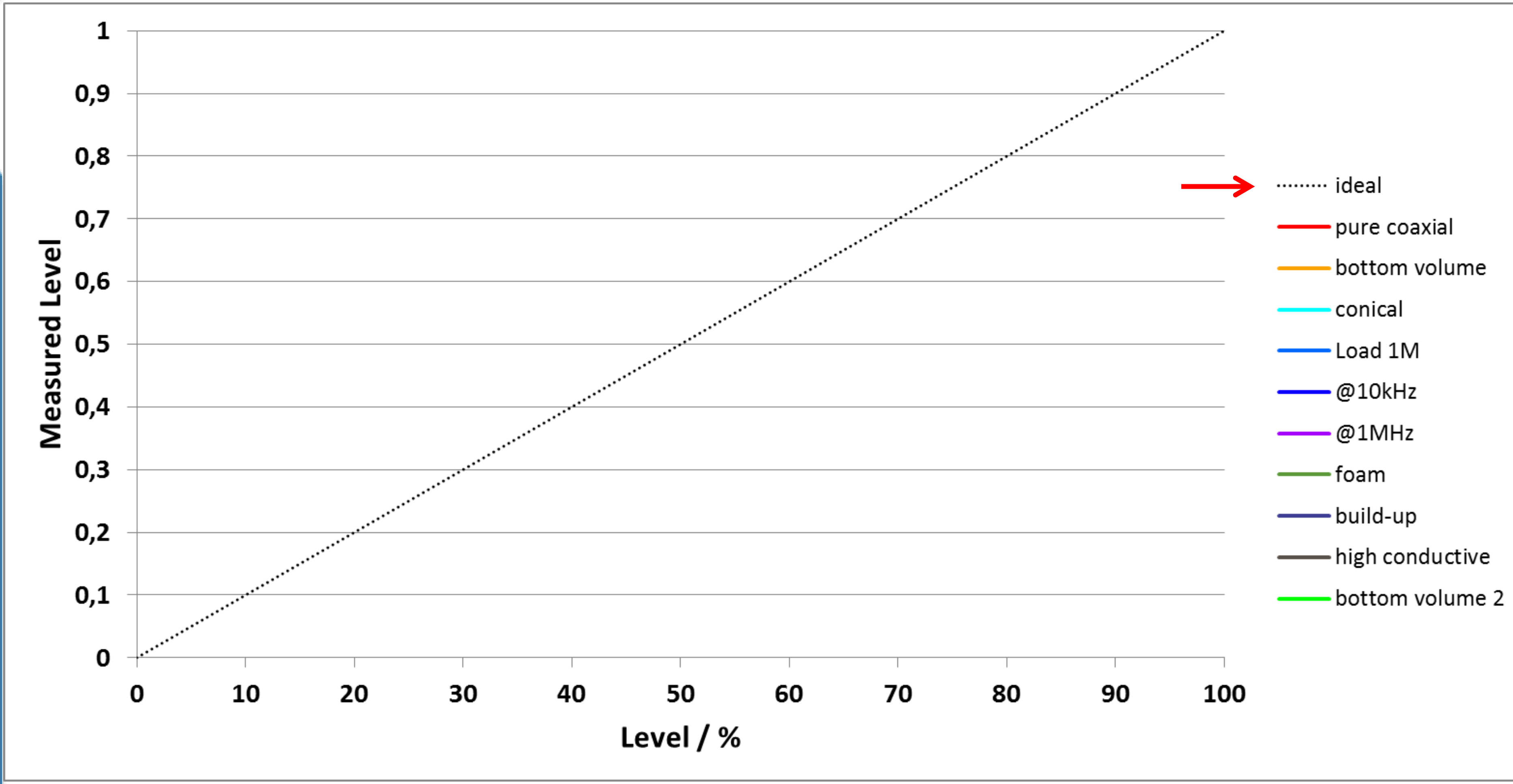
Measuring Liquid Levels with QuickField



- Simplification for simulation (vessel is potentially free)
- Potential difference between the rod's ends is 2 Volts to get normalized values.

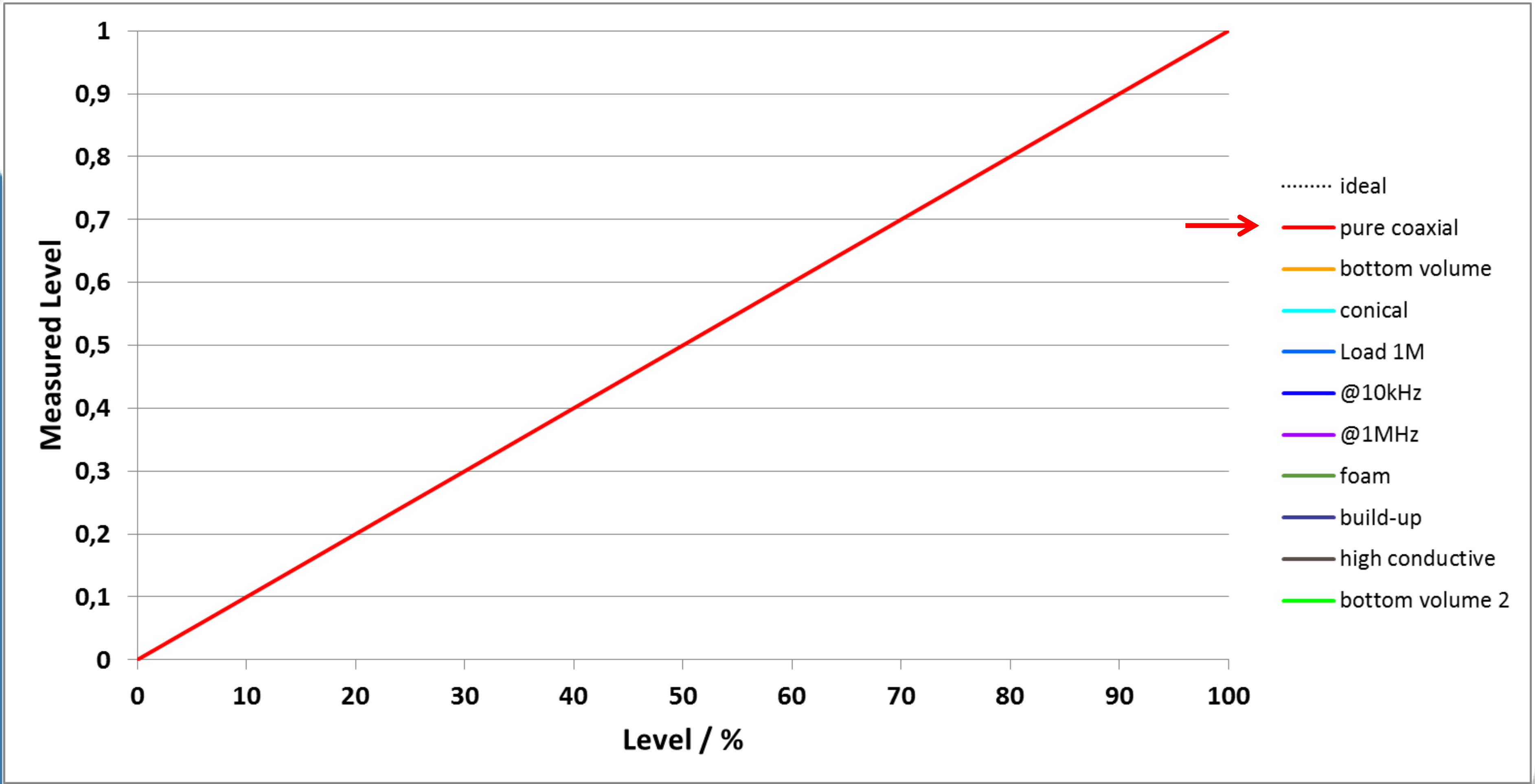
… we do a simplification for the simulation. Namely our bottom side of the rod is having 0 Volts, the vessel is potentially free and this is our measuring point at the same time. The third simplification is, that we don't need both partial voltages, as we assume the reference voltage to be defined and constant. Furthermore it is functional to use 2 Volts, as then the 100% covering medium will provide 1 Volt as a sign of maximum filling height, like it is by using normalized values.

Measuring Liquid Levels



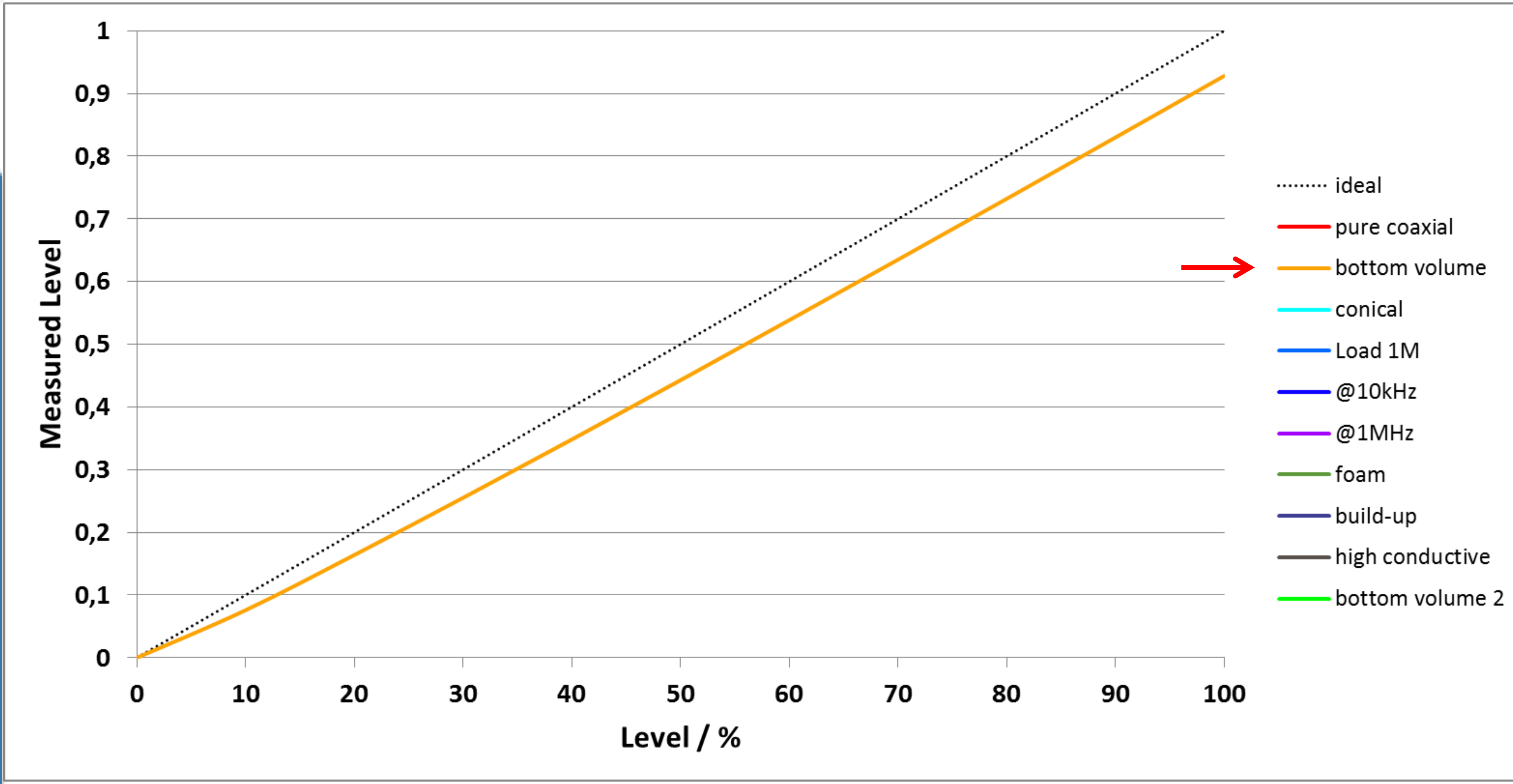
Now we want to have a look at all the results, which QuickField gave us by simulating several situations. The correlation between relative filling height and measured level will be shown in a diagram. The ideal behavior would be like the dashed line shows.

Measuring Liquid Levels



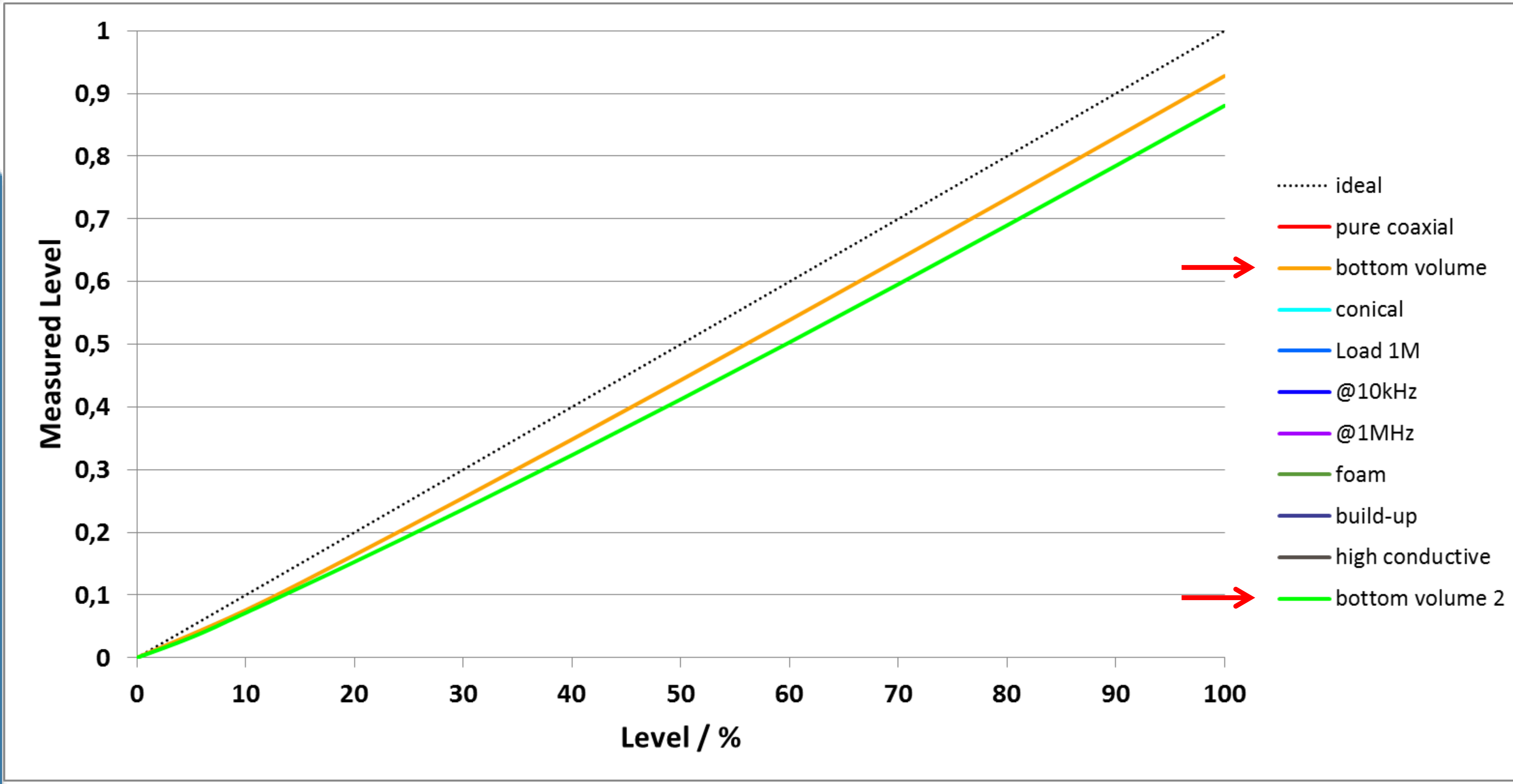
As long as we have coaxial medium exclusively, there is no deviation from the ideal curve. This would require the vessel's bottom to be isolated and the rod's bottom has to lie on here.

Measuring Liquid Levels



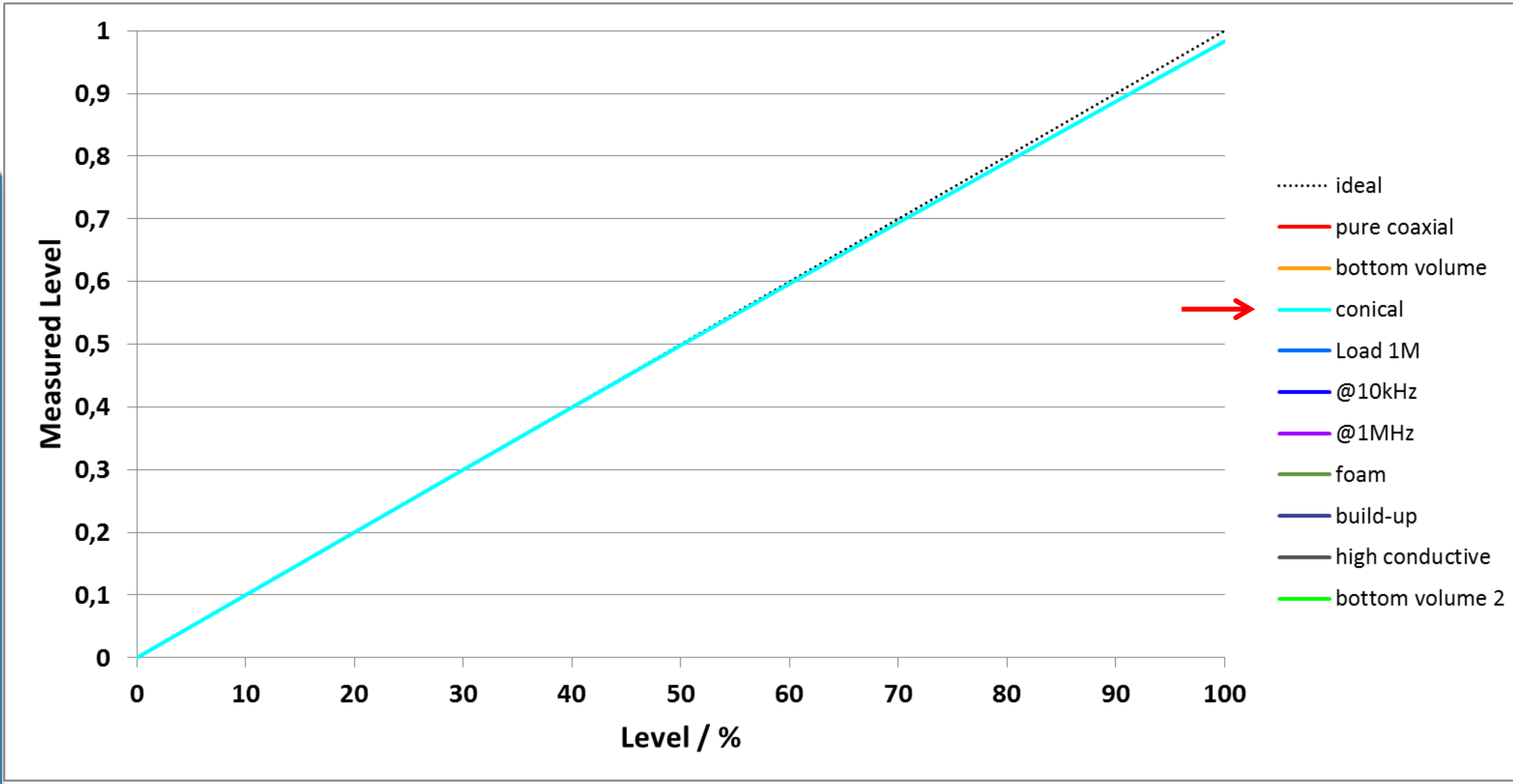
Other than this, we have bottom volume here, namely the distance of the rod to the vessel's bottom is the same like the vessel's radius. As you can see, the curve does not reach to 100% and there is some nonlinearity. Okay, you can always calibrate to 100%, but the nonlinearity remains.

Measuring Liquid Levels



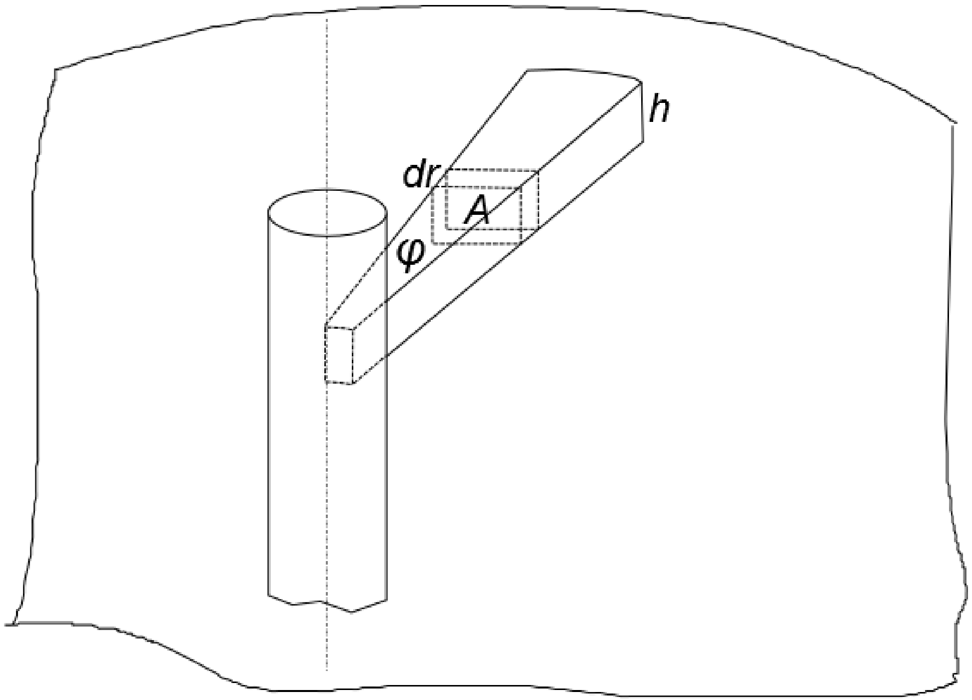
It becomes worse, when the distance from rod's tip to bottom is just the same like its diameter. The endpoint goes under 90 percent. But the effect is bearable.

Measuring Liquid Levels



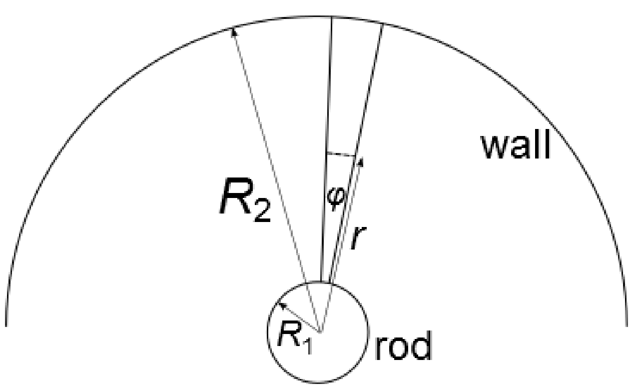
If the vessel is of a conical shape, the upper conductivity is less, so the expected curve is not reaching 100% either. But although the conical manner is strong, the effect is just slight. We can have a look …

Measuring Liquid Levels with QuickField



$$\left.\begin{aligned} A &= \varphi \cdot r \cdot h \\ dR &= \rho \cdot \frac{dr}{A} \end{aligned}\right\} \Rightarrow dR = \frac{\rho}{\varphi \cdot h} \cdot \frac{dr}{r}$$

$$R = \frac{\rho}{\varphi \cdot h} \cdot \int_{R_1}^{R_2} \frac{dr}{r} = \frac{\rho}{\varphi \cdot h} \cdot [\ln(x)]_{R_1}^{R_2}$$

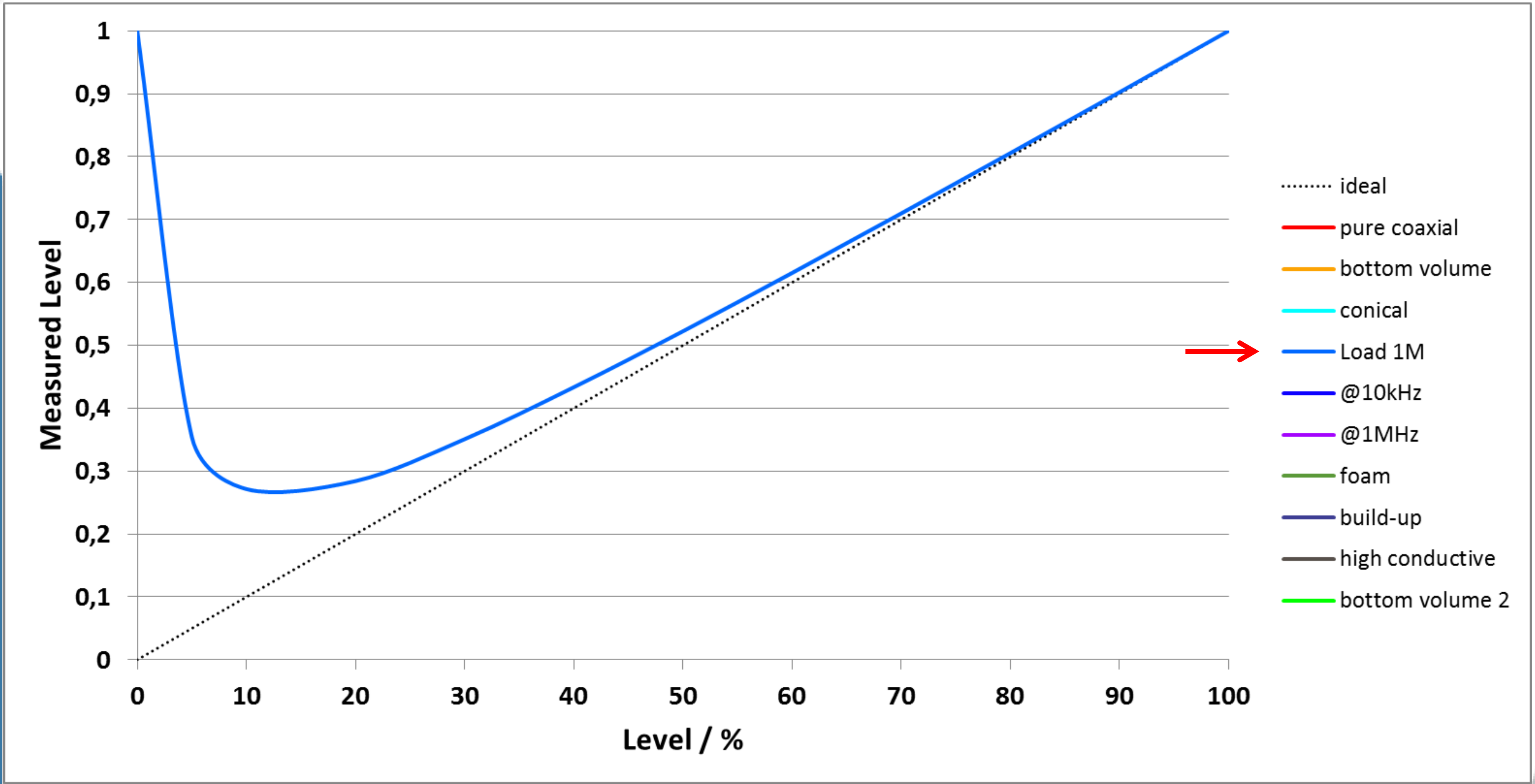


$$R = \frac{\rho}{\varphi \cdot h}[\ln(R_2) - \ln(R_1)] = \frac{\rho}{\varphi \cdot h} \cdot \ln\left(\frac{R_2}{R_1}\right)$$

… at the mathematical relationships to understand why. A resistor element is having a logarithmic correlation to the ratio of the radii. As long as this ratio is big, a relative increase of this makes just a slight growth of the logarithm.

By the way, it is not critical either, to position the rod not exactly in the center, but more at one margin of the vessel – by the same reason.

Measuring Liquid Levels

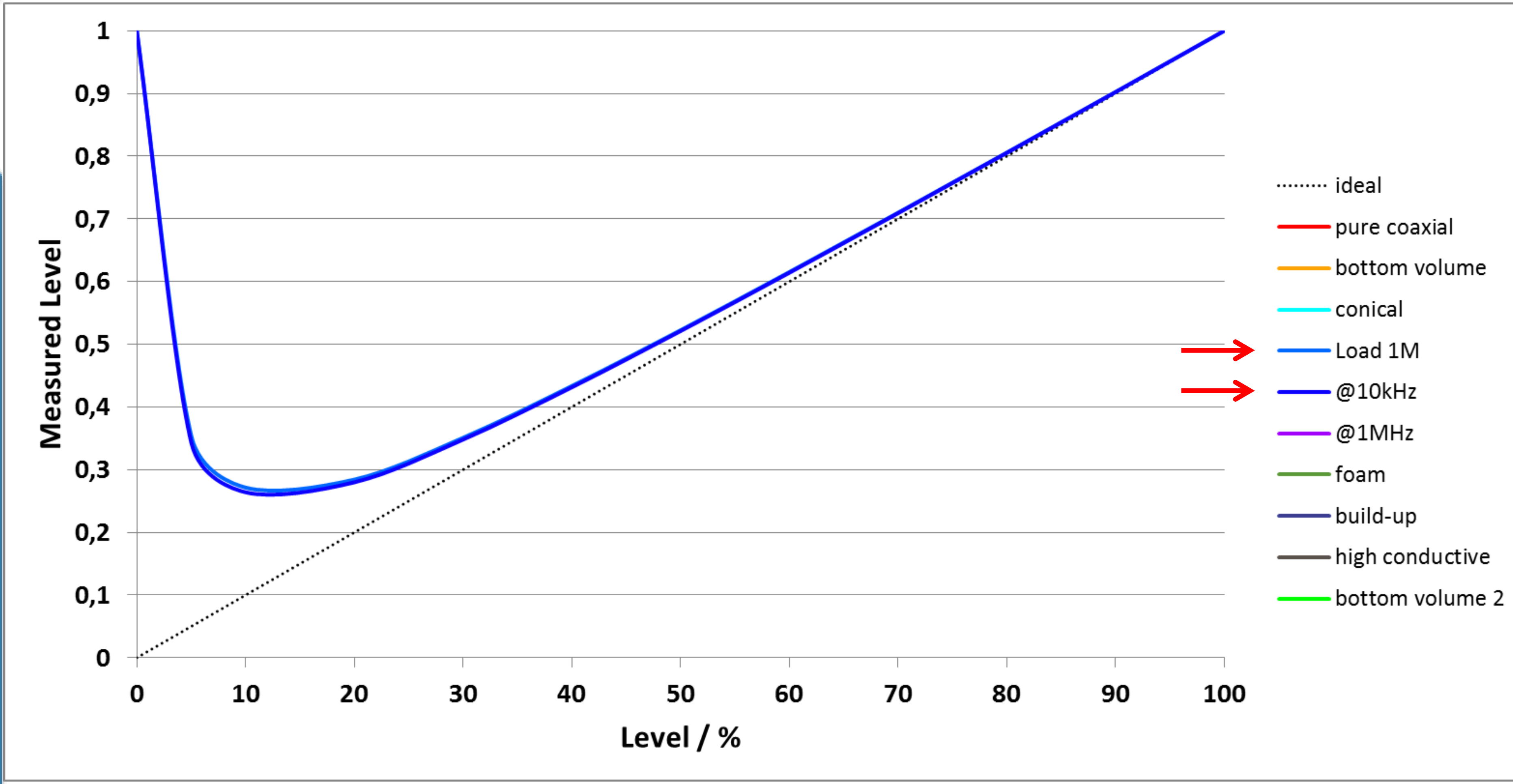


Normally, we cannot avoid that the amplifier system is having finite impedances. A value of 1 Megohm is a plausible value. We defined a conductive block in the model to achieve this. This load has to be connected to the midpoint of voltages of the rod's ends, that means 1 Volt. Please refer to the equivalent circuit diagram, where the impedances lead to ground, thus to the mentioned midpoint as well.

Thereby this load naturally pulls the voltage towards 1 Volt, especially if the medium's conductivity is low and/or the filling height is low.

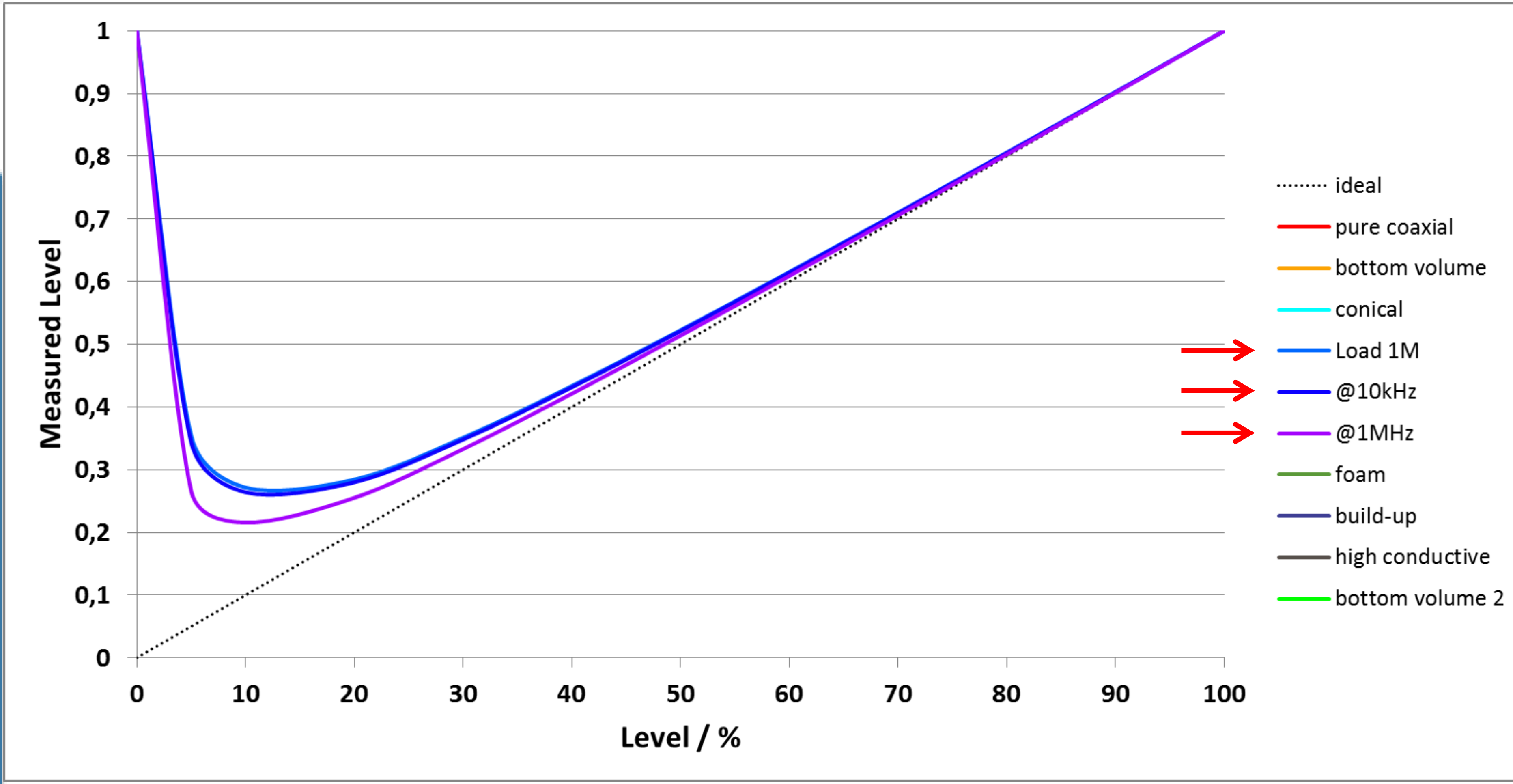
Sometimes it is a problem to differentiate high level detection. A reasonable way is to have a separate electronics system that says, whether or not the rod is immersed deep enough or not, quasi as a immerse detection with a threshold.

Measuring Liquid Levels



Up to now, we exclusively used DC situation. When we increase the frequency to 10 kHz, you can see a slight enhancement.

Measuring Liquid Levels



Further frequency increase makes the result still better. You can see, for measuring water with low conductivity, you do need higher impedances of the electronics, and you have to use AC measurement.

Measuring Liquid Levels with QuickField

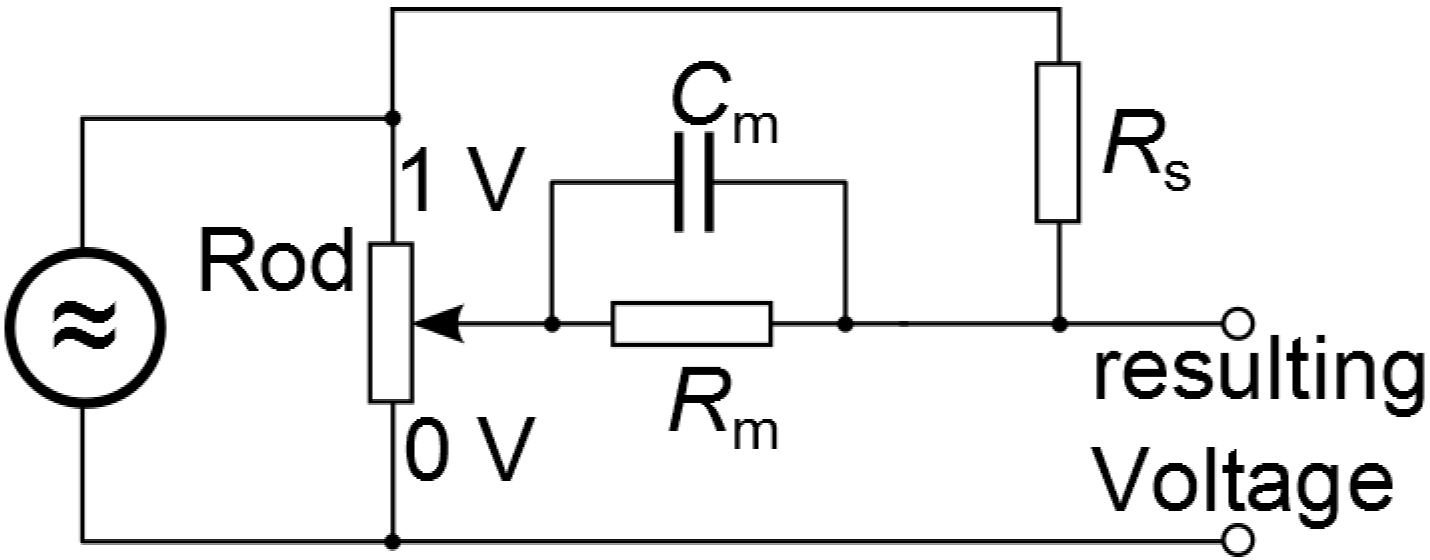
$$\kappa^* = \omega \cdot \varepsilon_0 \cdot \varepsilon_r$$

$$f = 10000\ \text{Hz},\ \varepsilon_0 = 8{,}85 \cdot 10^{-12}\,\frac{\text{As}}{\text{Vm}},\ \varepsilon_r = 81$$

$$\kappa^* = 2\pi \cdot 10000\ \cdot 8{,}85 \cdot 10^{-12}\ \cdot 81 \cdot \frac{\text{A}}{\text{Vm}} = 0{,}45\ \frac{\mu\text{S}}{\text{cm}}$$

By the way, you can calculate the permittivity of a medium as an equivalent to its conductivity. For instance, non-conducting water would represent a pseudo-conductivity (as permittivity) of 0,45 uS/cm, if you are using a frequency of 10 kHz.

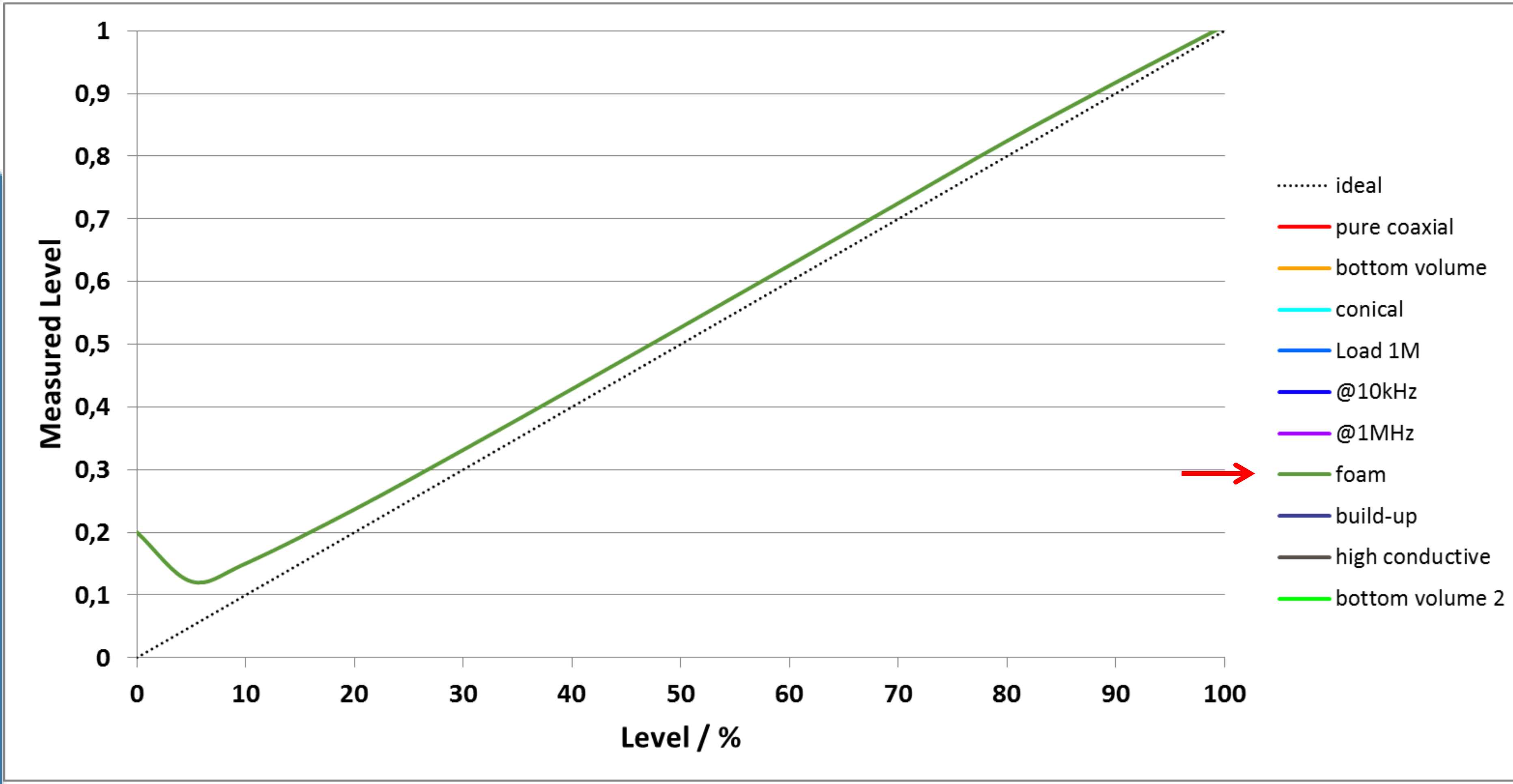
Measuring Liquid Levels with QuickField



C_m = capacitance of medium
R_m = resistance of medium
R_s = impedance of measurement system

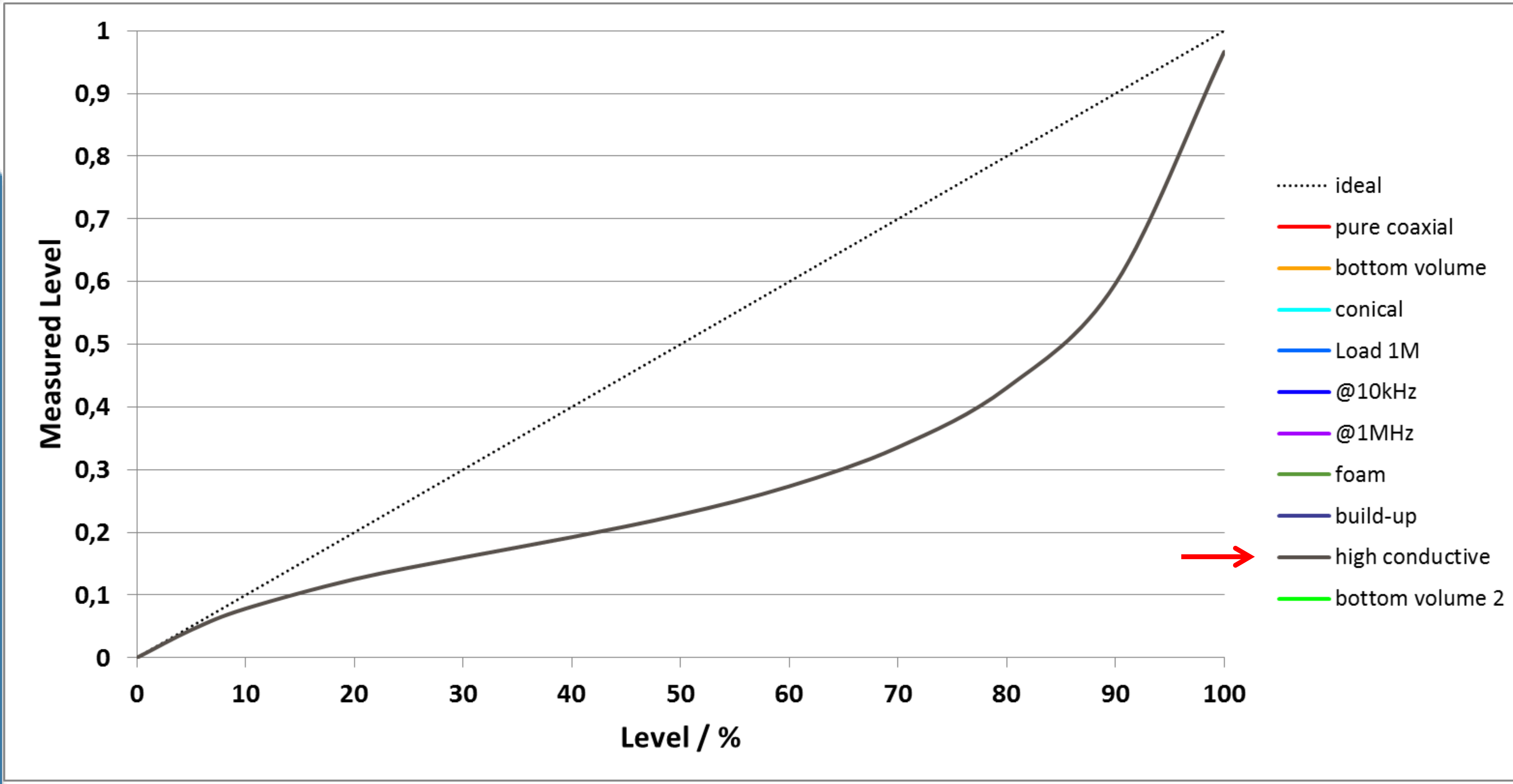
It is needless to say, that a combination of capacitance and resistance would cause phase shift effects to the measurement. Looking at the equivalent circuitry, we can see how medium capacitance is working. Please don't be bothered about the circumstance, that here the potentiometer's voltage is 1 Volt, while we always spoke about 2 Volts. This is because the wiper can fully go to the upper side for 100% filling level, while in praxi the wiper produced by the medium only can move to the middle of the rod's track.

Measuring Liquid Levels



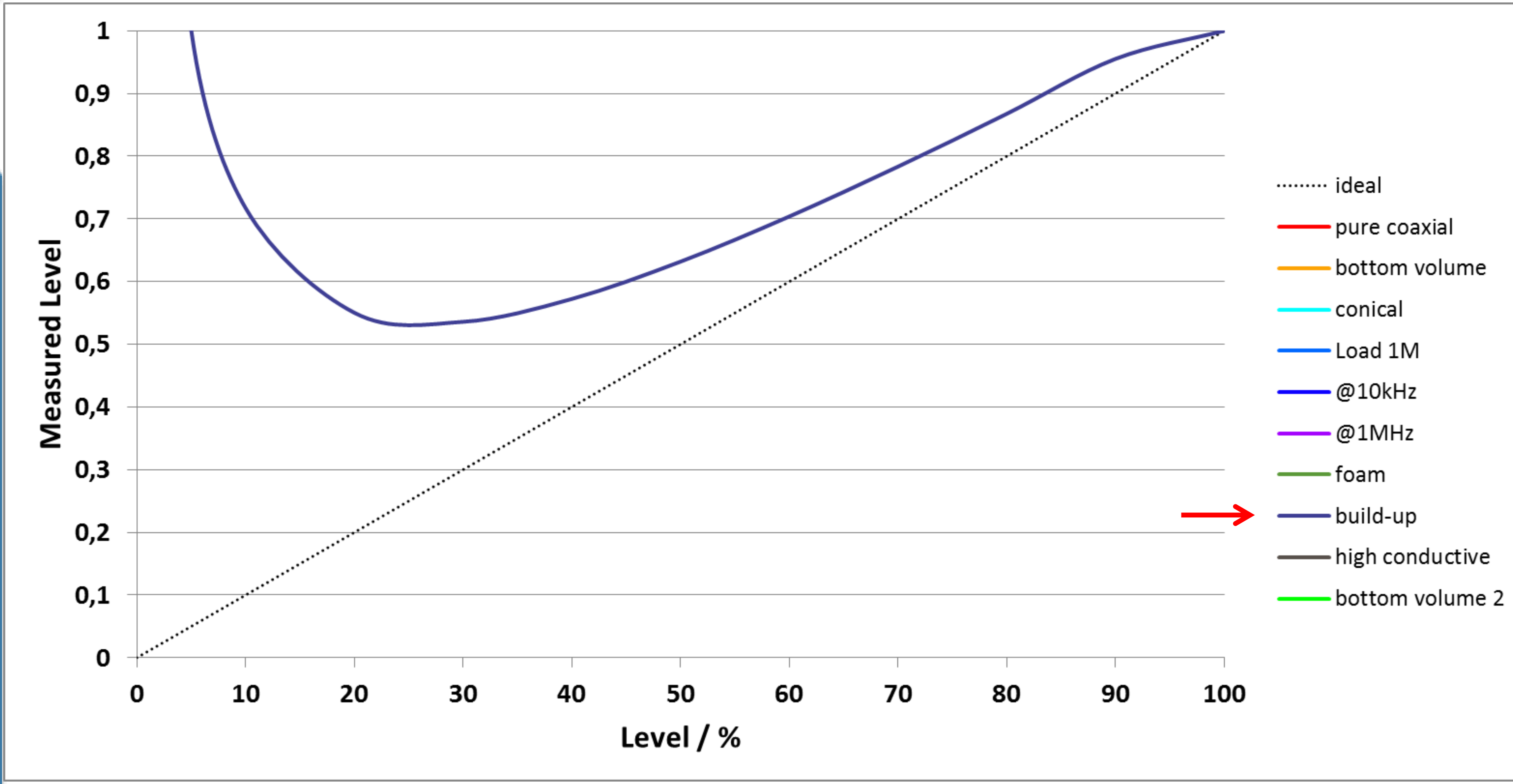
Similar to a load in the electronics, foam makes a shift of the measured level. But in opposite to that, there is an offset in the upper filling levels too. The foam is of 20% filling level on top of the liquid and its conductivity is 10% of that of the medium.

Measuring Liquid Levels



Very seldom you will have a non-linearity caused by the high conductivity of the medium. Shown example represents a medium with 10% of conductivity of the steel used in the vessel and the rod. The curve meets both endpoints of extreme levels, and the maximum deviation you will have in between. The roots of the effect are the currents more or less parallel to the rod.

Measuring Liquid Levels



If there is remaining medium between the upper side of the rod and the ground point of the detector, which has to be isolated, the non-linearity could be very dramatic. The shown case represents a build-up, which is positioned at the upper end of the rod and makes conductivity like 5% of full level. The curve is not monotonic either, similar to foam situations or low conductivity.