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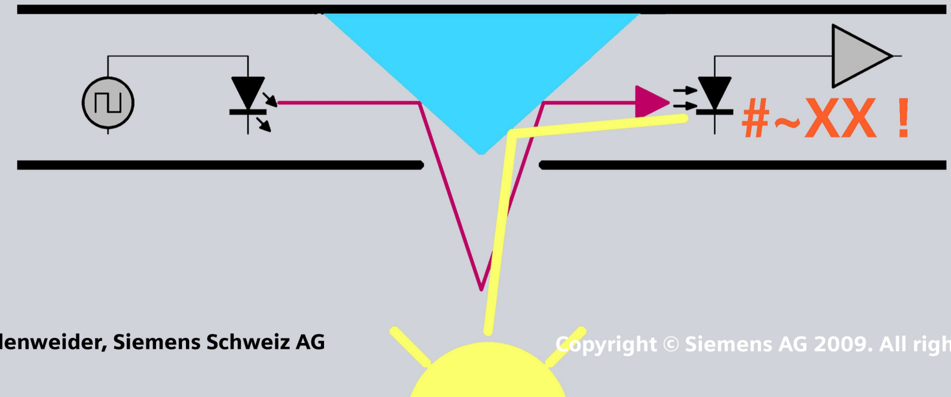
Optical Interferences from Fluorescent Lamps to Open Smoke Detectors

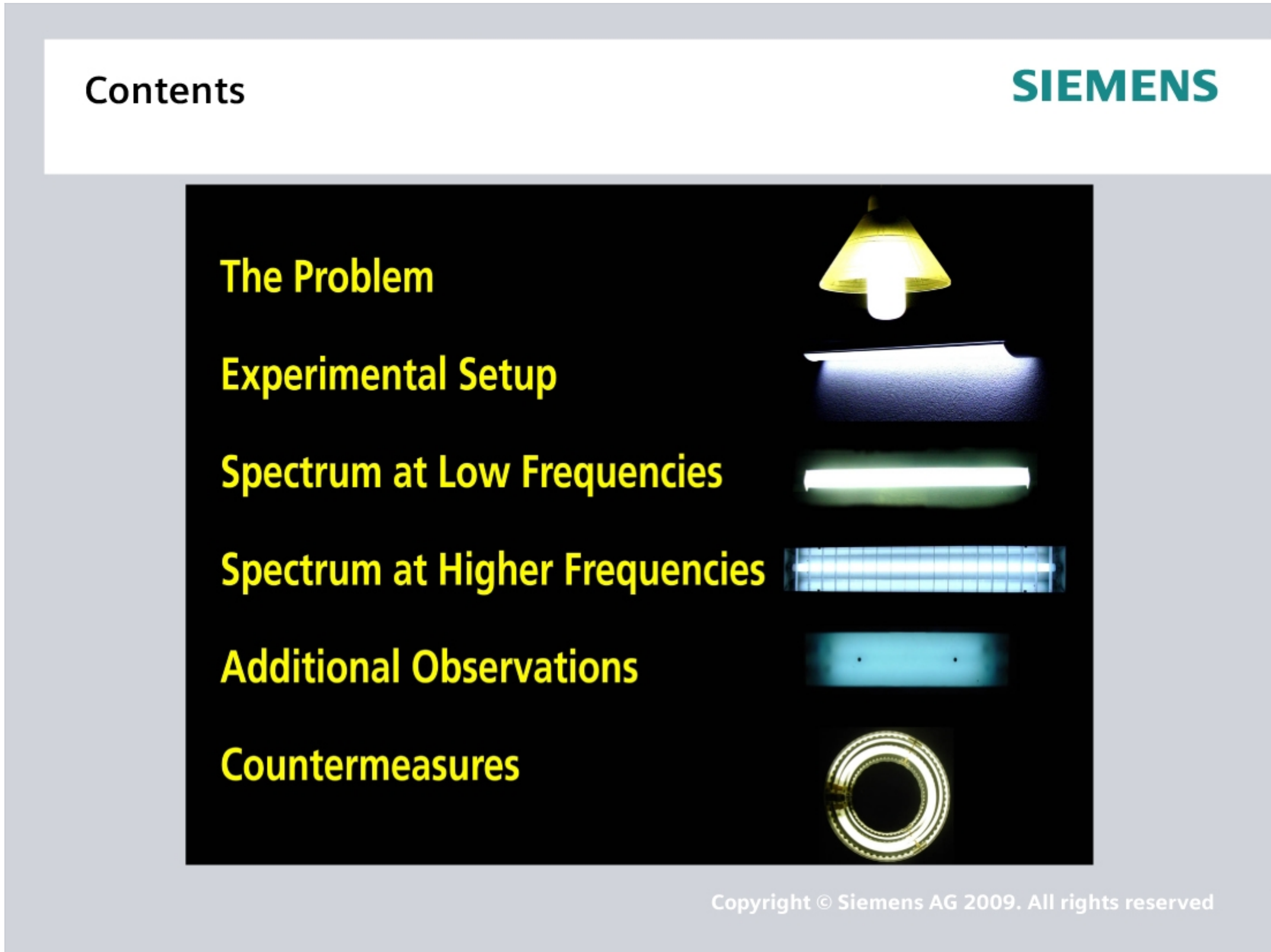


Walter Vollenweider, Siemens Schweiz AG

Conventional optoelectronic smoke detectors have a separation between the active volume and the environment. They are therefore protected against many kind of interferences. This is not true for an open smoke detector.

The light from fluorescent tubes is among the interferences which we fear most.

The title gives already some ideas on how an open smoke detector might look like. We do not need the optical transmitters for our measurements. A photo diode, an amplifier and a measuring instrument, e.g. a spectrum analyzer will do it.



Some fluorescent tubes are operated by a magnetic ballast. The light is modulated at low frequencies. Other tubes are operated by an electronic ballast. These tubes produce light which is modulated at higher frequencies.

We can see many more interesting things in the light of a fluorescent tube. This can be relevant for the receiver of an open smoke detector.

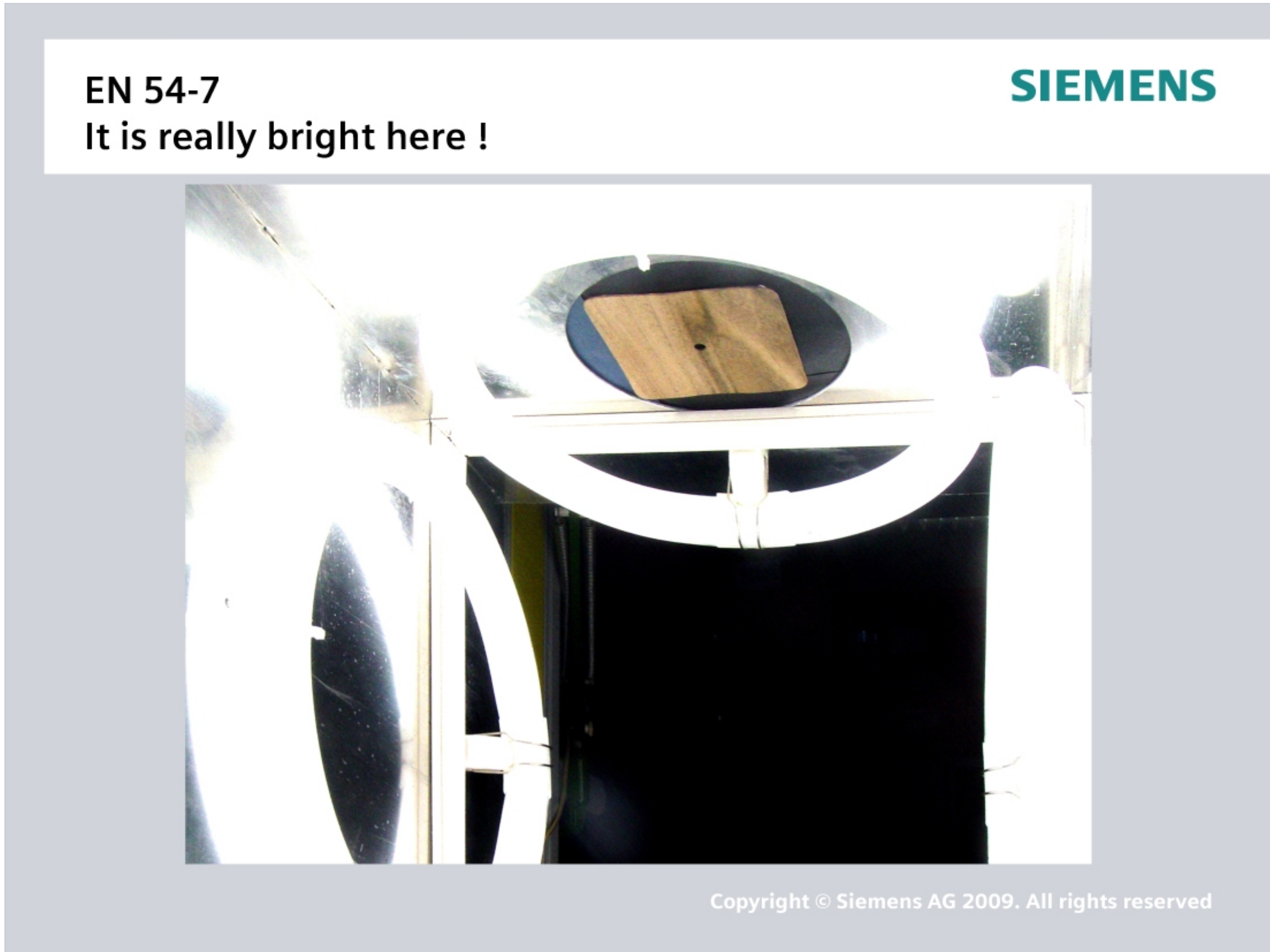
In the museum

An open smoke detector needs additional protection means in the receiver. This costs money. Why should a customer pay extra money for an open smoke detector if he can buy just an ordinary detector ? We visit a customer at his museum to find out.

We remark the exhibition hall, which has been redecorated in the style of the beginning of the 20th century. We admire the wonderful painting by Giovanni Segantini, and we are disgusted by the fire detectors.

The customer would prefer to see very flat detectors, or rather would prefer not to see them if they are sufficiently unobtrusive. Open smoke detectors have no smoke chamber. They can therefore be nearly as flat and unobtrusive as the customer likes them.

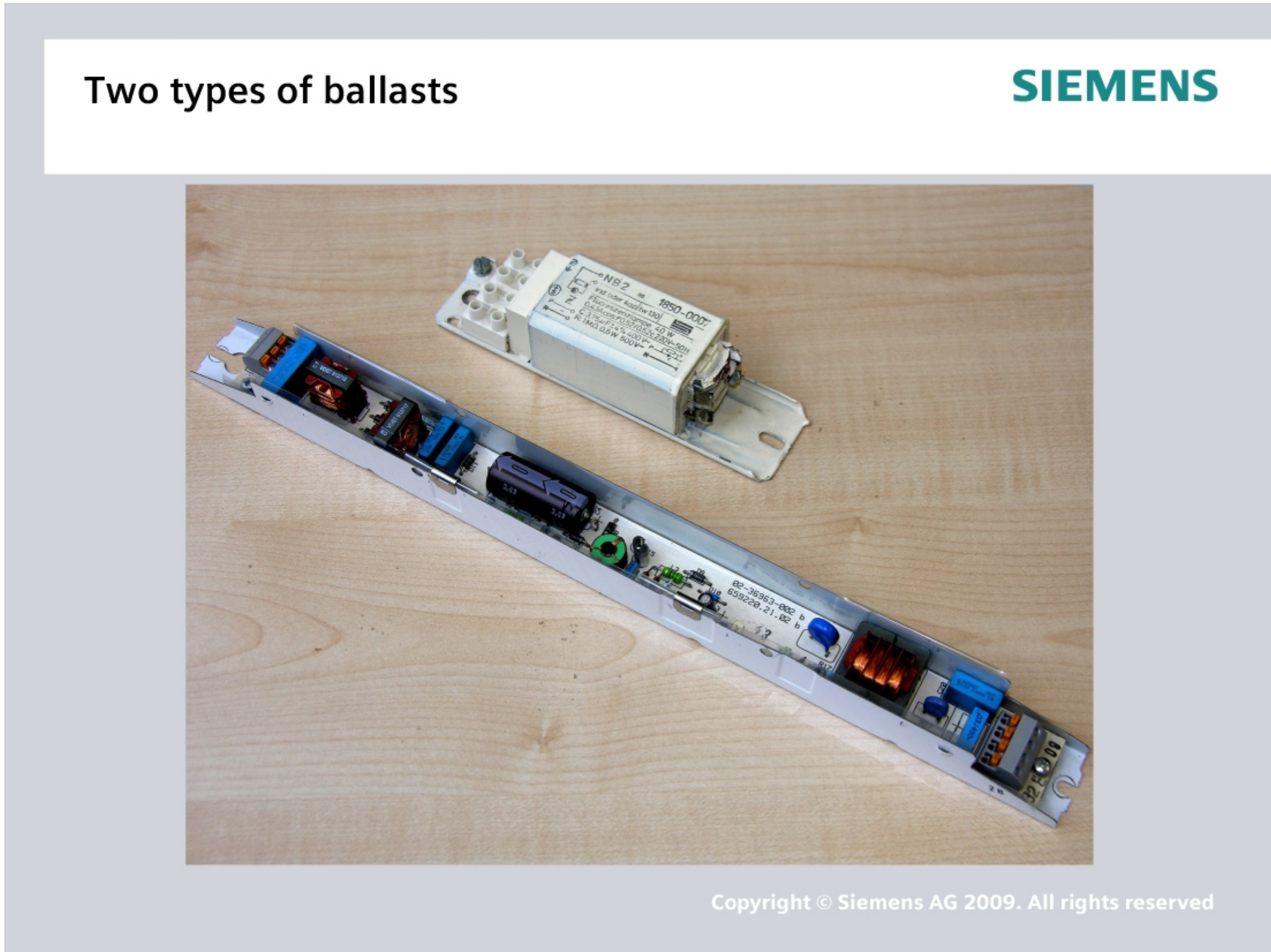
The very official test-box



There is a test in EN 54-7 which checks whether a smoke detector, be it an open or a conventional one is sensitive to ambient light. The detector is placed in a test-box. This box is illuminated by 4 circular fluorescent tubes with a total of 128 W electrical input power.

The light in the test set-up is much more intense than what we can expect under reasonable conditions. We might complain, but we don't. Serious testing is done in this way.

4 Experimental set-up



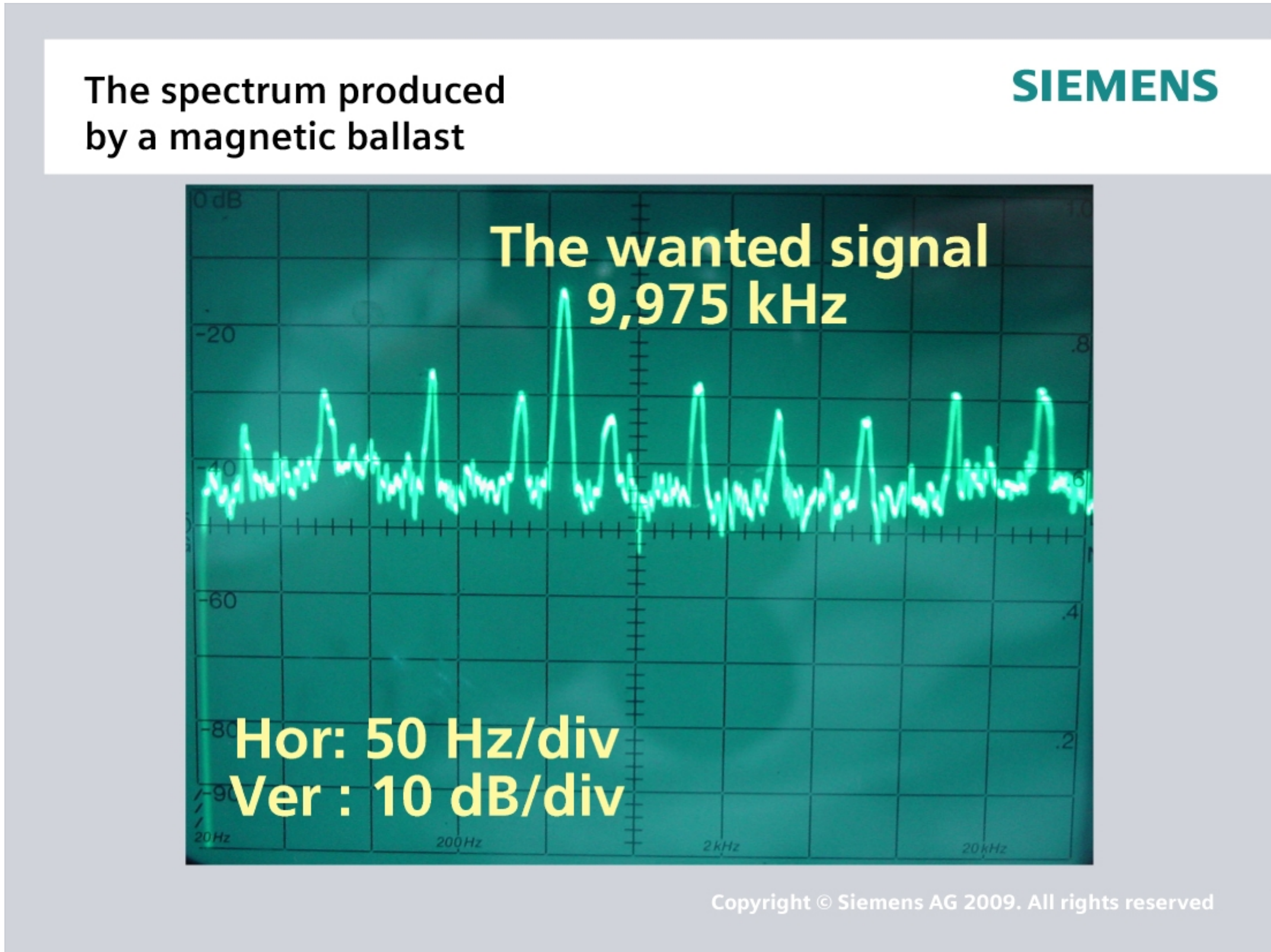
There exist two types of commonly used ballasts.

The magnetic ballast in the background is essentially an inductor. It has a certain impedance and limits the current in the lamp.

Electronic ballasts replace copper and iron by silicon to start the lamp and to operate it under optimal conditions. Electronic ballasts can be as simple as the one in the picture. Electronic ballasts can also be very sophisticated devices which are connected to a central management station.

The light from the two types of ballasts looks the same to the human eye. An open smoke detector sees it in a different way. The light from a magnetic ballast has components at multiples of the line frequency. The light of an electronic ballast has components at much higher frequencies.

5 Ambient light

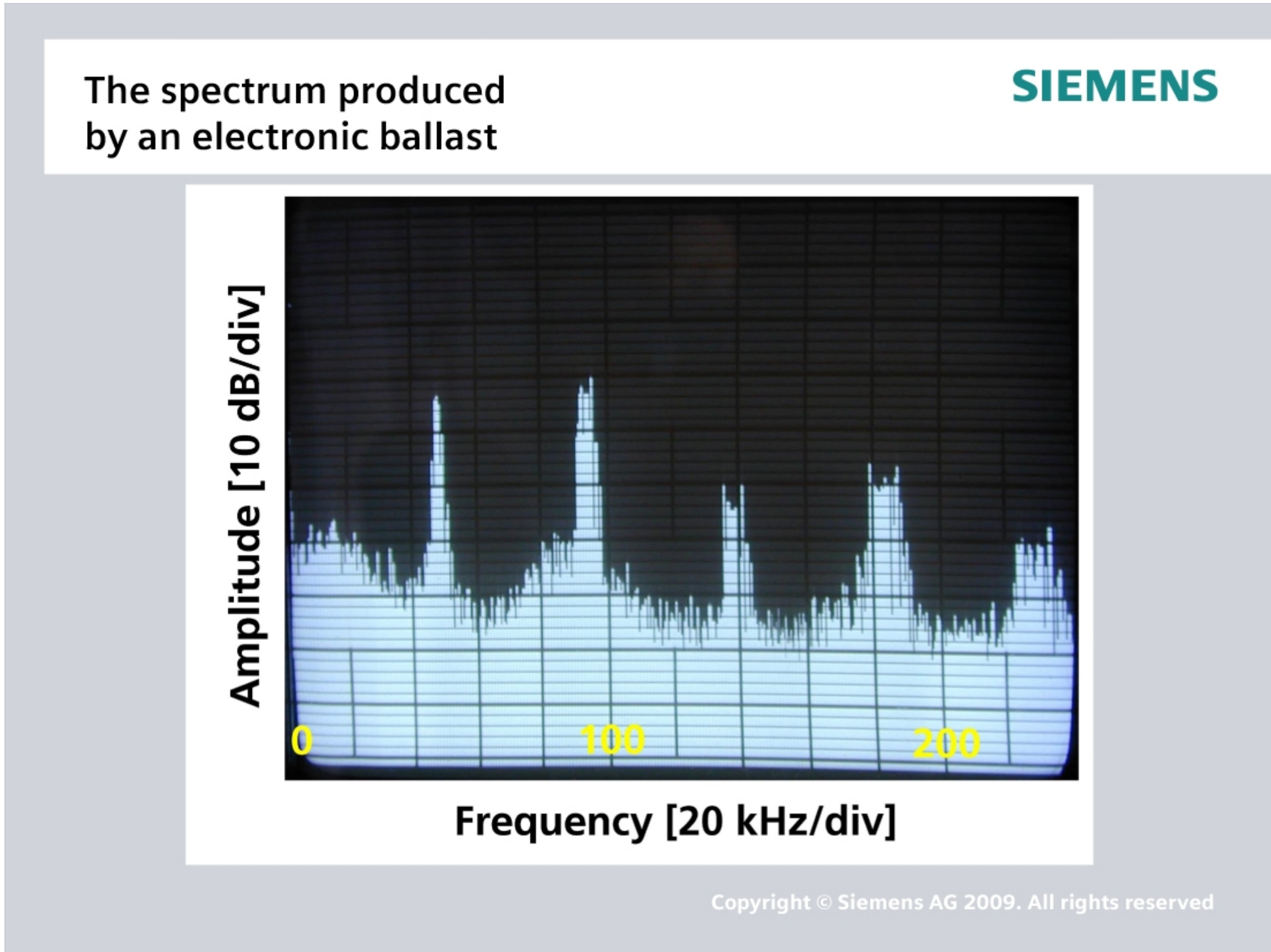


The picture shows the spectrum of the received signal in the test setup. It is measured close to 10 kHz. The horizontal scale is 50 Hz/div and the vertical scale 10 dB/div.

The highest peak is the wanted signal when the smoke has reached a certain density. The smaller peaks which appear every 50 Hz are harmonics of the line frequency. It is easy to see that a magnetic ballast is used.

The noise floor which we see is not generated in the test setup. The noise floor of the receiver and the spectrum analyzer is much lower. The noise seems to be generated in the lamp. A gas discharge is a stochastic process. We should therefore not be astonished that it is noisy. What I did not expect is that there is still so much energy in the noise and the harmonics of the line frequency at 10 kHz.

6 The spectrum at lower frequencies

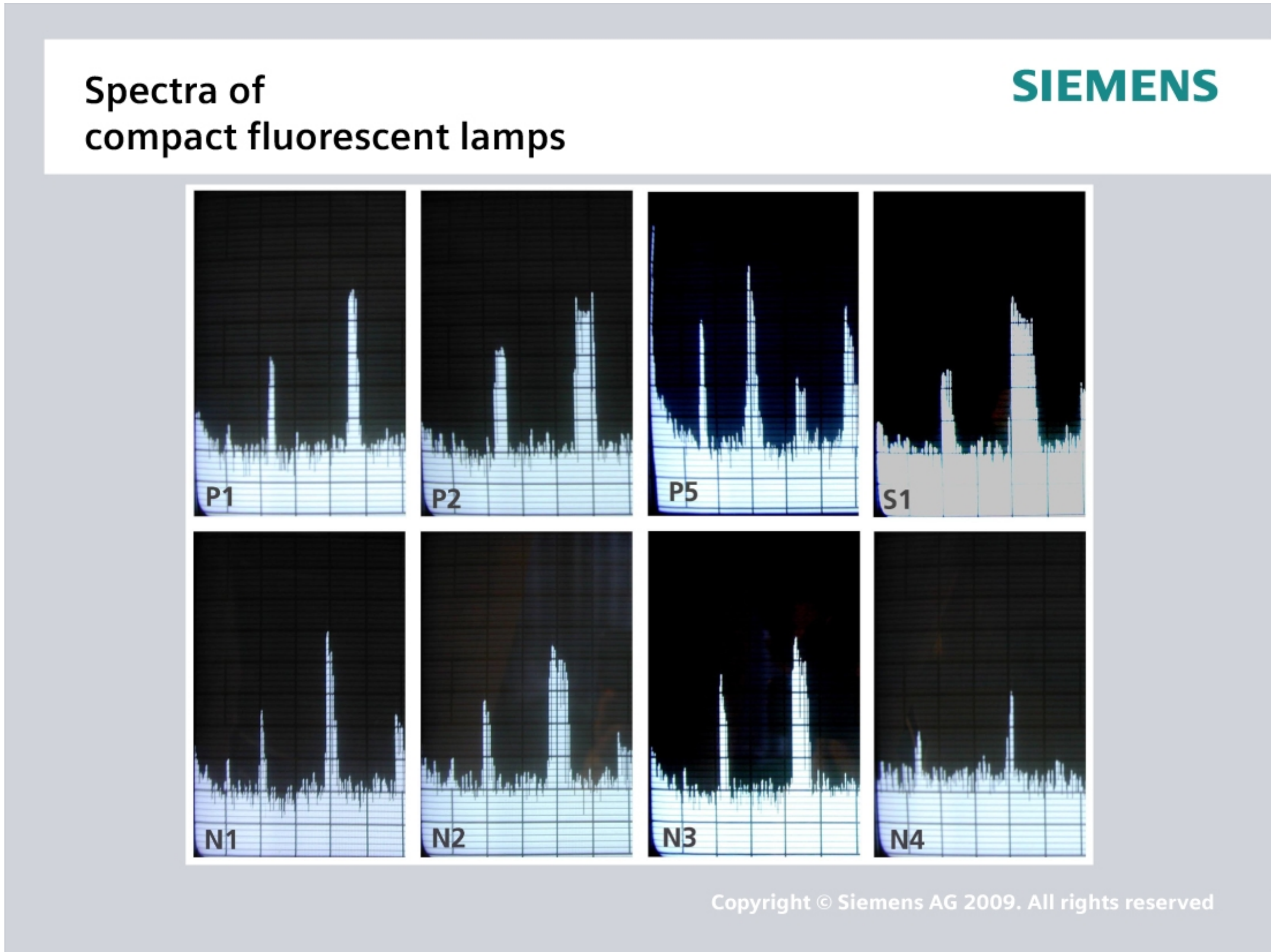


A fluorescent tube produces a very typical spectrum when it is operated with an electronic ballast. There is the fundamental frequency somewhere between 20 kHz and 50 kHz. It is 45 kHz in the case of this particular ballast. There is a second harmonic, which is at twice this frequency. It may be even stronger than the line at the fundamental frequency. There are more harmonics with a decreasing amplitude.

The signal seems to be frequency modulated for a reason which we do not know. The deviation is proportional to the order of the harmonic. We see therefore wider peaks at the right side.

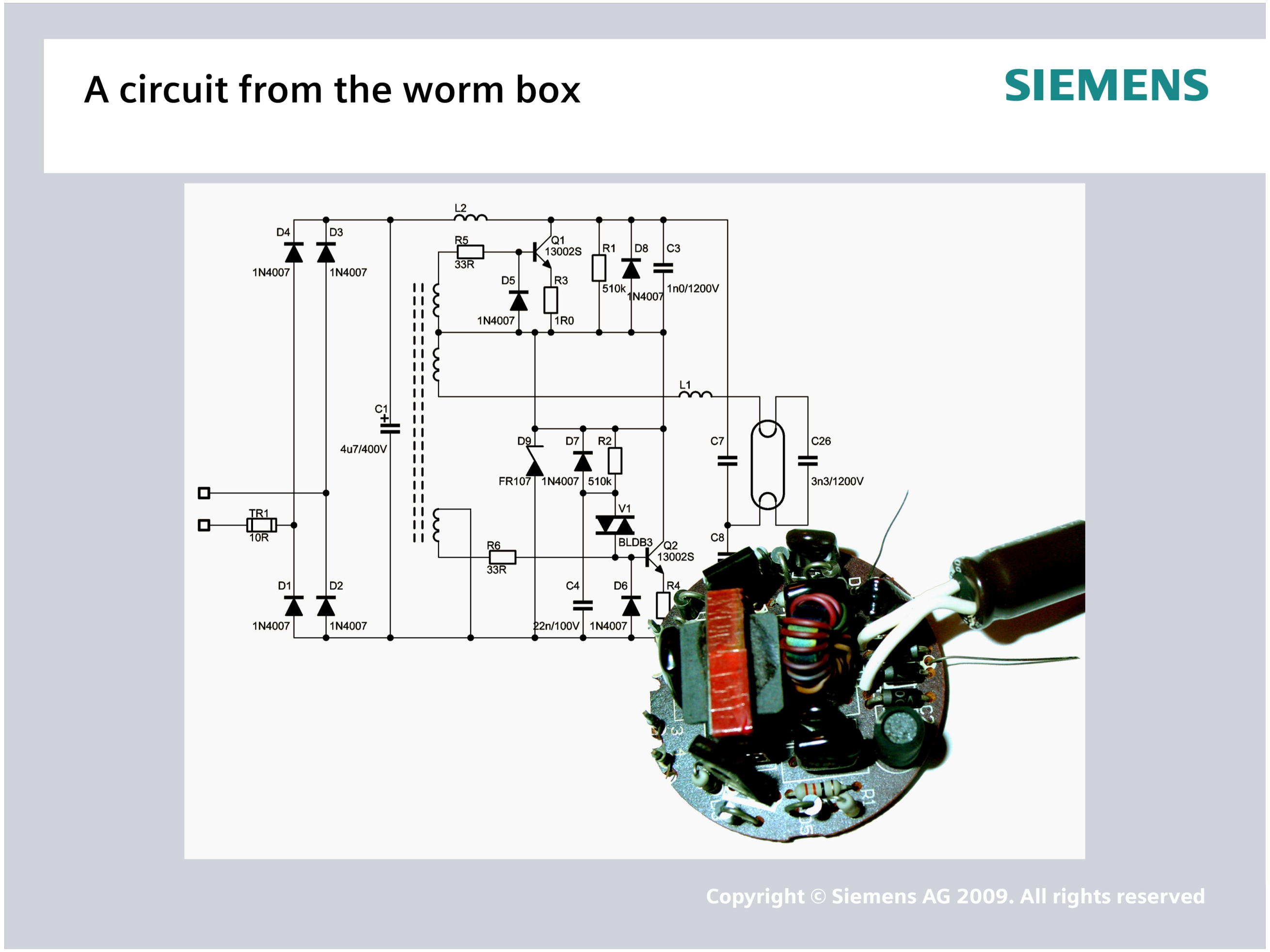
Osram, „ECG for T5 fluorescent lamps, technical guieline", May 2005, p.65

7 The spectrum at higher frequencies



We recorded the spectra of a number of compact fluorescent lamps. The vertical scale is 10 dB / div. The horizontal scale is 20 kHz / div., starting at DC at the left end of the display. The fundamental frequency is in the range of 20 kHz ... 50 kHz for all lamps. The harmonic at twice this frequency is usually stronger because light is produced in the two half waves.

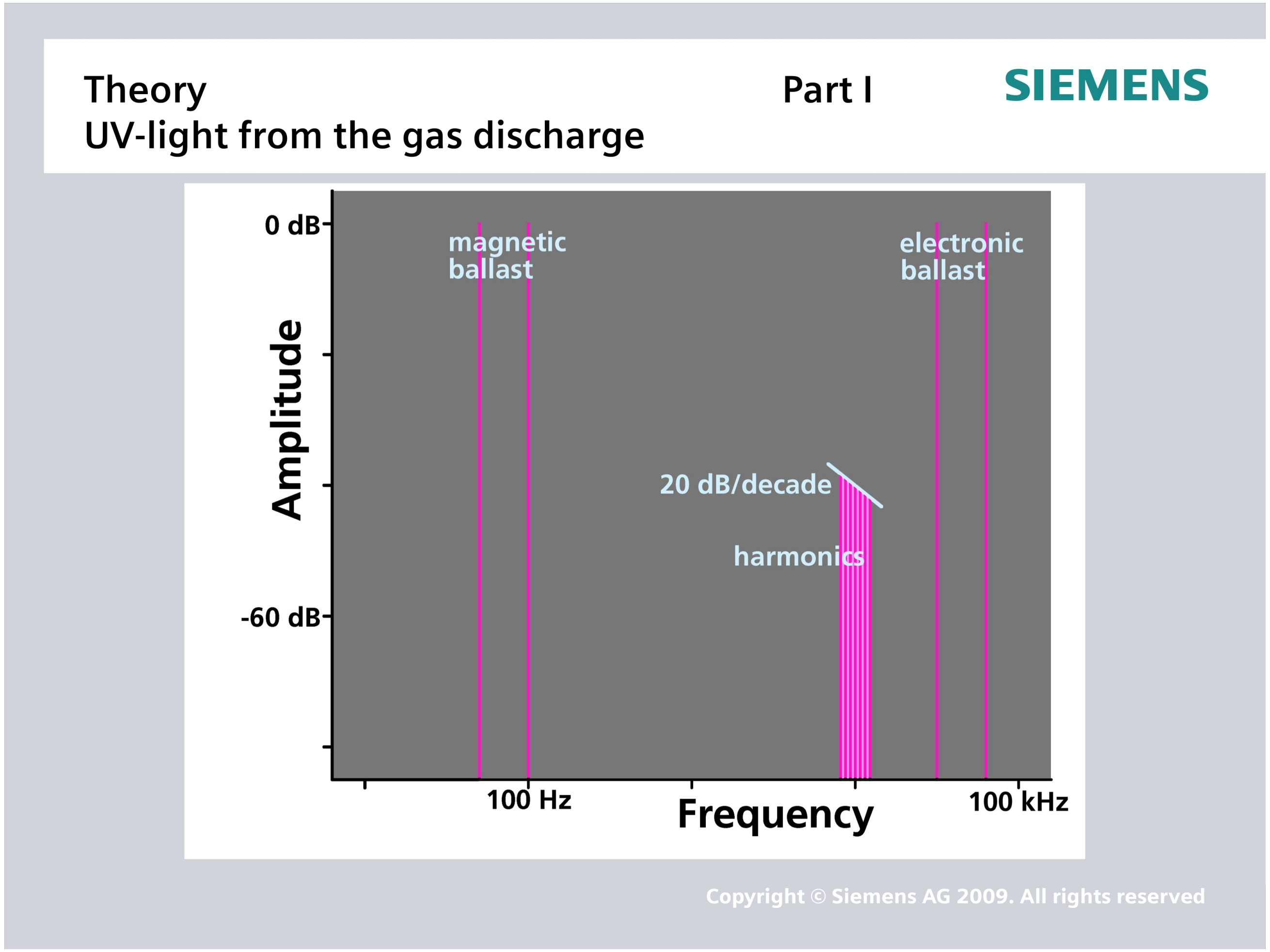
8 The spectrum at higher frequencies



I opened a burnt-out compact fluorescent lamp and copied the circuit. It is nearly the same as in a simple ballast for a fluorescent tube.

I have seen only one lamp, which was made in Europe quite a while ago, which used an IC. It seems that this simple circuit with the many inductive components is the cheapest one if it is made in the Far East.

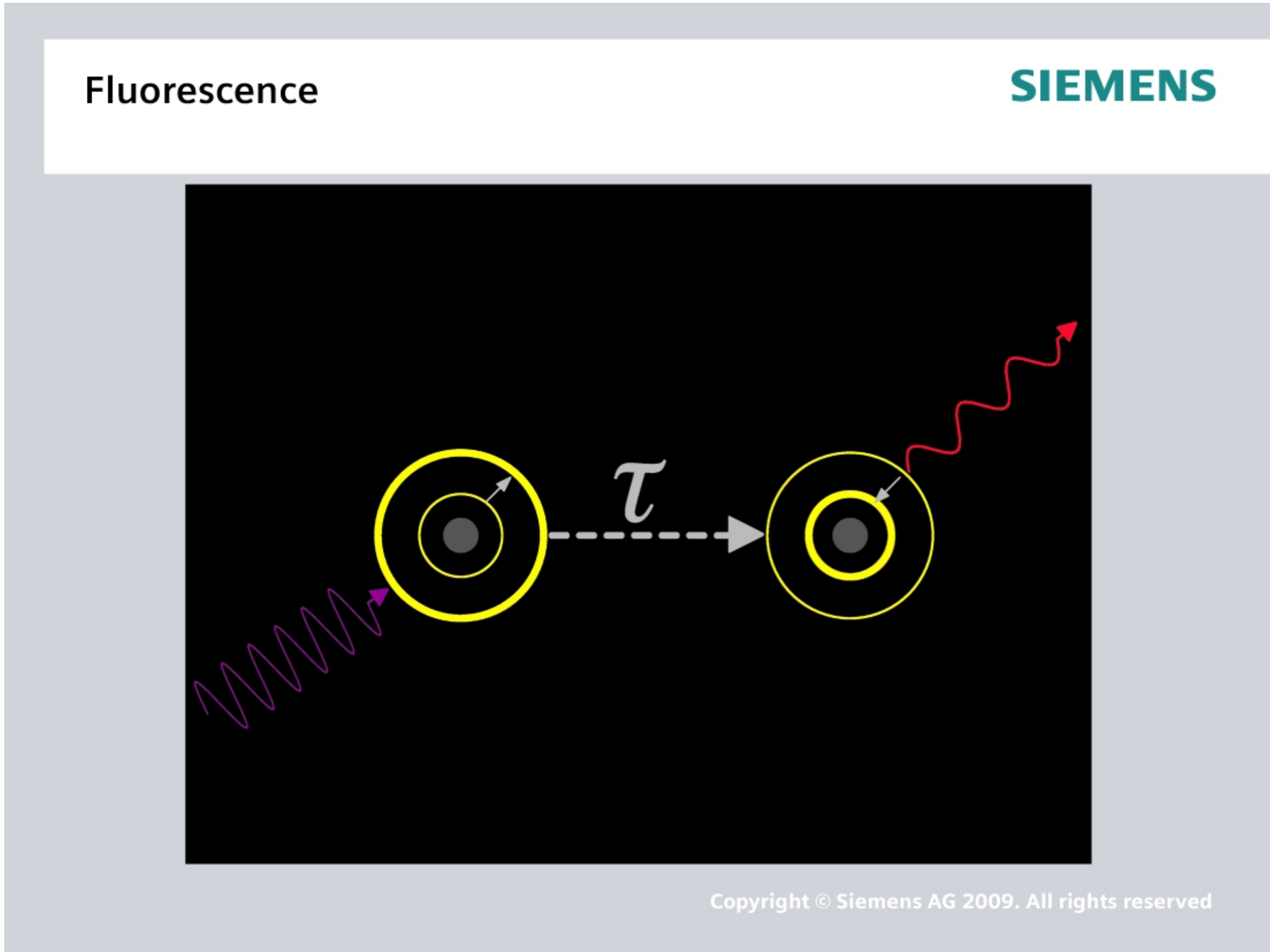
9 The spectrum at higher frequencies



The gas discharge in the tube produces ultraviolet light. The intensity of the light is modulated by the current which flows through the tube. The modulation frequency will be 50 Hz or 60 Hz, depending on the line frequency if the tube is operated by a magnetic ballast. There is a second harmonic, which is usually a few dB higher than the fundamental frequency. There are also many more harmonics. Usually they decrease following approximately a 1/f law, which is equivalent to a decrease by 20 dB/decade. A harmonic at 10 kHz will therefore be roughly 40 dB below the fundamental frequency.

The same is true for a lamp which is operated by an electronic ballast, but the fundamental frequency will be in the range between 20kHz and 50 kHz. The harmonics extend into the MHz range.

From the Textbook

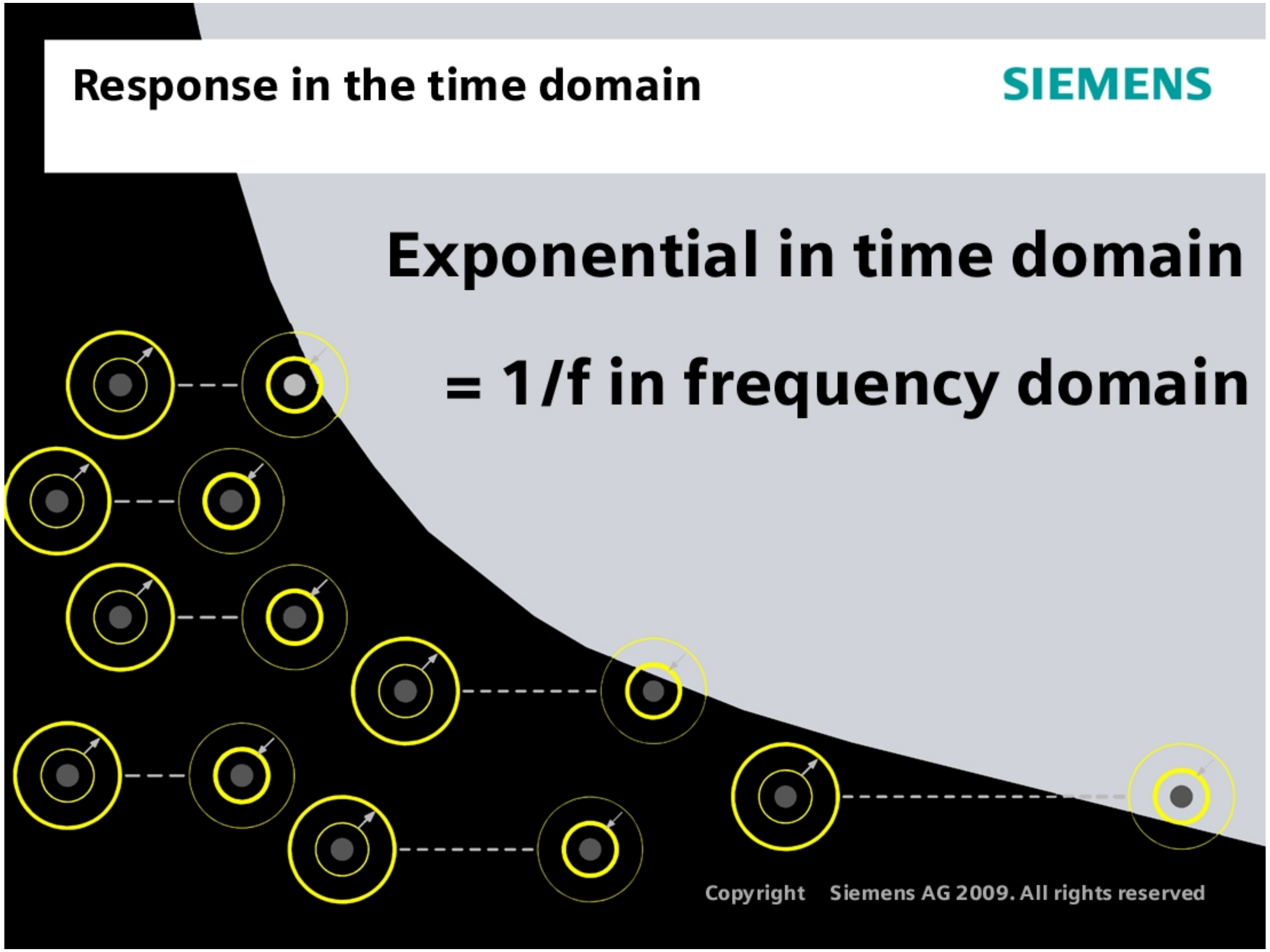


We read in the textbook about fluorescence:

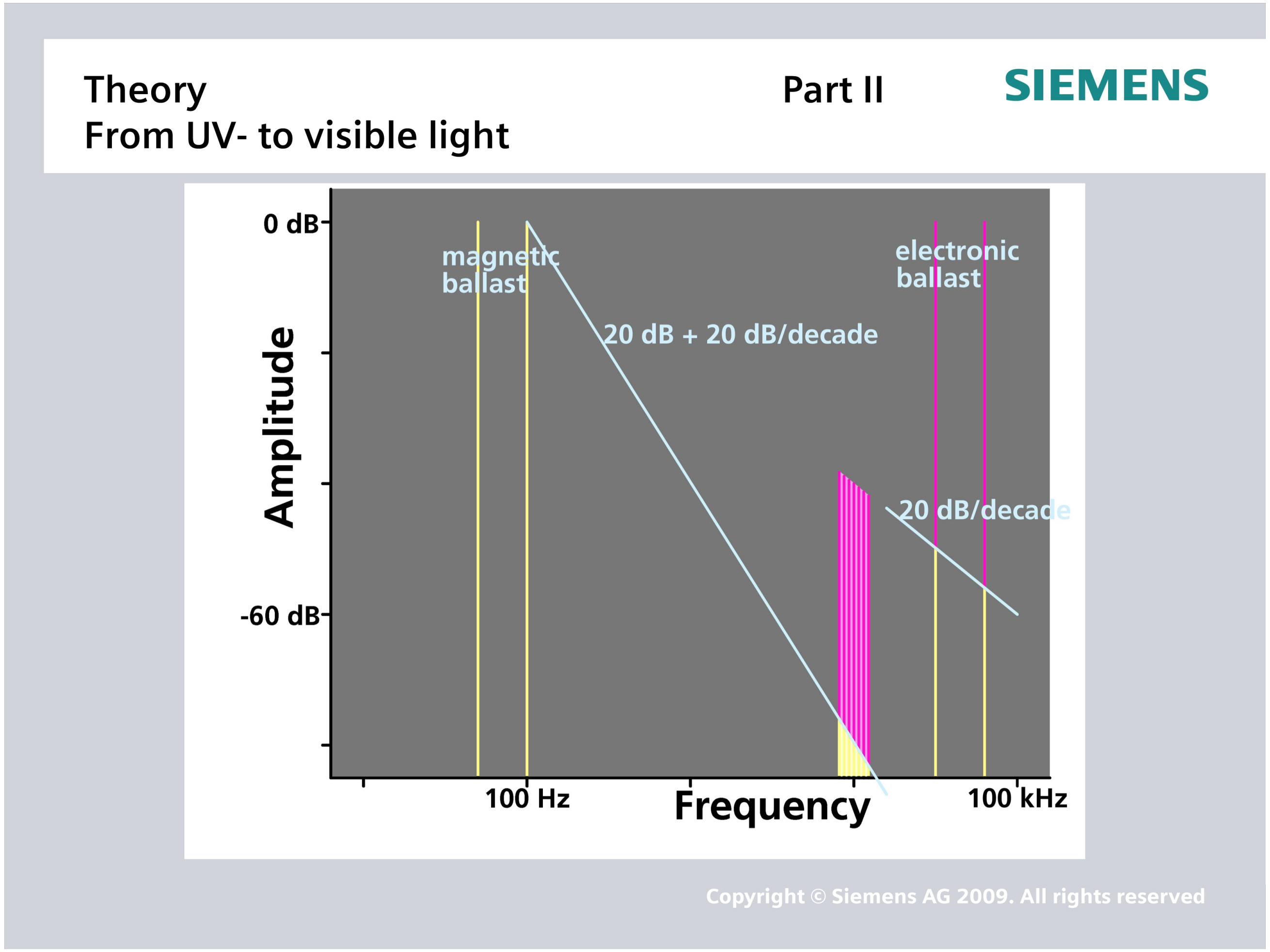
A photon with a sufficiently hight energy, e.g. in the ultraviolet range hits an atom. The atom transits into an excited state. It returns back to the fundamental state and gives the energy back. A part of this energy is radiated as a photon, which has a lower energy than the one which hit the atom in the beginning. The light is no longer in the ultraviolet region, but it can be visible light of a color which is determined by the nature of the atom.

11 Additional observations

From Time to Frequency Domain



The atom does not fall back immediately, but after a random delay. The probability that an atom falls back in a certain interval of time is constant. A large population of atoms which got excited at the same time will therefore not fall back at one moment. The number of atoms which fall back and therefore the light intensity will decrease exponentially in time. The transfer function of this system is equivalent to a first-order lowpass filter. High frequencies which are generated by an electronic ballast should therefore be considerably attenuated.



The ultraviolet light is converted into visible light in the fluorescent layer. The fluorescent layer has the effect of a first order lowpass filter with a 3 dB frequency in the range of 100 Hz. The amplitude of visible harmonics will decrease by roughly $1/f^2$ or 40 dB/decade. 20 dB/decade is due to the decrease of the amplitude of the ultraviolet light. The other 20 dB/decade is because of the fluorescent layer. The amplitude of a harmonic produced by a magnetic ballast at 10 kHz is therefore at approximately -80 dB.

The fundamental line which is produced by an electronic ballast, and which might be at 30 kHz will be attenuated to a value in the range of -50 dB.

This is what the simple theory predicts.

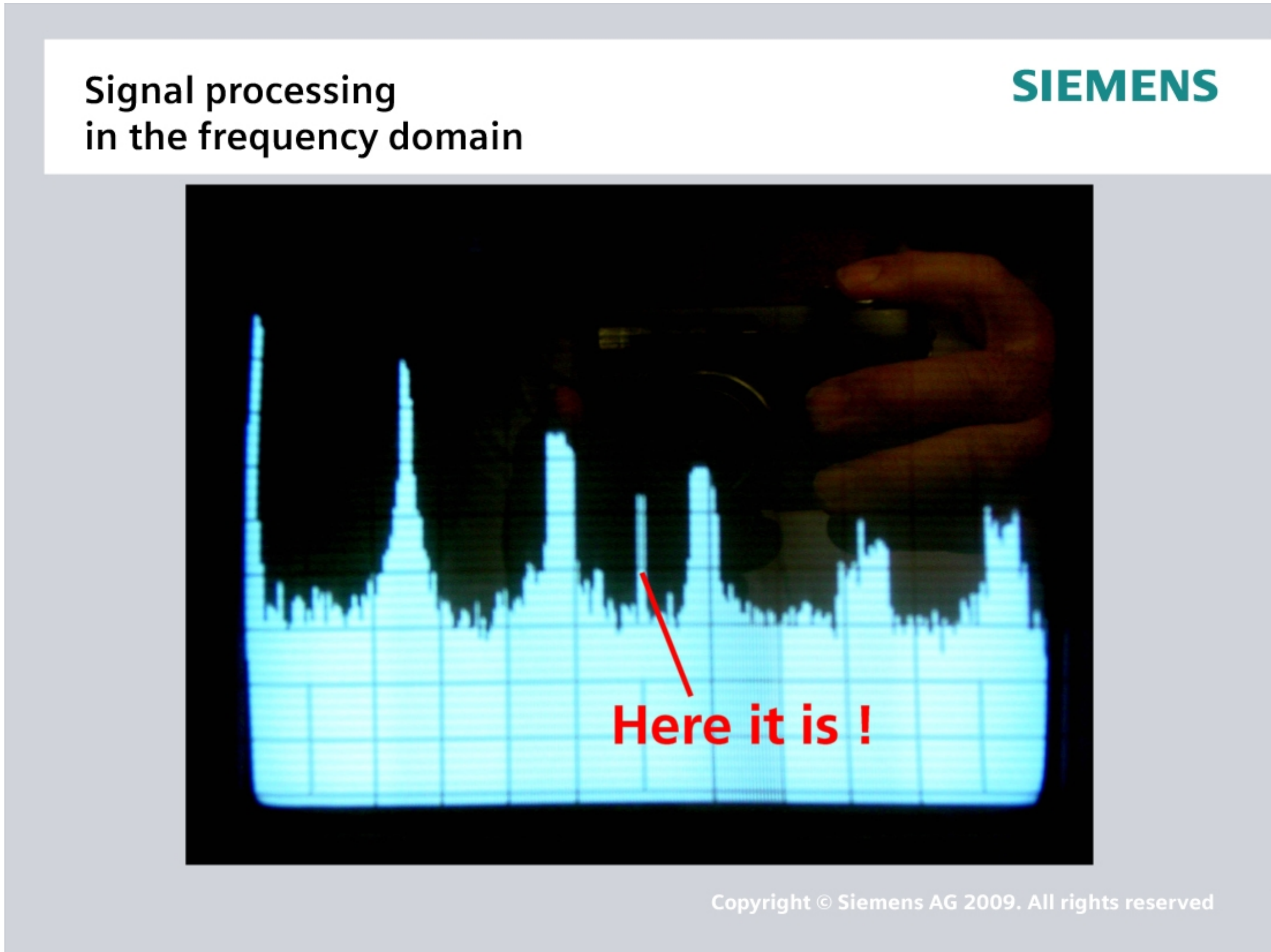
13 Additional observations

There exist tubes which look like fluorescent tubes, but which have no fluorescent layer. These tubes are used for the ultraviolet light which is generated in the gas discharge. The tubes are called Germicide because their light kills germs.

We compare the light of a Germicide and of a fluorescent tube, and we see nearly the same. The receiver of an open smoke detector has usually a daylight filter and is only sensitive to infrared light. We conclude therefore that the light in the infrared region is the same. It does not come from the fluorescent layer and we see no filtering action. This might be the reason that we observed stronger harmonics than expected when we measured the spectrum at 10 kHz.

I suppose that the effect is caused by a strong emission line of mercury close to 1'000 nm. It is clear that it goes merrily through a daylight filter.

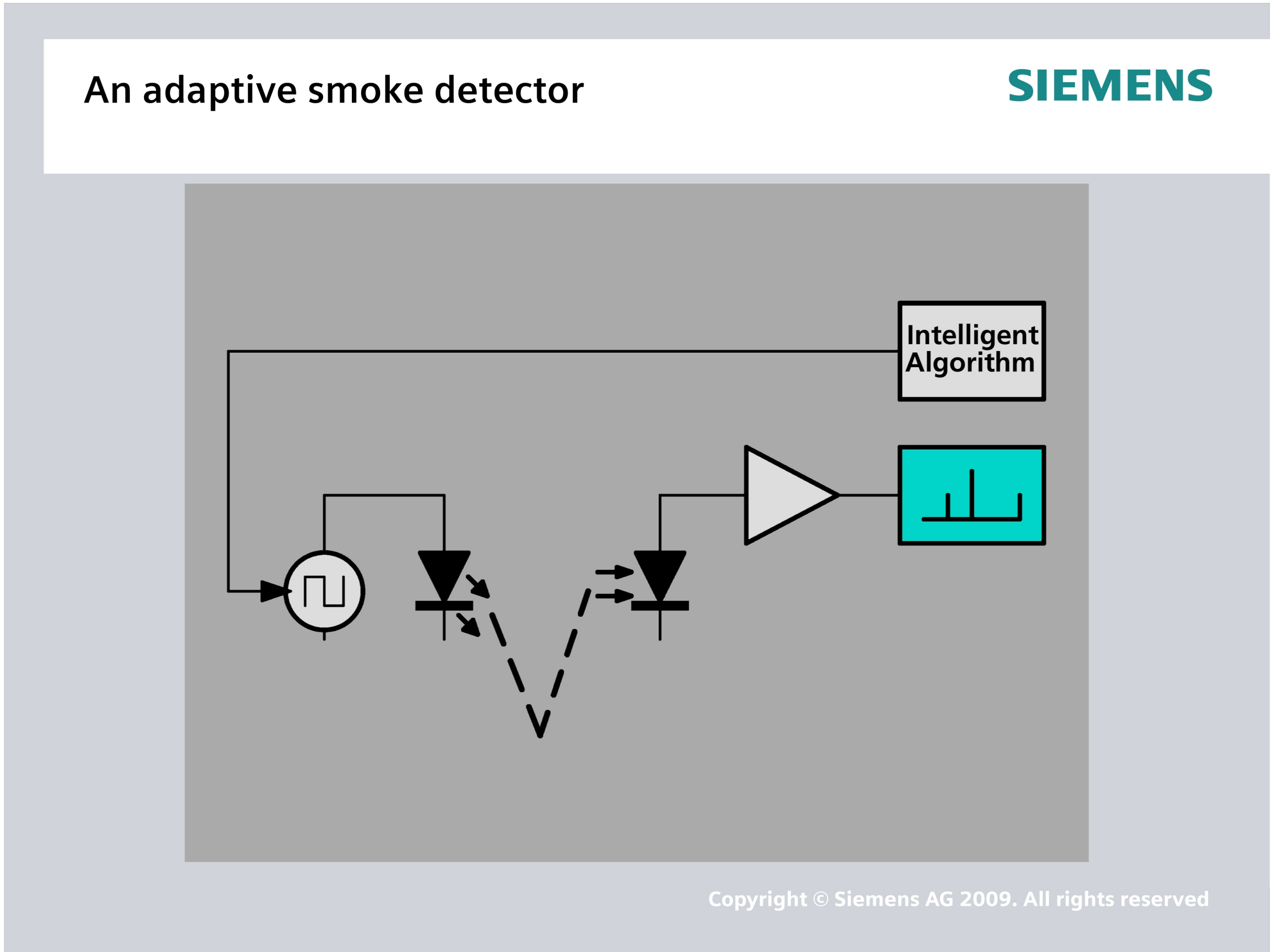
A. C. Boucouvalas, „Indoor ambient light noise and its effect on wireless optical links", IEE Proc. Optoelectron., Vol. 143, No. 6, December 1996, pp. 334 - 338



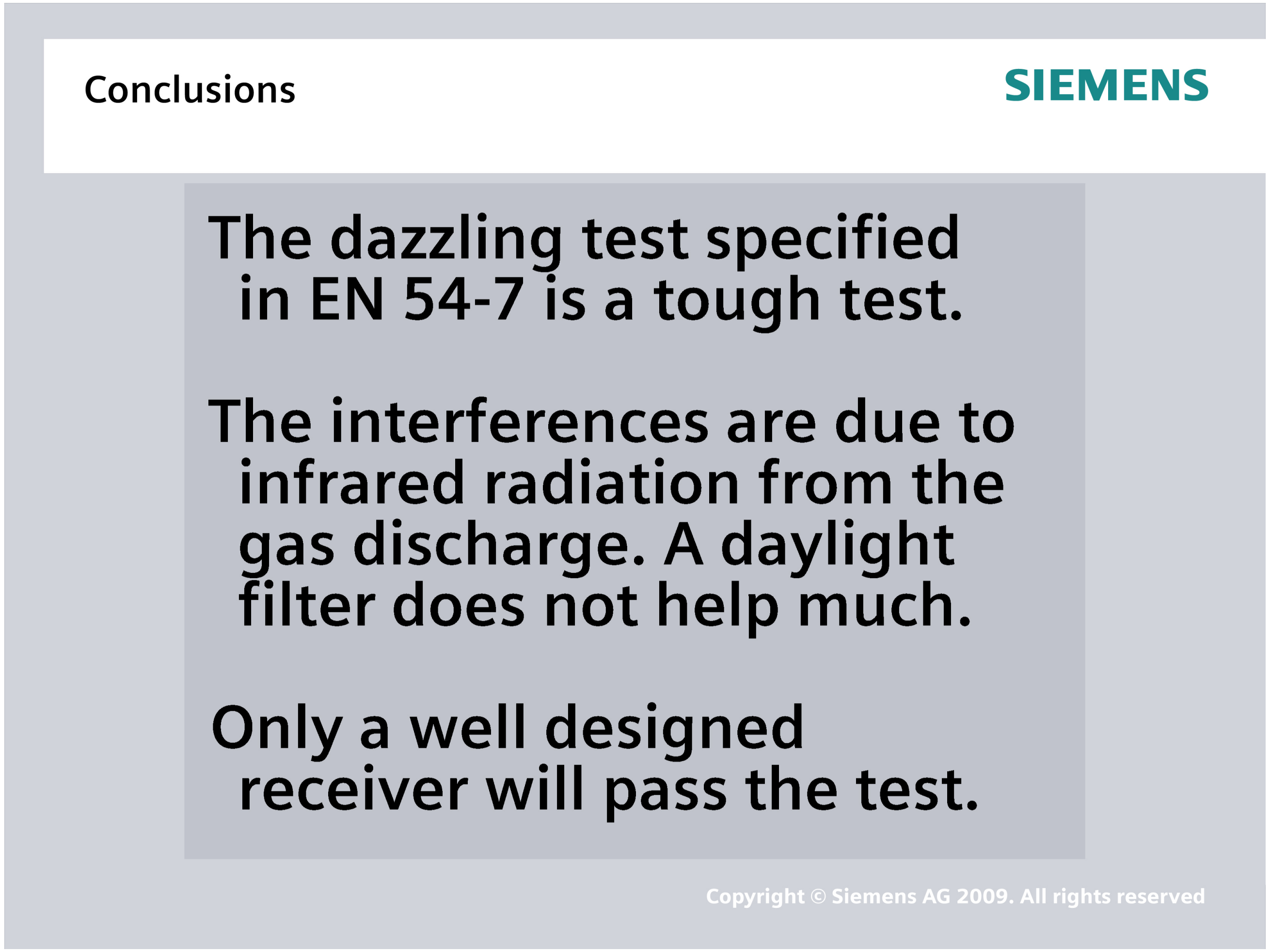
The received signal can be transformed from the time into the frequency domain. Many things become easier in this way.

The small peak is the wanted signal. It is close to 115 kHz. Some of the other peaks are stronger than the wanted signal. They are from an electronic ballast which operates at approximately 45 kHz.

It is only possible to separate the wanted from the interfering signals because of the transformation into the frequency domain. We use a spectrum analyser in this experiment which is big, heavy and expensive. It is clear that we need a circuit which is much simpler if we want to use it in a smoke detector.



It is essentially very simple to design an open smoke detector which is immune to ambient light. We have just to find out where the interfering spectral lines are and adjust the operating frequency accordingly. There might just be a few problems in the details.



17 Conclusions

The dazzling test of EN 54-7 is a tough test, but it seems to be possible to design open smoke detectors which pass it.

The photo receiver has usually a daylight filter. It doesn't cost much and removes some interferences. It does, unfortunately, not attenuate much the modulated light from a fluorescent lamp because some of this light is in the infrared region.

An open smoke detector has to operate in the presence of interferences which may be much stronger than the wanted signal. The situation can be compared to a radio receiver which has to operate close to a TV transmitter. We can apply the same ideas in the design of the photo receiver. This receiver will pass the test, but only if has been designed very carefully.

The future
Spectra of LED lamps

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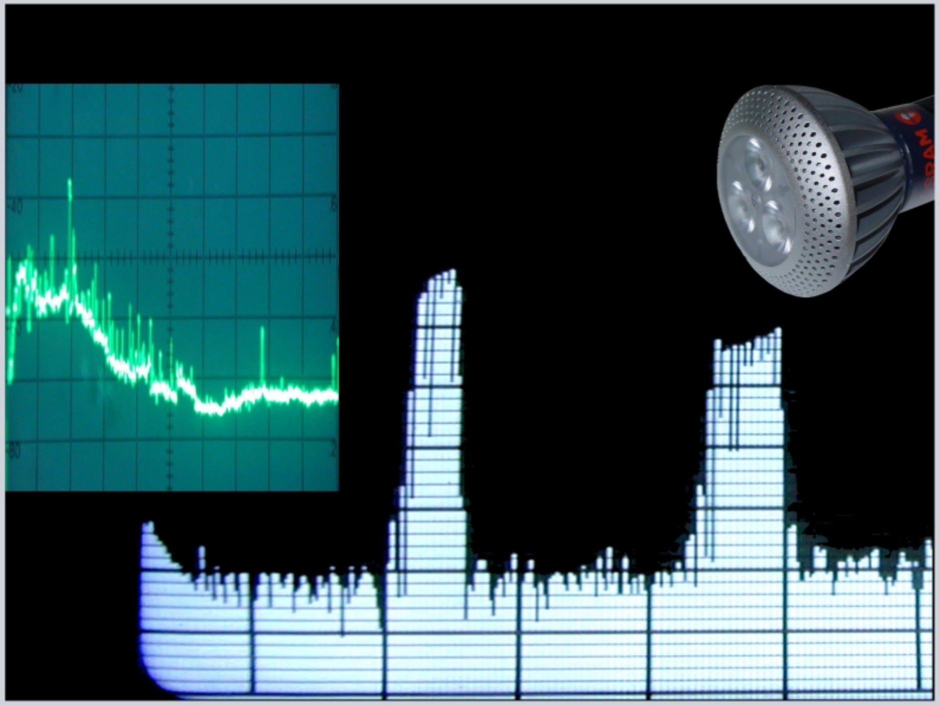

We may assume that fluorescent lamps will be replaced by LED lamps in a not so far away future.

There are not too many really useful LED lamps available yet, and they are dreadfully expensive. We tested just two of them.

One lamp produces a spectrum which is similar to a fluorescent lamp. The fundamental frequency is close to 45 kHz, and there are harmonics.

The other lamp shows a very different behaviour. Its spectrum is shown exactly with the same scales. The graticule is different, but this is only because I had to use different spectrum analysers.

I. L. Azevedo, M. G. Morgan, F. Morgan, „The Transition to Solid State Lighting", Proceedings of the IEEE, Vol. 97, p. 481 ... 510, March 2009