Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Fraunhofer Institut Zuverlässigkeit und Mikrointegration

Adaption to Scientific and Technical Progress under Directive 2002/95/EC

Results previous evaluation

Exemption request 1 under Directive 2002/95/EC

"Cadmium in photoresistors for analog optocouplers applied in professional audio equipment until 31 December 2013"

(Excerpt from Öko-Institut report 2007)

Öko-Institut e.V.

Freiburg Head Office
P.O. Box 50 02 40
79028 Freiburg, Germany
Street Address
Merzhauser Str. 173
D-79100 Freiburg
Tel. +49 (0)761 – 4 52 95-0
Fax +49 (0)761 – 4 52 95-88

Darmstadt Office
Rheinstraße 95
64295 Darmstadt, Germany
Tel. +49 (0)6151 – 81 91-0
Fax +49 (0)6151 – 81 91-33

Berlin Office
Novalisstraße 10
10115 Berlin, Germany
Tel. +49 (0)30 – 28 04 86-80
Fax +49 (0)30 – 28 04 86-88

pretation of the RoHS Directive is beyond the contractor's competence. The contractors' leave the decision to the respective European entities whether this interpretation is permissible.

A new exemption would be justified in line with article 5 (1) (b) of the RoHS Directive if this application is not considered to fall under exemption no. 5

5.2.4 Final recommendation

It is recommended to grant this exemption if this use of lead is not considered to fall und exemption no. 5 allowing the use of lead in glasses of electronic components as laid out in the previous paragraph under number 2 in section 5.2.3.

The wording of the exemption would be:

Lead in cermet-based trimmer potentiometer elements

5.3 "Cadmium in optoelectronic components" (set 6, request no. 23, Marshall Amplification plc), and "3 year grace period on the use of Cadmium-based photoresistors used in professional audio equipment, for the purpose of investigating suitable alternatives and redesigning audio products accordingly" (set 7, request no. 4, Sound Devices)

Marshall Amplification had already requested this exemption in a previous stakeholder round (4^{th} stakeholder consultation, request no. 5). A final recommendation was not pronounced at that time (see final report from July 2006, http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf). Marshall therefore has submitted an almost identical request again in the sixth stakeholder consultation.

Sound Devices submitted an exemption request in the seventh stakeholder consultation, which refers to the use of cadmium in optocouplers in professional audio equipment as well. Both exemption requests target an identical exemption for identical or very similar applications in the audio industry. Hence, they are reviewed together in the following.

5.3.1 Special terms and definitions

Audio limiter	A device that permits a high compression to be applied above a set threshold. It limits the output level from rising much above the set threshold. Vice versa, it facilitates the maximization of an audio signal to the upper limits of the capabilities of the audio circuitry. Audio limiters prevent overload distortion, or "clipping". Further on, it allows for maximization of the audio level of the desirable audio signal relative to the audio noise in the floor of the audio signal, an inherent artefact to audio circuitry. (Source: Sound Devices)

Clipping	An audio signal distortion, which occurs through attempts to increase the voltage or current in an amplifier beyond its threshold of power. (Source: Sound Devices)
DSP	digital signal processing
Gain	"...The power increase of a signal, usually expressed in dB." (Received from Sound Devices, source: The Sound Reinforcement Handbook, second addition)
Impedance	The electrical impedance $\underline{Z}$ is the quotient of the complex temporary values, complex amplitudes, or complex effective values of an alternate voltage and the current in a network element: $\underline{Z} = \frac{\underline{u}(t)}{\underline{i}(t)} = R + jX$ The resistance R is the real part of impedance, the reactance X the imaginary part. The unit is Ohm, like for the resistance. (Source: Taschenbuch Elektrotechnik, Band 1 Allgemeine Grundlagen, VEB Verlag Technik Berlin, 3. Auflage 1986)

5.3.2 Description of requested exemption

Although not mentioned explicitly in the proposed exemption wordings, the concrete application behind both exemption requests is the use of cadmium-containing photoresistors in optocouplers.

5.3.2.1 Application and function of photoresistors and optocouplers

Optocouplers are used in dynamic processors such as audio compressors, expanders, limiters, and guitar amplifiers for recording studio and live sound music performances. They are also applied in portable professional digital audio recorders, where they limit the audio input AC voltage while recording audio, like for remote news gathering or major motion pictures. In addition, they are applied for voltage limiting in microphone pre-amplifier and audio mixer products.

The applicants apply for an exemption allowing the continued use of photoresistors containing cadmium sulphide. While Marshall wants a general exemption for cadmium in opto-electronic components, Sound Devices limited its exemption request to cadmium used in photoresistors for professional audio products, which are mainly optocouplers. Depending on the application different numbers of optocouplers are used in such products. In Marshall's music instrument amplifiers, as an example, the different models use between one and nine optocouplers.

The photoresistors are combined in a single package with an LED to form an optocoupler. The optocoupler allows the transmission of analogue or digital signals between circuits using light as signal transmitter. The use of light ensures that the sending and receiving circuits are electrically unconnected (galvanic isolation).

The sending circuit controls an LED. The light of this LED strikes the surface of the photo-resistor in the receiving circuit. The photoresistor absorbs photons and changes its resistance according to the intensity of the LED-light it is exposed to. It absorbs the photons, whose energy pushes electrons into the conduction band. The electrons (and their resulting hole partners) conduct, lower the resistance of the photoresistor and thus control the electrical current in the resistor and the receiving circuit. The resistance of the photoresistor thus gradually decreases with increasing light intensity.

An important use of optocouplers is their application as optical isolators. The sending circuit operates with a low voltage direct current (5-24 V DC, direct current), the receiving circuit with a high voltage AC (alternate current, hundreds of volts) current. The optocoupler facilitates the optical control of such high currents with a low current without electrical contact between the two circuits. This physical separation is a safety protection for the user of the product. He can only access the low voltage areas of the product, but is protected from the dangerous high voltage circuit.

The semiconductor in the receiving high voltage circuit needs time to arrive at and to return from the higher to the lower resistance state. The resistance of the device falls and returns to high resistance over a matter of seconds. This gives the optocoupler device an important characteristic, the dR/dT characteristic (change of resistance over time). The gradual change from one state to another one, under a constant LED current, allows the device to switch audio signals gradually and free from distortion. The dR/dT response is a crucial parameter for the proper functioning of the product.

PMI provided the information that analogue processors account for approximately 90% of all sales of professional audio processors worldwide. Digital ones account for 10%. The annual worldwide market value of this kind of product is some 400 million US dollars (sources: audio trade publications, industry publications, US Census Bureau, PMI). This market share is expected to remain stable for the foreseeable future.

The amount of cadmium used in an optocoupler is around 100 micrograms. Sound Devices sells around 12,000 of such optocouplers in products to Europe resulting in a total amount of cadmium of around 1.2 g per year in Europe. Total figures for all producers using such devices in professional audio equipment are not available. Marshall did not provide any figures on this at all.

The applicants propose the following wordings for the exemptions:

Cadmium in optoelectronic components (set 6, Marshall)

3-year grace period on the use of cadmium-based photoresistors used in professional audio equipment, for the purpose of investigating suitable alternatives and redesigning audio products accordingly (set 7, Sound Devices)

5.3.2.2 Main discussion lines and key stakeholders

This exemption request is complex, as it has different technical argumentation lines and levels. Additionally, two applicants and several stakeholders were involved in the consultation and the exemption review process expressing contradicting, conflicting standpoints.

- Digital signal processing (DSP) is a new technology and a possible alternative to analogue technology. DSP does not require optocouplers, and hence does not depend on the use of cadmium-containing photoresistors. Part of the review process therefore is whether DSP is a viable alternative to the use of the non-RoHS-compliant optocouplers in professional audio equipment.
  The following stakeholders oppose the use of DSP as a viable substitute in professional audio equipment:
- Marshall (manufacturer of professional audio equipment, applicant in stakeholder consultation 6, Europe)
- Sound Devices (manufacturer of professional audio equipment, applicant in stakeholder consultation 7, USA)
- Casco Silonex (manufacturer of optocouplers, stakeholder, Europe)
- PMI Audio Inc. (manufacturer of professional audio equipment, stakeholder, Europe)
- Optocouplers using digital components like silicon-based photocells and phototransistors instead of cadmium-containing photoresistors are available on the market. The "On Institute for Optical & Electronic Technology", a stakeholder from China, in the 7th stakeholder consultation submitted a document claiming that digital components can replace the cadmium-containing photoresistors in optocouplers. It must be clarified whether such devices are a viable option for the professional audio industry.
- This exemption request also is related to the exemption request no. 21 Cadmium sulphide photocells from stakeholder consultation no. 2. Applicants had requested an exemption for Cadmium in photocells for dimming lights. The request was recommended not to be granted as RoHS-compliant alternatives had been available. These alternatives might as well be suitable substitutes to achieve RoHS-compliance in optocouplers.
- Another part of the review process is the conflict whether the photoresistors and the optocouplers, which a manufacturer of optocouplers (Macron) claims to be RoHS-compliant, actually are RoHS-compliant.

Stakeholders involved are:

- Macron, a Chinese manufacturer of optocouplers, in stakeholder consultation 6 claimed to have a RoHS-compliant photoresistor that can fully replace the cadmium-containing, non-RoHS-compliant photoresistors in optocouplers for audio applications. Macron has submitted test results from two laboratories (SGS and RWTT) in the 6th and 7th stakeholder consultation, which, according to Macron, prove the RoHS-compliance of its photoresistor/optocouplers. Additionally, Macron has provided supporting letters from professional audio manufacturers confirming that the Macron optocouplers are a substitute for other manufacturers' non-RoHS-compliant optocouplers in professional audio equipment.

Other stakeholders oppose this view:

- Casco Silonex submitted test results from a laboratory (ERA) in stakeholder consultation 6 and 7, which, according to Casco Silonex, prove that the Macron photo-resistors/optocouplers are not RoHS-compliant.
- Sound Devices, Casco Silonex and PMI Audio argue that the Macron optocouplers technically are not appropriate for the use in the professional audio industry.
- Finally, it must be reviewed whether the Macron optocouplers, in case that they are RoHS-compliant, actually are a substitute for cadmium-containing photoresistors for optocouplers in professional audio equipment. Casco Silonex and PMI Audio oppose this view, while Macron had submitted letters from some of its customers supporting Macron's position.

5.3.2.3 Lack of Cooperation from Marshall

Marshall applied for a general exemption of cadmium in opto-electronic components. In order to clarify this rather broad scope and further open questions the consultant asked the applicant several times for further information. Although Marshall confirmed the receipt of the questions and announced to reply, Marshall later on cancelled the further cooperation via e-mail. Against this background the consultant decided to focus only on the almost identical exemption request no. 4 from Sound Devices (SD) in the 7th stakeholder consultation, but nevertheless took into account the various documents, which several stakeholders had submitted in the 6th stakeholder consultation. Marshall's wording for a general exemption of cadmium in opto-electronic components was cancelled, and the contractors' further investigations and review of information focused on the use of cadmium in photoresistors for professional audio applications, as proposed by Sound Devices.

5.3.3 Justification for exemption as submitted by applicant and stakeholders

The following subsections summarize the information from Marshall, Sound Devices, PMI Audio and Casco Silonex submitted in the 6th and 7th stakeholder round and during the review process.

5.3.3.1 Digital signal processing in professional audio equipment

RoHS-compliant digital signal processing (DSP) based on silicon-technologies, in opposite to the analogue electronics circuitries using cadmium-based optocouplers, is discussed as an alternative. The stakeholders state that digital formats are increasingly used for non-professional applications such as for music compact discs, recording and playback, but that current digital technology does not reproduce music and sound perfectly, particularly at high and low frequencies. The stakeholders say that although this is acceptable for audio equipment used by consumers, it is unacceptable for professional music recording, publishing and for real time applications like concerts where the sound quality must be an order of magnitude better than non-professional equipment. The dynamic range of the human ear is very wide and it is not possible, using current digital techniques, to accurately reproduce sound at very high and very low frequencies. The following paragraphs sum up the applicants' and stakeholders' arguments why DSP is not an alternative to the analogue technology using optocouplers with cadmium-based photoresistors for the professional audio industry.

Conversion from analogue to digital signals

Audio is an AC (alternating current) signal (see Figure 4), so the current must flow through the resistive element in both directions, and the resistance therefore must be the same for current travelling in either direction through the resistive element to achieve the linearity of the device. According to SD, photodiodes and phototransistors used in optocouplers or in DSP allow current to flow in one direction only and are therefore inherently "non-linear".

To process an analogue signal digitally, it must be sampled. Its instantaneous amplitude is measured at fixed time intervals (the "sampling rate"). While analogue has infinite resolution, the sampling process results in a finite resolution and changes the nature of the audio signal. Although the digital signal can be converted back to analogue, digitalization is an approximation process of the sampled signal to the original input signal. The faster the analogue input waveform changes, the worse the approximation.

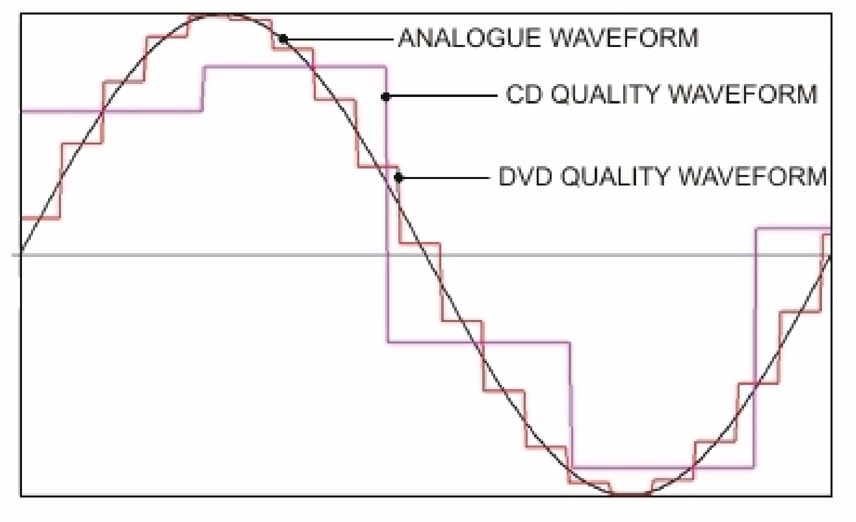


Figure 4: Digitalisation of an analogue waveform (source: PMI Audio)

Higher sampling rates reduce the error and give a better approximation, but, according to PMI Audio, remain an approximation only, while professional audio equipment must be optimised to reproduce the original input sound. PMI Audio quotes the Nyquist theory. To avoid quantification errors, the sampling frequency must be at least twice the maximum frequency of up to 100 kHz, which is actually necessary to faithfully reproduce the 20 kHz audio spectrum. Only the recent “DVD” standard with its sampling frequency of 192 kHz meets this criterion.

PMI Audio says that another source of signal information loss is that digital circuitry operates at between 3 Volts and 5 Volts, whereas analogue circuitry is ten times that. Hence an analogue signal must be attenuated by a factor of ten (20 dB) in order to be digitalised. The process of attenuation inevitably looses some information and increases noise slightly, due to the additional components required. Conversion back to analogue also worsens noise and distortion, because of the 20 dB of amplification required.

Digital signal processing

Once the analogue audio signal is digitalised, it must be processed. The amplitude of an audio signal with a resolution of 0.1 dB is a reasonable requirement for a professional audio processor. This is easy to achieve in the analogue domain, PMI says, but not in the digital one. A gain reduction of 0.1 dB requires the use of non-integer, floating-point arithmetic. This means that the digital word length used for computation needs to be much greater than that needed for sampling. ADC- (analogue-to-digital conversion) and DAC-unites (digital-to-analogue conversion) can use 24 bits to achieve a dynamic range of 140 dB, whereas the DSP needs at least 64 bits, even to approach an acceptable emulation of an analogue processor. Commonly available DSPs are currently 32-bit.

The digitalised audio signal is subjected to many stages of approximation, which produce unsatisfying results regardless of the accuracy of the emulation algorithms. Emulation further is complicated by the complex response of the photocell that is being emulated. All these factors result in approximation errors, which all reduce the sonic accuracy of the DSP system compared with an analogue one.

PMI put forward that measurable differences between analogue and digital systems very often could not be revealed by simple measurements using simple test equipment. Commonly measured parameters, such as noise and harmonic distortion of a steady-state signal, actually reveal very little about how an audio signal will “sound”. Analysis performed by the human brain is far more sophisticated. An appropriate method to compare the similarity of the analogously and digitally processed signals is the “invert and add” method. One of the two signals, either the original analogue or the processed digital one, is inverted and summed (mixed) with the other. Providing the two signals have identical amplitude, the two signals should extinguish each other such that nothing audible remains. Any residue represents the inaccuracy of the DSP in emulating the analogue process. In PMI’s experience, this method always reveals clear differences between the analogue and digital audio signals.

“Analogue sounds better than digital” has also been validated by the discipline of study known as “Psychoacoustics”. This uses the methods of experimental psychology, such as “double blind” listening tests and statistical analysis (http://en.wikipedia.org/wiki/Analog_sound_vs._digital_sound#Subjective_evaluation; source cited by PMI Audio).

Latency

Conversion from analogue to digital, DSP processing and conversion back from digital to analogue takes time known as latency. Typical latencies for current digital technologies are:

Analogue to digital	1 to 2 milliseconds
DSP	3 to 4 milliseconds
Digital to analogue	1 to 2 milliseconds
Total:	5 to 8 milliseconds

According to PMI, studies have shown that a good drummer can be time-accurate to 150 microseconds. Simple changes to the “mood” of playing, for example from “rock-steady” to “laid-back”, involve a change in timing of just 1 millisecond of hits on a snare drum. A latency of several milliseconds makes it impossible to play along with Digital Audio Processors in real time. PMI states that this is completely unacceptable in many situations within the professional recording and broadcast industries. Digital audio processing would require a hundred-fold increase in processing speed to remove this objection. At the current state of the art, this is not achievable, according to PMI.

Environmental Implications of DSP and shorter usage time of portable equipment

The stakeholders say that a DSP-based system contains much more active components. Any digital system also requires analogue input and output filter circuitry, which alone uses more components than the entire circuitry of an analogue device. Figure 5 shows a DSP circuit and a Joemeek compressor (see paragraph “Tradition” in section 5.3.3.2) in approximately the same scale.

Figure 5: Typical twin-board DSP module (left) and Joemeek analogue compressor (right) (source: PMI Audio)

The analogue Joemeek version (right) uses three 8-pin chips, while the digital "equivalent" uses three 144-pin chips on the upper DSP board alone. All the circuitry for analogue to digital and the digital to analogue conversion and filtering is on the lower board. The stakeholders say that the manufacturing of the digital chips and the larger printed circuit board with far more soldered joints requires more energy and material, but did not provide quantitative data.

During operation, photoresistor-controlled circuits do not consume energy when they are not operating. According to PMI, a Joemeek compressor circuit as an example for analogue signal processing consumes less than 0.5 W, while a digital system typically consumes 5 W continuously, whether it is under operation or not. The power consumption and heat production of a DSP-unit increases with the processing power of the DSP.

According to Sound Devices (SD), energy consumption is a critical parameter in particular for portable devices operating on battery power. Analogue portable audio mixers are designed for extremely low power consumption to maximize battery life in the film and newsgathering industries. Using DSP in such devices decrease the battery-life performance and the use time of the portable devices in field shortens, while battery consumption and wastes increase.

Sound Devices says that due to their simplicity compared to DSP units, the use of optocouplers with cadmium sulphide photoresistors enable products with minimum size and weight for the broadcast and film markets. According to SD, these light and small products provide a substantial health benefit as Location Audio engineers carry them over their shoulder for a full workday. It was not uncommon for a Location Audio Engineer to retire at age 40 to 45 due to typically spinal ailments. Reduction in weight by up to 50% of audio tools in recent years has improved the health and extended the careers of these Audio Engineers.

5.3.3.2 Specific properties of cadmium-based photoresistors for optocouplers

The stakeholders and applicants explain which unique properties of cadmium-based optocouplers make them indispensable for the audio industry. The following explanations are a summary of the applicant's and stakeholders arguments.

Suppression of electrical noise and low distortion

A crucial property of cadmium-based photoresistors for optocouplers in professional audio equipment is the change of resistance over time as a reaction to light, the dR/dT characteristics, or the inherent fast-attack/slow-release characteristic. The "attack time" refers to the time it takes for the photo-resistor to go from a high to a low resistance, and vice-versa for "release time". The dR/dT-characteristics can be adapted to the specific requirements of the respective application. A typical attack time is 50 ms, a typical release time 500 ms.

The attack time of around 50 ms is fast enough to allow a distortion-free transfer of signals without e.g. blurring spoken words. On the other hand, the attack time is slow enough to suppress electrical noise and inharmonic distortions from the sending circuit generating short flashes of light from the LED. Such short flashes of light will not affect the resistance of the photoresistor. Electrical noise in the sending circuit is thus eliminated in the receiving circuit.

Audio equipment must reliably represent the material being mixed or recorded without adding any electrically created noise or distortion. Inharmonic distortion examples include white noise, digital pulses, initial overdriving, and electrical noises generated outside of the audio circuitry.

The long release time of photoresistors keeps the harmonic distortion low. The gain only affects the amplitude of the waveform without affecting the basic shape of the waveform, which would result in harmonic distortions. Linearity is another typical property of optocouplers with cadmium-based photoresistors. Their electrical response is a regular linear function of the input light level. The linearity of the optocoupler translates directly into minimization of harmonic distortion.

Phototransistors and diodes as a possible replacement of cadmium-based photoresistors in optocouplers do not have the unique dR/dT characteristics and their response is not linear, according to the applicant Sound Devices. They also react with resistance changes to light. The conduction of the silicon device occurs in the moment the AC signal's amplitude exceeds the photovoltaic voltage drop. The silicon device then conducts, which causes an unacceptable deformation of the audio signal. Further, audio signals are AC signals. As silicon-based components like photodiodes and phototransistors allow current to flow through it in one direction only, the audio signal deformed. Electrical noise and distortions are not eliminated, or it requires considerable additional circuitry to achieve a quality of the audio signals, which is still below the quality of the audio signal from cadmium-based optocouplers. Optocouplers for professional audio applications need components with continuously variable resistance providing a wide linear and consistent resistance change.

Dynamic range

Optocouplers with cadmium-based photoresistors can respond to a large range of light levels. Typically they react to light levels from 0.02 Lux to over 10,000 Lux with an equally large range of resistance. Resistance values are typically from 2 ohm to 50 Mega-ohm.

Professional high quality audio applications like audio limiters for field use require such high dynamic ranges to handle the broad range of audio stimuli: capturing wildlife sounds such as birds at 50 meters when a deer approaches at 10 meters, or if a gun fires at 10 meters. The loud sounds should be undistorted, and at the same time the quiet sound of the birds should not be clouded by noise produced by the audio circuitry. The nominal sound levels can be as much as 100 dB apart. Optocouplers based on photodiodes cannot provide the necessary range of light sensitivity levels and reactive resistance changes, as the next table shows.

Table 7: Dynamic range of main photocell types

Photocell type	Dynamic range; light sensitivity for typical devices, actual vales depend on design but range is not significantly affected	Wavelength response
CsS/CdSe	0.02 Lux - >10,000 Lux	400 – 700 nm
Single crystal silicon	100 Lux – 1000 Lux	~400 – 1200 nm
Amorphous silicon (a-Si)	200 Lux – 600 Lux	<400 nm – ~820 nm
GaAs, GaAlAs	100 – 1000 Lux	~ 600 – ~950 nm

Source: Casco Silonex document no. 8 in references, section 5.3.6

Low cost and short development time

Optocouplers are less expensive than other analogue circuit or DSP-based options. They allow cost-effective and, due to their simplicity, quick solutions with short development times.

According to PMI, DSP technologies are around 20 times more expensive than the existing analogue circuitry, which makes DSP commercially unacceptable.

Tradition

PMI says that its products are based on the "Joemeek Compressor Circuit", a classic piece of audio engineering using a cadmium sulphide photoresistor pioneered by record producer Joe Meek in the 1960's. PMI puts forward that the technology itself is a brand and stands for a tradition and as such cannot be replaced, even if it would be technologically possible to imitate the effect with RoHS-compliant devices. Should the exemption not be granted, an entire tradition of technology would be put beyond reach of manufacturers and consumers, both amateur and professional, and would cause enormous damage to the viability of PMI's and other manufacturers' business. It would also give the rest of the world an unfair advantage over the EU in the field of music recording and production.

5.3.3.3 Sound Devices' justification for the 3-year exemption period

Sound Devices asks for a three-year exemption for the use of cadmium in photoresistors in professional audio equipment. SD says that analogue circuitry simulating the performance of an optocoupler is possible, as due to the ongoing miniaturization the sizes of electrical components are shrinking and power requirements have been going down. The applicant foresees a strong future potential that if he is given appropriate design time, he can produce RoHS-compliant products with alternative circuits replacing the non-RoHS-compliant optocouplers within the next three years.

In February 2007, Sound Devices first attempted the implementation in a prototype of portable microphone preamplifier. It was not successful but showed promise. After two more design changes the applicant says that the circuit is close to being suitable for portable professional audio, and he believes that he can start the integration into products in February 2008. Sound Devices says that each product requires a unique design to accommodate the variations in the audio circuitry. Sound Devices says that it has ten other existing products that require modifications to this new circuit design, or a complete product redesign for the use with the new limiter circuit concept replacing the non-RoHS-compliant optocouplers. According to the applicant, the redesign for all of these products would require a minimum of two years, and a maximum of three years depending on the number of PC Board revisions required to produce acceptable results.

5.3.4 Critical review of information as submitted by applicant and stakeholders

5.3.4.1 Overview on different test results for RoHS-compliance of Macron photoresistors and role in the review process

There are different test results available leading to different conclusions about the RoHS-compliance of Macron photoresistors. To some extent, these results diverge as a result of different interpretation in the understanding of "homogeneous material". In this context, it must be taken into account that neither the Commission nor the contractor, but only the European Court of Justice decides about the interpretation of the RoHS Directive. Against this background, the contractors solely present the test procedures, results, and implausibilities, as far as possible.

Macron presents four models of photoresistors, which also contain cadmium. According to Macron, the concentration of cadmium in the homogeneous material of these photoresistors remains below 0.01 % of weight, which is the maximum allowed cadmium level for RoHS-compliance.

The supporters of the exemption request challenge Macron's claim that these photoresistors for optocouplers are RoHS-compliant. Both the supporters of the exemption request and Macron have submitted several test reports dealing with the RoHS compliance of the Macron devices. The Macron test reports confirm RoHS-compliance; the opponents' test reports the opposite.

The following sections show an overview of the most important tests and their results. For detailed information, please refer to Annex II.

Macron test reports

Macron had submitted testing documents in the 6th stakeholder consultation confirming the RoHS-compliance of the tested photoresistors and optocouplers. None of the reports, however, clearly indicated which photoresistors and optocouplers had been tested and hence are not further reviewed in this subchapter. To allow an overview of the different testing approaches and the chronological submission of the different test reports by both Macron and Casco Silonex as a reaction to each other, all tests and their results are described in detail in Annex II.

In the review process following the seventh stakeholder consultation, Macron submitted a new test report (document no. 12 in references, section 5.3.6). The report explains that traditional photocells usually contain a layer of CdS/CdSe which acts as a photosensitive layer. Macron says it uses less cadmium it mixes cadmium into the ceramic base, which allows the ceramic base to have photosensitive function. The testing laboratory refers to this specific ceramic as "white ceramic" and considers it as homogeneous material, as the following figure underpins.

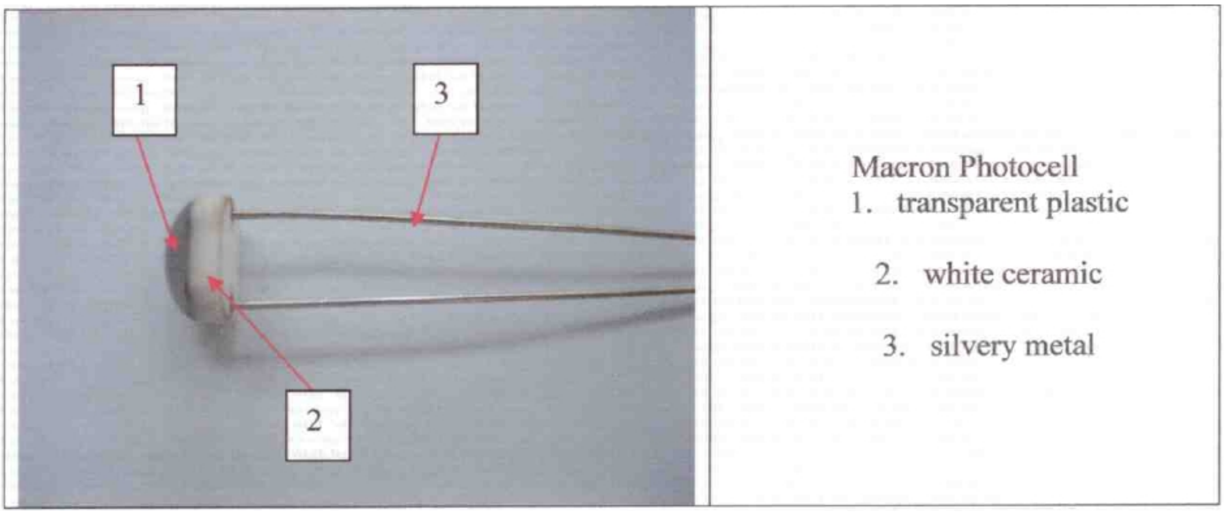
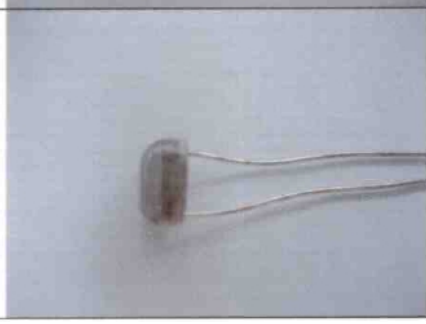
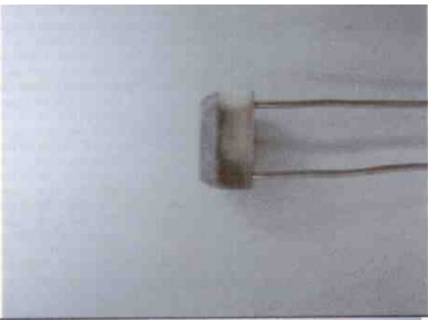
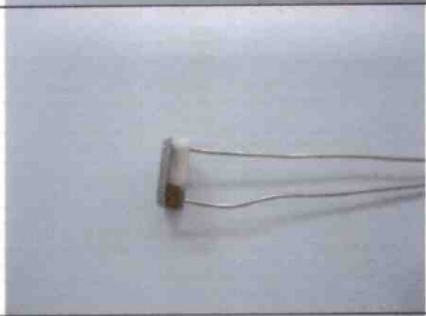
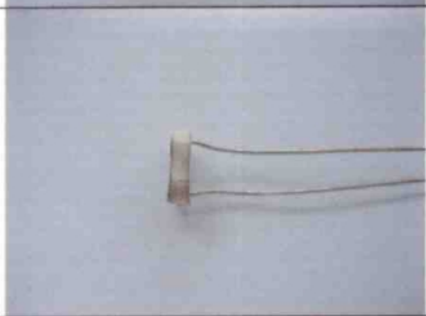


Figure 6: Physical appearance and homogeneous materials in Macron photoresistors (source: RWTT test report, document no. 12 in references in section 5.3.6)

The report specifies the tested product as Macron's MI 1210CLA-R (A-type), which according to Macron has the highest content of cadmium to achieve a high photosensitivity. The following table shows the sampling procedure and the cadmium content for each of the obtained samples. The samples were analyzed using XRF analysis.

Table 8: Sampling and XRF analysis results of obtained samples (accuracy ± 50 ppm)

Removal stage	Cadmium concentration (ppm)	Other element detected	Physical Appearance
With complete resin layer	N.D.	Sn, Pb, Cu, Fe	
After 1st abrasion to remove a layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	

After 2nd abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 3rd abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 4th abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 5th abrasion to remove all the transparent plastic, white ceramic and metal silvery pin has been exposed	31.1	Sn, Pb, Cu, Fe	
After 6th abrasion to remove a layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	

Source: Macron test report/RWTT, document no. 12, section 5.3.6

The testing laboratory conducted a total of ten abrasions, but did not detect any cadmium in any of the further abrasions after the fifth one.

According to these test results, only the last bit of transparent layer (material of 5th abrasion) would contain 0.0031 % (31.1 ppm) of cadmium, which is below the maximum allowed level of 0.01 % for RoHS compliance. The photoresistor would thus be RoHS-compliant. For details refer to document no. 12 in references in section 5.3.6.

Macron was asked to explain the results. The cadmium, according to the process description in the test report, is mixed into the ceramic base. The test result, however, indicates no detectable cadmium in the ceramic base, but only in the last bit of abraded transparent plastic. Macron explained that the cadmium was detected in the 5th abrasion of the transparent layer because RWTT might have abraded parts of the white ceramic with the last bit of transparent layer. There is no cadmium in the transparent layer, according to Macron, but the cadmium concentration should be higher nearer to the photo-sensitive surface of the ceramic and it was therefore detected with the first abrasions of the white ceramic.

Macron further on states the test result might as well have to do with the XRF analysis. The XRF analysis deviates within ± 50 ppm (± 0.005%), as also mentioned in the ERA report. Macron states that its photosensitive ceramic contains cadmium under the surface layer, too, but that it cannot be detected due to the inaccuracy of the XRF analysis.

In another statement, Macron says that for each of its optocouplers, a total of around 80 ppm of CdS and CdSe referring to the weight of the solid ceramic is added into the ceramic liquid for mixing. For further details, please refer to Annex II.

ERA test reports

The most important ERA test by the order of Casco Silonex was submitted in the review process following the 7th stakeholder consultation (document no. 11, section 5.3.6). The following Macron devices had been tested:

- MI 1210CLA-R (type “A”)
- MI 1210CLB-R (type “B”)
- MI 1210CLH-R (type “C”)

The above models are the models of the Macron MI1210CL-R series, for which Macron claims RoHS compliance. The “C”-denomination of the last of the three series, the MI1210CLH-R, however, is not congruent with Macron’s information. According to Macron, this is the “H”-series, and there is no information from Macron whether a “C”-series actually exists. In the ERA test report, the MI 1210CLH-R model is sometimes addressed as “C”-type, sometimes as “H”-type (e.g. in Table 9).

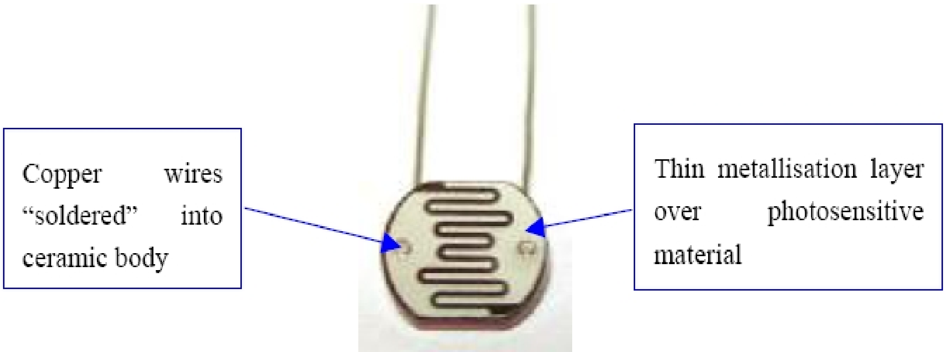


Figure 7: Image of Macron photocell (source: ERA, see document 7 in references, section 5.3.6)

ERA challenges the homogeneous material definition of the RWTT test reports. ERA says that the “white ceramic” (sample 1 in the Macron test report) can be mechanically disjointed into two homogeneous materials:

- the ceramic base
- photosensitive layer containing cadmium and the metallisation (cannot be mechanically disjointed from cadmium layer)

ERA describes that the light dependent resistors have coatings of a transparent gel over a thin metal mask that defines the resistor path which is made of the photosensitive material.”

Figure 8: Light dependent resistors from Macron optocoupler type “A”, type “B” and type “C” (left to right) (source: ERA, see reference document no. 11, section 5.3.6)

ERA scraped off the transparent gel with a surgical scalpel. The very thin metal layer could not be separated from the photosensitive layer. The photosensitive layer with metal mask was removed from the substrate from between the metal pins as one material with the scalpel.

Figure 9: Light dependent resistors from Macron optocoupler type “A”, “B”, “C” (left to right) after the gel and photosensitive material coatings had been removed (source: ERA, document no. 11, section 5.3.6)

The scraped off material was analyzed with a Scanning Electron Microscope (SEM) and energy dispersive X-ray (EDX) analysis.

Table 9: SEM/EDX analysis of photosensitive coating from Macron optocouplers

	Results (weight percent)	Comments
“A“	Cadmium 60,6 %, sulphur 15,5%, selenium 5,5 %	This material is cadmium sulphide/selenide
“B“	Cadmium 70 %, sulphur 18,4 %, selenium 4,1 %	This material is cadmium sulphide/selenide
“H“	Cadmium 58,2 %, sulphur 15,1 % selenium 2,3 %	This material is cadmium sulphide/selenide

(Source: ERA, document no. 11, section 5.3.6)

ERA explains that the figures in the table for the cadmium-containing elements do not add up to 100% because small amounts of impurities from the gel coating (carbon and oxygen) and the alumina substrate (aluminium and oxygen) have not been included.

According to the test results in Table 9, the cadmium content in the analyzed Macron photoresistors would be clearly above 0.01 %. The optocouplers would thus not be RoHS-compliant. For details, refer to document no. 11 in references, section 5.3.6.

Conclusions

The test reports submitted by Macron and Casco Silonex arrive at contradicting statements on the RoHS-compliance of the Macron photoresistors and optocouplers. The consultant cannot take a position on the correctness of the testing and the test results, as mentioned before.

The question whether the tested Macron photoresistors actually are a technically appropriate substitute for the other, non-RoHS-compliant photoresistors in optocouplers of professional audio equipment thus becomes obsolete. The potential users of such devices are in the best position to decide whether or not the Macron products are a viable option for their specific professional audio applications.

5.3.4.2 Non-cadmium-based optocouplers as alternative to cadmium-containing optocouplers

A stakeholder from China, the ON institute, had submitted a document opposing the exemption of cadmium in optoelectronic components (see document 10 in references, section 5.3.6). The stakeholder reasons that appropriate RoHS-compliant optocouplers are available on the market and lists examples:

- PC817 from different manufacturers,
- HCNR200 (USA, Avagotech, www.avagotech.com),
- TIL300 (USA, Burr Brown Inc.).

A crosscheck on the internet showed that the Burr Brown component is no longer available on the market. The Avagotech component, however, was found on the manufacturer's website. It is an optocoupler, which does not use photoresistors, but photodiodes. Whether this component is actually RoHS-compliant was not clear from the information available on the manufacturer's website. It was not possible to obtain a list with RoHS-compliant optocouplers including the necessary application-relevant technical data.

Nevertheless, Sound Devices was asked to explain why such optocouplers are not appropriate for its products. Sound Devices explained that audio is an AC (alternating current) signal, so current must flow through the resistive element in both directions, and the resistance therefore must be the same for current travelling in either direction through the resistive element. Sound Devices says that this is the essence of what is called the "linearity" of the device. According to SD, photodiodes and phototransistors allow current to flow in one direction only and are therefore inherently "non-linear", thus making them inapplicable for implementation as resistive elements around an operational amplifier. Further information on silicon-based elements as substitutes for cadmium-based photoresistors in optocouplers was already explained in subchapter 5.3.3.2.

This exemption request is also related to the exemption request no. 21 Cadmium sulphide photocells from stakeholder consultation no. 2. Applicants had requested an exemption for cadmium in photocells for dimming lights. The request was recommended not to be granted as RoHS-compliant alternatives had been available. These alternatives were presented to Sound Devices as well in order to check whether they might be a possible solution or part of a solution. Sound Devices replied that the devices are not variable resistors, but only light sensors with a current output, which cannot be used in an audio gain stage.

They cannot be used to achieve the required properties of cadmium-based photoresistors in optocouplers as described in chapter 5.3.3.2.

5.3.5 Final recommendation

Apart from some economical arguments and the argument that a traditional circuit like the Joemeek circuit must be allowed an exemption, the applicants and stakeholders technical and environmental arguments justifying an exemption.

The applicants and stakeholders explained that DSP at the current state of technology is not an alternative to replace analogue sound processing circuits in order to avoid the use of cadmium-based optocouplers in all professional audio applications. The applicants and stakeholders are not fully in line where DSP might already be used today and where not. They showed, however, that forcing the professional audio industry to switch to DSP or other possible alternatives would arise technical and environmental impacts. Increased energy consumption linked to shorter product battery times in case of in-field-use devices, use of more and more complex electronics components and printed wiring board materials, and possibly heavier products burdening the health of workers in in-field-use of these products.

Technically, the use of DSP in many cases will not allow the sound quality sufficing the high demands of professional audio applications as with analogue technologies based on cadmium-containing optocouplers. The same applies to the use of alternative optocouplers that work with photodiodes or other RoHS-compliant, photosensitive elements as substitutes for the basic, light-depending functionality of cadmium-dependent photoresistors.

The above technical and environmental drawbacks must be weighted against the use of minor amounts of cadmium. Sound Devices ships around 1 g of cadmium into Europe annually. The applicants did not provide total figures for Europe. Assuming, however, that the total amount is 1,000 times higher, it is around 1 kg of cadmium involved in the requested exemption in Europe.

The contradicting RoHS-compliance tests did not allow assessing whether the Macron cadmium-based photoresistors contain cadmium below the allowed threshold level of 0.01 % and therefore are RoHS-compliant. The technical properties of the Macron components regarding their appropriateness as a substitute for non-RoHS-compliant photoresistors were not assessed, as the RoHS-compliance could not be decided either. It is thus currently not possible to recommend a RoHS-compliant, cadmium-based alternative for optocouplers.

The applicants and stakeholders have different opinions about the future possibilities of DSP and alternative analogue technologies to substitute the cadmium-dependent analogue technologies. Sound Devices presented a roadmap suggesting that a RoHS-compliant solution is possible within three years and proposes an exemption limited to three years starting in beginning of 2006.

Taking into account all the facts reviewed the contractors assume that the technical and environmental arguments might suffice the requirements of article 5 (1) (b). As for some applications, RoHS-compliant alternatives like DSP might be a solution; the exemption could be limited to specific applications, which would require a further investigation and information gathering round to assess the products where technically viable RoHS-compliant alternatives are possible and where not. The environmental implications, however, at the current status of technology might allow a general exemption for the use of cadmium in optocouplers for professional audio equipment providing that the Commission gives higher priority to these environmental and possible health implications than to the avoidance of a maximum of 1 kg of cadmium, probably less.

In this case, the contractors recommend granting an exemption with the following wording, which was changed from the original wording in accordance with the applicant Sound Devices:

Cadmium in photoresistors for optocouplers applied in professional audio equipment until 31 December 2009.

5.3.6 References

The below files are attached to this report.

The following documents are stakeholder documents submitted in the 6th and 7th stakeholder consultation rounds:

1. Stakeholder document "Attachment 1 SGS Photocell report1.jpg" submitted by Macron Electronics Limited (testing laboratory: SGS),
2. Stakeholder document "Attachment 1 SGS Photocell report2.jpg" submitted by Macron Electronics Limited (testing laboratory: SGS),
3. Stakeholder document "Attachment 3 SGS Optocoupler report1.jpg" submitted by Macron Electronics Limited (testing laboratory: SGS),
4. Stakeholder document "Attachment 3 SGS Optocoupler report2.jpg" submitted by Macron Electronics Limited (testing laboratory: SGS),
5. Stakeholder document "RoHS_and_WEEE_Macron_Photocell_RT069686.pdf" submitted by Macron Electronics Limited (testing laboratory: RWTT),
6. Stakeholder document "RoHS_and_WEEE_Macron_Optical_Isolator_RT069701.pdf" submitted by Macron Electronics Limited (testing laboratory: RWTT),
7. Stakeholder document "Silonex Macron RoHS status letter.pdf" submitted by Silonex (testing laboratory: ERA),
8. Stakeholder document "Marshall_Marshall support letter 01 08 07A-1.doc", submitted by Marshall,
9. Stakeholder document "PMI Support Cadmium in Optocouplers.htm" submitted by PMI Audio Inc.,
10. Stakeholder document "About Cd.doc" submitted by the On Institute for Optical & Electronic Technology.

The next documents were submitted or referenced in documents submitted to Ökoinstitut and Fraunhofer IZM during the RoHS exemption review process:

11. Report “ERA opto coupler analysis Aug 2007-new.pdf”, received in August 2007 via e-mail from Euan Davidson, Chromotechnic Ltd. (testing laboratory: ERA),
12. Report “RT079366_R2.pdf”, received in August 2007 via e-mail from Stephen Leung, Macron.
13. RoHS Enforcement Guidance Document, Version 1 – issued May 2006, (http://www.rohs.gov.uk/Docs/Links/RoHS%20Enforcement%20Guidance%20Document%20-%20v.1%20May%202006.pdf); the document is informative and advisory, but has no legal authority.

5.4 “Pb and Cd in printing inks for the application of enamel on glasses, such as borosilicate and soda lime glasses” (set 7, request no. 1a, ELCF)

5.4.1 Requested exemption

The European Lamp Companies Federation (ELCF) has submitted this request for a change in wording of an existing exemption: entry no. 21 of the Annex to the RoHS Directive reads “Lead and cadmium in printing inks for the application of enamels on borosilicate glass”. ELCF requests to have following new wording for entry no. 21:

“Lead and cadmium in printing inks for the application of enamel on glasses, such as borosilicate and soda lime glasses.”

According to the applicant, lead is used in printing inks on parts of the outer surface of lamps (e.g. fluorescent lamps). These markings are essential for product identification, as requested by safety standards. The marking has several functions, during entire life cycle:

- To identify the producer,
- to identify lamp type and wattage, which is relevant for safety, correct lamp replacement and recycling,
- CE, WEEE marking.

The applicant states:

“Product identification is required by the relevant product safety standards, which are the basis of the CE Marking according to the LVD Directive (2006/95/EC). Product identification must be legible for the consumer or other stakeholders during the entire life cycle of the product (safety, replacement, recycling etc.)

Intensive heat and light during lamp operations result in quality challenges for the marking of a lamp. Some luminaries, state a maximum wattage in order to avoid excessive heat. If a mark is not properly legible for the user, the user might place the wrong lamp into a luminaire

Annex I: Monthly reports 1-9

See attached zip file

Annex II: Stakeholder documents requests no. 22 set 6, no. 23 set 6 and no. 4 set 7

See attached zip files

Annex III: Testing of Macron optocouplers for RoHS compliance and test results

Similar to the situation in the 4th stakeholder consultation, a manufacturer of photoresistors and optocouplers, Macron, opposes the exemption of cadmium use in photoresistors. Macron claims to have a RoHS-compliant photoresistor solution that can fully replace the photoresistors in optocouplers, which are not RoHS-compliant.

Macron's photoresistors also contain cadmium, but, according to Macron, the concentration of cadmium in the homogeneous material remains below 0.01 % of weight, which is the maximum allowed cadmium level for RoHS-compliance.

Macron claims RoHS-compliance for the following models of photoresistors:

- MI1210CL-R
- MI65CL-R
- MI0202CL-R

According to Macron, the MI1210CL-R is the most popular out of the three models. The number "1210" refers to the dimension of the optocoupler, the area measurement of the model is 12mm * 10mm. The "65" in the MI65 model means 6mm * 5mm of area, and so on. The height of the optocoupler is a standard of ~10mm and therefore is not indicated in the model name.

Within each model, Macron explains, English letters differentiate the characteristics of each series of optocoupler. The MI1210CLA-R is the A series of the MI1210CL-R model, MI1210CLB-R the B series, and MI1210CLH-R stands for the H series of this model. The A series is most sensitive to light. The more sensitive the photocell, the more cadmium it needs to produce the high sensitiveness to light.

Series A of each of the three models therefore has the highest content of cadmium among the three models for which Macron claims RoHS-compliance.

The supporters of the exemption request oppose the Macron statements. They challenge Macron's claim that its photoresistors and optocouplers are RoHS-compliant. Both the supporters of the exemption request and Macron have submitted test reports dealing with the RoHS compliance of the Macron devices. The Macron test reports confirm RoHS-compliance; the opponents' test reports the opposite.

Macron test reports from stakeholder consultation 6

During the 6th stakeholder consultation, Macron had submitted certificates from laboratories confirming the RoHS-compliance of the assessed Macron photoresistors (see in reference documents 1, 2, 3, 4, 5 and 6 in section 5.3.6). The documents 1 and 2 are reports stating the RoHS-compliance of the assessed Macron photoresistors, documents 3 and 4 that of Macron optocouplers. The tests were conducted by the SGS laboratory, and the test reports specify the silvery pins of the photoresistor as a homogeneous material and the rest of the photoresistor as another homogeneous material, both in the photoresistor and the optocoupler tests (see photos of photoresistors in the figure below).

Testing documents 5 and 6 separate the photoresistors into three homogeneous materials instead of only two. Document 6 is a test report certifying the RoHS compliance of the entire optocoupler, comprising the LEDs, the black case and the photoresistors. Document no. 5 is a test report of photoresistors only. In both reports, the sampling and the analysis of the photoresistors are identical.

As the discussion of RoHS compliance is about the cadmium in the photoresistors only, the photoresistor tests are the important ones. In both cases, the testing laboratory RWTT states the RoHS compliance of the photoresistors.

The following figure and table show the analysed samples and the essential results.

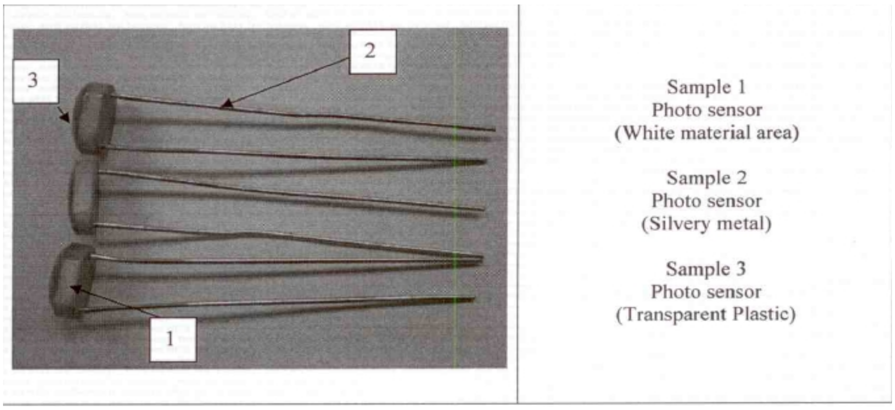


Figure 11: Homogeneous materials (samples) according to RWTT test report (source: RWTT test report in stakeholder document no. 5 in references, section 5.3.6)

Sample 1 is the crucial sample. It consists of

- the ceramic body,
- the photosensitive, cadmium-containing material,
- a thin metallization.

The testing laboratory considered this sample 1 as a whole as homogeneous material. The transparent plastic on top (sample 3) had been removed and was treated as an own homogeneous material.

Table 10 shows the results of the analyses for the three samples. The crucial result is the cadmium content of sample 1. The RoHS Directive allows a maximum content of 0.01 % (100 ppm) of weight in the homogeneous material. The analysis of sample 1 indicates a cadmium content of 0.0052 % (52 ppm), measured by ICP (inductive coupled plasma).

Table 10: Results of RoHS-compliance test (source: RWTT, see test report in stakeholder document no. 5, section 5.3.6)

Testing Item	**Result (ppm)**		
	Sample ID		
	1	2	3
Cadmium	52	N.D.	N.D.
Lead	N.D.	N.D.	N.D.
Mercury	N.D.	N.D.	N.D.
Chromium VI	N.D.	N.D.	N.D.

The stakeholder, Macron, says that these results prove that the cadmium content of its photoresistors are below the maximum allowed threshold limits and therefore claims these photoresistors to be RoHS-compliant. For details of the tests please refer to the stakeholder document no. 5 section 5.3.6. The crucial point is that sample 1 comprising the ceramic body, the photosensitive, cadmium-containing material and the thin metallization are considered as homogeneous material.

Both test reports in documents no. 5 and 6 only indicate that photoresistors and optocouplers had been tested. No producer or article numbers or other specifications of the tested products are indicated.

ERA test reports from stakeholder consultation 7 and from the review process

In the 7th stakeholder consultation, Casco Silonex had submitted a test report by ERA stating that the Macron photoresistors are not RoHS-compliant (see section 5.3.6, document no. 7). However, it was not indicated in the report, which Macron model of photoresistor had been assessed. Macron stated that it produces both RoHS-compliant and non-RoHS-compliant photoresistors and optocouplers, and that the photoresistor tested by ERA was not from its RoHS-compliance models.

Another test reports was submitted during the review process (document no. 11, section 5.3.6). This test report is from ERA by the order of Casco Silonex as well and negates the RoHS compliance of the assessed Macron products. In opposite to the first ERA report, ERA this time specifies the tested Macron devices:

- MI 1210CLA-R (type “A”)
- MI 1210CLB-R (type “B”)
- MI 1210CLH-R (type “C”)

ERA states that Macron claims these three photoresistors to be RoHS compliant. This statement of ERA in principle is congruent with Macron’s information that the three versions of its MI1210CL-R model is one of its three RoHS-compliant photoresistor models. The “C”-denomination of the last of the three series, the MI1210CLH-R, is not congruent with Macron’s information. According to Macron, this is the “H”-series, and there is no information from Macron whether a “C”-series actually exists. In the ERA test report, the MI 1210CLH-R model is sometimes addressed as “C”-type, sometimes as “H”-type (e.g. in Table 9).

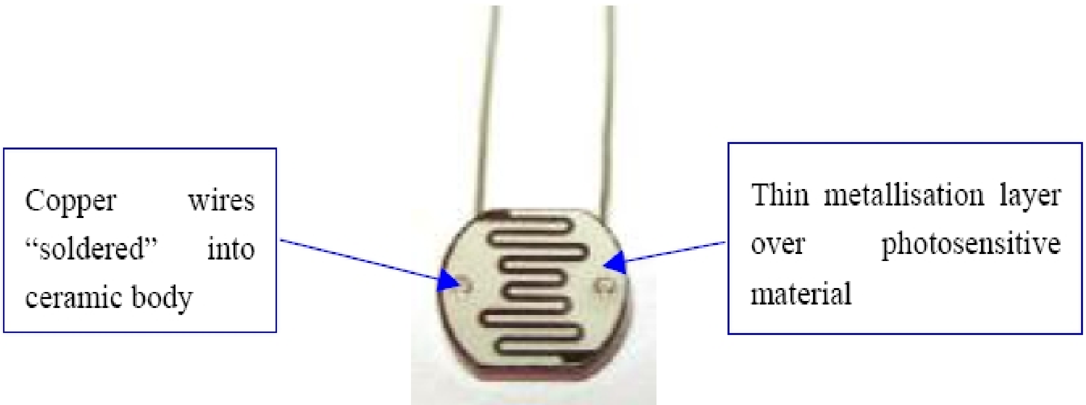


Figure 12: Image of Macron photocell (source: ERA, see document 7 in references, section 5.3.6)

The above image is from the first ERA report submitted during the stakeholder consultation. It is not clear which photoresistor this image shows, as the report does not specify this. It is shown here nevertheless as it helps understanding the sampling and the results of ERA in the second report. As only the second ERA report (document no. 11 in references) allows a clear attribution of the test results to clearly specified products, the following results were taken from this second report.

ERA challenges the homogeneous material definition of the RWTT test reports. The sample 1 in the Macron test report no. 5 can be mechanically disjointed into two homogeneous materials:

- the ceramic base
- photosensitive layer containing cadmium and the metallisation (cannot be mechanically disjointed from cadmium layer)

ERA describes the preparation of the homogeneous material and the testing as follows (document no. 11, section 5.3.6):

"Each device was cut into two parts using a diamond saw. This separates the LEDs from the light dependent resistors [the Macron devices obviously are optocouplers, not single photoresistors; the contractors]. The light dependent resistors have coatings of a transparent gel over a thin metal mask that defines the resistor path which is made of the photosensitive material."

Figure 13: Light dependent resistors from Macron optocoupler type "A", type "B" and type "C" (left to right) (source: ERA, see reference document no. 11, section 5.3.6)

"It was possible to use a surgical scalpel to scrape off the transparent gel. The metal layer was very thin and could not be separated from the photosensitive layer and so these are removed together with the scalpel as one material which was transferred to an adhesive stub."

ERA says that they scraped the photosensitive layer with metal mask off the substrate from between the metal pins, which are visible as the two silvery circles in each type of photoresistor in the above and below figures. According to ERA, the pins are soldered into position and the solder contains tin but no tin was detected in the analysis sample and this shows that it was possible to avoid the pins.

Figure 14: Light dependent resistors from Macron opto-coupler type "A", "B" "C" (left to right) after the gel and photosensitive material coatings had been removed (source: ERA, document no. 11, section 5.3.6)

"The stubs are designed for insertion into a Scanning Electron Microscope (SEM) and materials are analysed using energy dispersive X-ray (EDX) analysis.

This analysis technique was chosen, as it is able to analyse very small quantities of material. If many optocouplers had been available, it would be possible to scrape off sufficient photosensitive layer for analysis by other techniques such as Inductively Coupled Plasma (ICP) Spectroscopy but ERA had only two of each type available. "

Table 11: SEM/EDX analysis of photosensitive coating from Macron optocouplers

	Results (weight percent)	**Comments**
"A"	Cadmium 60,6 %, sulphur 15,5%, selenium 5,5 %	This material is cadmium sulphide/selenide
"B"	Cadmium 70 %, sulphur 18,4 %, selenium 4,1 %	This material is cadmium sulphide/selenide
"H"	Cadmium 58,2 %, sulphur 15,1 % selenium 2,3 %	This material is cadmium sulphide/selenide

(Source: ERA, document no. 11, section 5.3.6)

ERA explains that the figures in the table for the cadmium-containing elements do not add up to 100% because small amounts of impurities from the gel coating (carbon and oxygen) and the alumina substrate (aluminium and oxygen) have not been included.

According to the test results in Table 11, the cadmium content in the analyzed Macron photoresistors would be clearly above 0.01 %. The optocouplers would thus not be RoHS-compliant. For details, refer to document no. 11 in references, section 5.3.6.

Additional Macron Test Report

Macron, as a reaction on the ERA test report submitted during the seventh stakeholder consultation (document 7, section 5.3.6), insisted on the RoHS compliance of its photoresistors and submitted a new test report during the exemption review process (document no. 12 in references, section 5.3.6).

The report contains an explication about Macron's technology:

"Traditional photocells usually contain a layer of CdS/CdSe which act as a photosensitive layer. However, Macron has developed a new technology where much lesser cadmium is required to obtain the same function. The innovative manufacturing method from Macron is a new process that mixes cadmium into the ceramic base, which allows the ceramic base to have photosensitive function. For this reason, Macron's photocell can only be separate into three homogeneous materials (transparent plastic, white ceramic and silvery metal).

Macron uses the innovative technology of photosensitive ceramic instead of using an additional photosensitive CdS/CdSe layer. According to the definition of the EU Commission, this ceramic base cannot be "mechanically disjointed" from the white ceramic part. Therefore, the ceramic base -cadmium mixture should be counted as the same homogeneous material with the white ceramic part."

Macron was asked whether the ceramic base and the white ceramic part are two different materials. Macron explained, "The ceramic base and the white ceramic part refer to the same ceramic part. It must be a typo. In this sentence "According to the definition of the EU Commission, this ceramic base cannot be "mechanically disjointed" from the white ceramic part.", "ceramic base" should really mean "cadmium". In our manufacturing process, cadmium was mixed into the ceramic before it cools; there is only 1 ceramic part in the photocell unit." (Source: Macron, received via e-mail 31 August 2007).

"White ceramic" is also used in other sections of the test report, e.g. in the following figure as well as in the description of the samplings and the analyses in Table 8 in section 5.3.4.1.

This denomination is consistent throughout the test report no. 12 in section 5.3.6. The testing laboratory considers the white ceramic part as homogeneous material, as the following figure underpins.

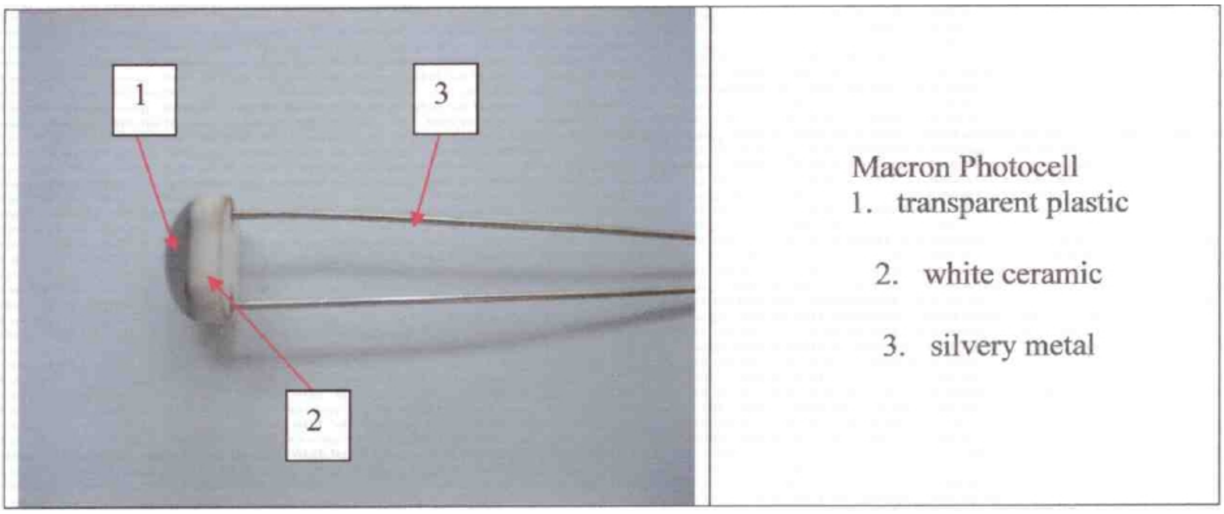
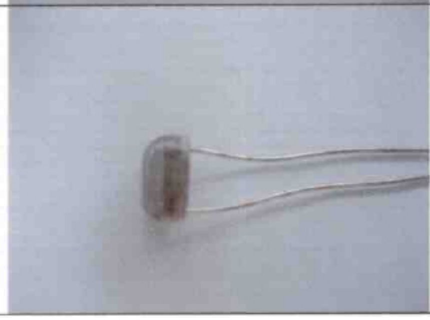


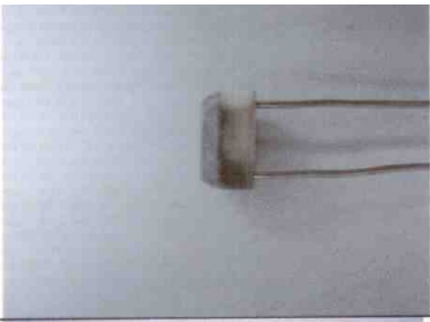
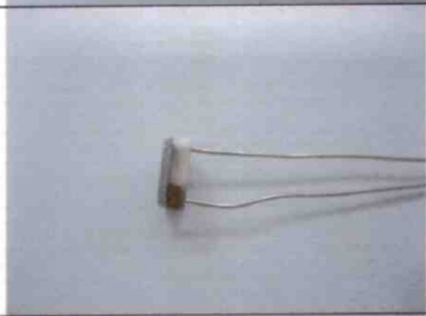
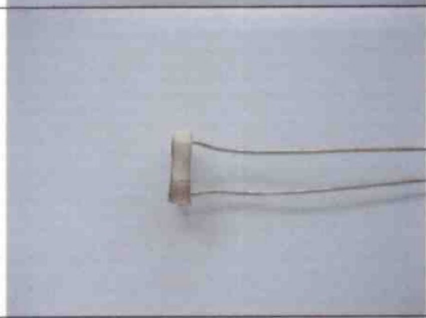
Figure 15: Physical appearance and homogeneous materials in Macron photoresistors (source: RWTT test report, document no. 12 in references in section 5.3.6)

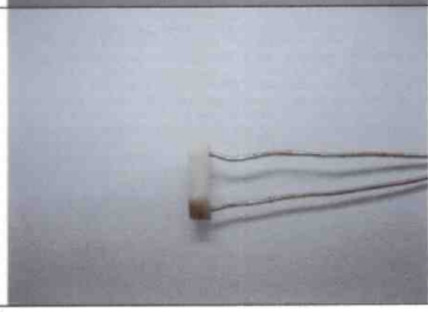
The report specifies the tested product as Macron's MI 1210CLA-R (A-type), which according to Macron has the highest content of cadmium to achieve a high photosensitivity.

The testing laboratory, RWTT, has taken a different approach for the sampling this time compared with the previous Macron reports described before. The following table shows the sampling procedure and the cadmium content for each of the obtained samples. The samples were analyzed using XRF analysis.

Table 12: Sampling and XRF analysis results of obtained samples

Removal stage	Cadmium concentration (ppm)	Other element detected	Physical Appearance
With complete resin layer	N.D.	Sn, Pb, Cu, Fe	
After 1st abrasion to remove a layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	

After 2nd abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 3rd abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 4th abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 5th abrasion to remove all the transparent plastic, white ceramic and metal silvery pin has been exposed	31.1	Sn, Pb, Cu, Fe	
After 6th abrasion to remove a layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	

After 7th abrasion to remove another layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	
After 8th abrasion to remove another layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	
After 9th abrasion to remove another layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	
After 10th abrasion to remove another layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	

* Accuracy estimated by instrument as ± 50 ppm for cadmium.

Source: Macron test report/RWTT, document no. 12, section 5.3.6

According to these test results, only the last bit of transparent layer (material of 5th abrasion) would contain 0.0031 % (31.1 ppm) of cadmium, which is below the maximum allowed level of 0.01 % for RoHS compliance. The photoresistor would thus be RoHS-compliant. For details, refer to document no. 12 in references in section 5.3.6.

Macron was asked to explain the results. The cadmium, according to the process description in the test report, is mixed into the ceramic base. The test result, however, indicates no detectable cadmium in the ceramic base, but only in the last bit of abraded transparent plastic.

Macron explained that the cadmium was detected in the 5th abrasion of the transparent layer because RWTT might have abraded parts of the white ceramic with the last bit of transparent layer. There is no cadmium in the transparent layer, according to Macron, but the cadmium concentration should be higher nearer to the photosensitive surface of the ceramic and it therefore was detected with the first abrasions of the white ceramic. Macron said it could not prove the higher cadmium surface at the surface, as it had no clear evidence. Macron stated that it did not see how the sampling was done and there is no standard of how deep the sample should be abraded before each analysis. Macron itself relativised this statement in a later e-mail saying that the detected cadmium comes from the top of the ceramic abraded with the last bit of transparent layer, and there is a gradient of cadmium content from the surface towards the inside of the ceramic body. Macron did not explain why later it was sure of the gradient of cadmium content, while before it was just expressed as an assumption.

Macron states that the process of making the photo-sensitive ceramic is one possible explanation for the cadmium content of 0.003 % analysed with the last bit of transparent layer. During the early stage of the cooling process of the photosensitive ceramic, before the ceramic hardens, a small amount of cadmium added is sedimented to the bottom of the photo-sensitive ceramic. The bottom of this photosensitive ceramic becomes the photosensitive surface, where a layer of the transparent plastic is added. This processing makes plausible that there could be a gradient of cadmium content with higher contents of cadmium in the material directly under the transparent layer. This would mean, on the other hand, that the cadmium is not really mixed INTO the liquid ceramic, as described before. Macron did not give further explanations on the processing issue.

Macron says the fact that no cadmium could be detected in the later abrasions after the 5th one may have to do with the XRF analysis. The XRF analysis deviates within ± 50 ppm (± 0.005%), as also mentioned in the ERA report. Macron states that its photosensitive ceramic contains cadmium under the surface layer, too, but, as the inside only contains trace amounts of cadmium, it cannot be detected with the XRF analysis. In another statement, Macron says that for each of its optocouplers, a total of around 80 ppm of CdS and CdSe are added into the ceramic liquid for mixing. Macron says that the 80 ppm of CdS/CdSe are already related to the weight of the solid ceramic, not the liquid ceramic.

This corresponds to a cadmium content of around 0.004 % of cadmium for CdSe and around 0.006 % for CdS. As both cadmium compounds are mixed, the calculatory average cadmium content should be somewhere in between neglecting the gradient of cadmium content from the surface towards the inner ceramic.

The contractors did not go further into details of the test results, as this would be beyond the possibilities of their mandate.

Homogeneous material definition and interpretations in the tests

The applicants and stakeholders have submitted tests which arrive at different, contrary and controversial results. While the ERA test reports by the order of Silonex shall prove that the products, which Macron specifies as RoHS-compliant, are not RoHS-compliant, the RWTT test reports by the order of Macron shall prove the opposite.

A part of the discussion is what should be considered as the homogeneous material in the assessed products. As mentioned before, the contractors will not assume a position in this discussion, but just show the different standpoints.

The Commission's frequently-asked-questions (FAQ) document (http://ec.europa.eu/environment/waste/weee/pdf/faq_weee.pdf) informs in section 2.3:

“2.3. Are maximum concentration values set in the RoHS Directive?

For the purposes of Article 5(1)(a) the Commission has adopted Decision 2005/618/EC whereby a maximum concentration value of 0.1% by weight in homogeneous materials for lead, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) and of 0.01% weight in homogeneous materials for cadmium shall be allowed.

Homogeneous material means a material that cannot be mechanically disjointed into different materials.

Definitions:

The term “homogeneous” means “of uniform composition throughout”. Examples of “homogeneous materials” are individual types of: plastics, ceramics, glass, metals, alloys, paper, board, resins and coatings.

The term “mechanically disjointed” means that the materials can, in principle, be separated by mechanical actions such as: unscrewing, cutting, crushing, grinding and abrasive processes.

Examples:

- A plastic cover is a “homogeneous material” if it consists of one type of plastic that is not coated with or has attached to it or inside it any other kinds of materials. In this case, the limit values of the Directive would apply to the plastic.
- An electric cable that consists of metal wires surrounded by non-metallic insulation materials is an example of a “non-homogeneous material” because the different materials could be separated by mechanical processes. In this case, the limit values of the Directive would apply to each of the separated materials individually.
- A semi-conductor package contains many homogeneous materials which include: plastic moulding material, tin-electroplating coatings on the lead frame, the lead frame alloy and gold-bonding wires.”

(End of quotation from the Commission's FAQ-document)

Both test reports refer to the above definitions in the Commission's FAQ-document or the respective phrases in the RoHS Directive and technical guidance documents.

ERA adds that the definition of homogeneous materials is simply a definition; it is clearly not an instruction for chemical analysis. ERA explains that if one material in principal can be separated from another then these are separate materials, even if a "clean" separation is not possible or it is impossible to separate sufficient material for chemical analysis to be carried out. ERA cites a document published by the RoHS Enforcement Network (see page 13 of document no. 12 in section 5.3.6) as reference for this position.

ERA in its test report describes the photoresistors for which Macron claims RoHS compliance and draws conclusions:

"The photocell is made from a ceramic disc with a deposited layer containing cadmium. This is heated then to create the photosensitivity. Macron state that after heating, the surface layer cannot be "mechanically disjointed" from the ceramic substrate. This is a crucial point and one that needs to be tested. Note that the definition of mechanical disjointing is that the materials can, in principal, be separated by mechanical actions indicates and so implies that separation need not be perfect." (source: document no. 7, section 5.3.6)

ERA made several abrasions of the ceramic base after removal of the transparent plastic layer. The materials obtained via these abrasions are considered as homogeneous material. The cadmium content in these abraded materials is clearly above the maximum allowed threshold level of 0.01 % of cadmium. ERA concludes that the tested Macron photoresistors are not RoHS-compliant.

RWTT has tested the Macron photoresistor and describes the product as well as how it is manufactured and draws conclusions concerning the homogeneous material:

"In the traditional photocell manufacturing method, a thin layer of CdS/CdSe is sprayed onto a ceramic base. [...] However, Macron has developed a new technology where much lesser cadmium is required to obtain the same function. The innovative manufacturing method from Macron is a new process that mixes cadmium into the ceramic base, which allows the ceramic base to have photosensitive function. For this reason, Macron's photocell can only be separate into three homogeneous materials (transparent plastic, white ceramic and silvery metal). Macron uses the innovative technology of photosensitive ceramic instead of using an additional photosensitive CdS/CdSe layer. According to the definition of the EU Commission, this ceramic base cannot be "mechanically disjointed" from the white ceramic part.

Therefore, the ceramic base cadmium mixture should be counted as the same homogeneous material with the white ceramic part." (Source: document no. 12, section 5.3.6).

RWTT made several abrasions of the ceramic body including the silvery pins. Each of the different abraded materials was tested for its cadmium content.

None of these materials exceeded the 0.01 % of cadmium content. RWTT concludes that the assessed Macron photoresistor is RoHS-compliant.

ERA says that the abrasion of material was conducted in between the silvery pins. The tested material thus did not include any constituents of these silvery pins. RWTT had abraded the tested material after removal of the transparent plastic layer from the surface including the silvery pins. It is not clear whether and how far this has an influence on the test results.

Furthermore, Macron says that its A-type photoresistor has the highest contents of cadmium and therefore had this type tested. ERA, however, measured the highest cadmium contents in the B-type photoresistor. According to the ERA results, its cadmium content is around 10 % higher than in the A-type.

The RWTT and the ERA tests arrive at contrary, conflicting results. They state the RoHS-compliance and non-RoHS-compliance of the tested Macron photoresistors respectively. The differences cannot only be explained with different homogeneous material definitions. The description of the tested Macron photoresistor from ERA and from RWTT already differ considerably, as the above quotations from the test documents show, although the article numbers coincide. It could have been expected that the ERA test and the second RWTT test (document no. 12 in section 5.3.6) arrive at similar results, as in both cases the sampling is done by abrasion from the ceramic body. The inclusion of the silvery pins in the RWTT test might in parts explain the differences. Several reasons might be possible for the deviations, although, considering the huge differences between the results ranging from “not detectable” up to around 61 % of cadmium content, this might be a difficult task. The evaluation of the test procedures and the deeper investigation into the differences between the results is, however, beyond the contractors’ mandate.

The opposing parties could agree on a test procedure and a testing lab and then have the tests conducted again. In case an agreement or other solutions are not possible, both parties may file a lawsuit at the European Court of Justice.