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WHITE PAPER

XenoLogic™

INNOVATIVE OPERATING TECHNOLOGY EXTENDS LAMP LIFE

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AMETEK®

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1. Executive Summary

Accelerated lightfastness/weathering instruments based on xenon arc lamps for sunlight simulation are in widespread use across all industries. Xenon arc lamps, like most light sources, will decline in performance until the end of their service life. However, although unusable for the specified test, there often is substantial residual life remaining, albeit at lower performance levels.

There are several causes of xenon lamp degradation, and operating power is one of the key drivers as lamp life is exponentially and inversely related to operating power. When operated at lower power levels, the usable lamp service life can be greatly extended.

This paper briefly describes a new patented xenon lamp operating technology called XenoLogic™ which has been developed to provide longer lamp operational service life and reduce downtime and operating costs. Additionally, other technological developments are briefly described which contribute to improved weathering instrument measurements and operational performance, ultimately providing more reliable test results.

New technology extends lamp life and reduces downtime and operating costs

2. Introduction

Accelerated laboratory weathering instruments typically employ xenon gas discharge long arc lamps as the radiation source. When properly optically filtered, they provide the best full spectral match to a defined solar reference spectrum such as outlined in CIE Publication 85 Table 4 [1] or similar standards.

Both air and water-cooled xenon lamps are used. Lamp cooling is primarily required to prevent overheating of the electrodes and inner wall of the quartz envelope to prevent premature degradation in performance or failure.

Xenon lamp degradation resulting from normal ageing or abnormal operating conditions is a complex subject, involving aspects such as devitrification and solarization of the envelope; electrode erosion, vaporization and redeposition; oxygen contamination of the gas from degradation of the SiO2 -matrix into the xenon gas; metal-to-quartz seal leakage (particularly at temperatures above 200°C); and other causes.

Xenon lamps can be operated over a fairly wide power range; a key factor is that the spectral power distribution does not change with lamp operating power. However, higher values of power and irradiance result in decreased lamp efficiency and life. Therefore, techniques which can extend the lamp usable service life can result in substantial savings in lamp replacement costs, operating downtime, instrument recalibration and lost productivity. This paper describes one such new technology, Atlas' XenoLogic™ [2].

Lamp life is directly related to operating power

3. Patented XenoLogic™ Technology

Medium-sized rotating rack air-cooled lightfastness/weathering instruments (e.g., Xenotest® 1200, Xenotest® Beta+) have previously utilized three xenon lamps which are operated simultaneously to provide the targeted irradiance (E) level. These lamps have been equidistantly arranged near the geometric center of the rotating specimen rack to provide the best irradiance uniformity. XenoLogic advances this concept to operate two or more lamps either independently or simultaneously as needed.

For example, in Figure 1a two xenon lamps, here designated A and B, are positioned in close proximity near the center of the rotating specimen rack. Note that the illustrations are not to scale.

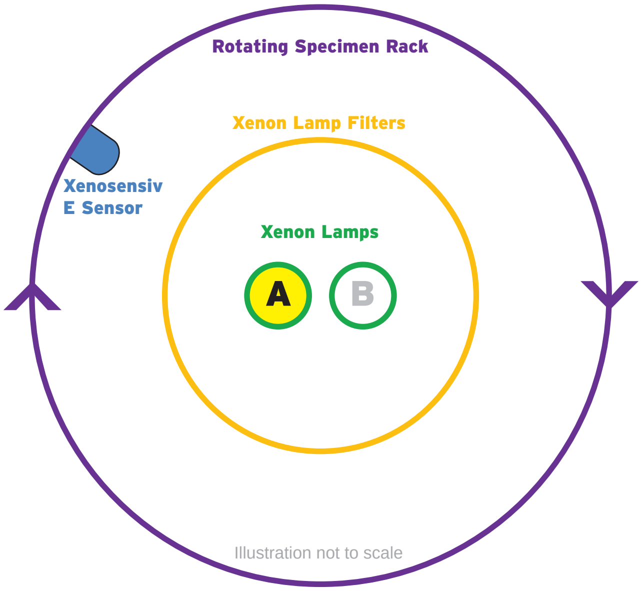

Figure 1a - Lamp A is operated at "normal" power, e.g., resulting in an average specimen irradiance of E = 60 W/m² (300-400 nm) while lamp B remains off.

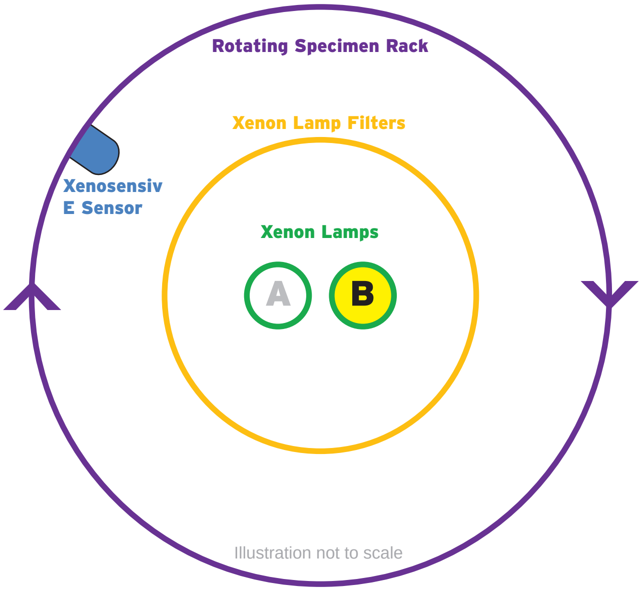

Figure 1b - Lamp B is operated at "normal" power, e.g., resulting in an average specimen irradiance of E = 60 W/m² (300-400 nm) while lamp A is off.

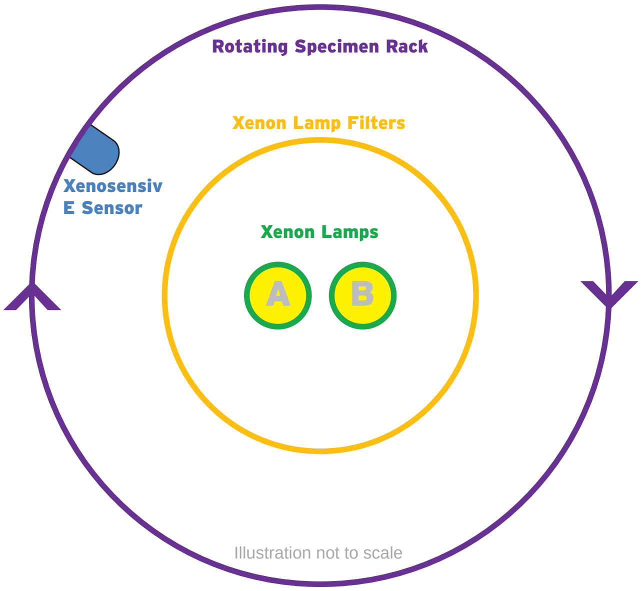

Figure 1c - Both lamps A+B are simultaneously operated at the same reduced power levels, e.g. each providing an average irradiance of 30 W/m² (300-400 nm) with the total specimen target of E = 60 W/m² (300-400 nm).

XenoLogic uses a new operating mode to extend usable lamp life

In Figures 1a and 1b, both lamps are shown operated at "normal" power levels in a sequential mode, alternating between lamps to provide the required irradiance level. The timing sequence is automatically determined and controlled by the XenoLogic™ algorithms to optimize lamp lifetimes based on operating conditions. Only one lamp is operating in this mode while the other remains unpowered.

In Figure 1c, both matched lamps are operated at both the same time and reduced power level such that each contributes to provide to the total specified irradiance (E) at the specimen plane. Operating the lamps at lower power greatly reduces lamp degradation and results in an exponential increase in usable lamp service life.

Approximating the inverse square law*, there will be small, but measurable, variations in irradiance at each rack position as the specimens rotate around the offset "binary" lamp arrangement. These variations will be different for individual and two lamp operation, as well as for variations in the light caused by obstructions (e.g., specimen water spray plumbing) and any reflections from surfaces. The use of on-rack cosine corrected irradiance measurement and signal data processing, therefore, are additional key elements for implementing the XenoLogic concept.

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*Note: The inverse square law for light, derived from Newton's law of universal gravitation, is only approximated as the long-arc xenon lamp is not a point source and the specimen rack geometry resembles stacked cylinders rather than a true spherical surface.

4. Implementation and Results

When operated in simultaneous mode, both lamps are operated at the same electrical power level. To ensure equal optical output, and therefore irradiance, Atlas provides lamps in pairs which are optically matched to provide the same spectral power distribution for a specified electrical power. Integrated circuit chips embedded in the lamps record operating use parameters and contain unique identifier codes. The timing of lamp alternation is such that the operating time difference between the two lamps is kept ≤ 100 hours to minimize non-uniformity due to ageing. When target $E < 50$ W/m^2 (300-400 nm), only single lamp operation is used. At $E > 50$ W/m^2 (300-400 nm), dual lamp operation is used.

XenoLogic™ has been incorporated into the model Xenotest® 440 using two 2200 Watt air cooled xenon lamps, providing $30 < E < 120$ W/m^2 (300-400 nm). The effect of irradiance on lamp service life can be seen in Figure 2, and varies on with outdoor or indoor window glass daylight.

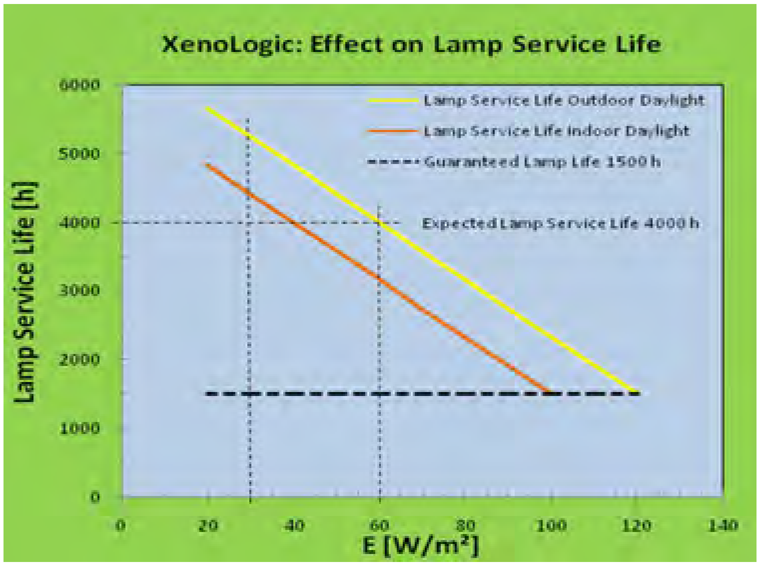


Figure 2 - Relationship of irradiance to lamp service life.

XenoLogic two lamp operating life is typically 2.5X longer than one lamp systems

Normally, using outdoor "daylight" filters (yellow line in Figure 2) these lamps each have a guaranteed minimum 1500 hour (dotted black line) life at $E \leq 60$ W/m^2 (300-400 nm). Sequencing two lamps at a typical 60 W/m^2 (300-400 nm, approximately "1-sun") would yield a life of 3,000 hours (during light cycle operation) before requiring lamp replacements. Using XenoLogic with A, B and A+B sequencing extends the combined expected service life to 4,000 hours. At $E < 60$ W/m^2 (300-400 nm), the useable combined expected service life increases to as much as 5,300 hours.

Similarly, for "window glass" indoor daylight filters (orange line), the combined lamps are calculated to last 3,914 hours at E = 42 W/m^2 (300-400 nm) and longer at lower irradiance. The combined lamp life is 1,916 hours at the window glass maximum 90 W/m^2 (300-400 nm). In the Xenotest® 440 instrument, the remaining lamp life is displayed. This is calculated, based on the operating conditions, by a proprietary algorithm. This information can be valuable for scheduling routine service interruptions and minimizing unexpected shutdown errors.

As the combined lamp pair life is typically 2.5 times longer than conventional one-lamp systems, additional savings may result from increased operational uptime. Lamp replacements and instrument recalibration is reduced to only twice per year, even with continuous use, as compared to five times for equivalent one-lamp systems.

5. Enabling Technological Developments

While an innovative concept in itself, XenoLogic™ is made possible through the prior development and implementation of several other innovative technologies. The first involves proper optical sensing of the irradiance in multiple lamp systems.

Regardless of the lamp cooling method, two xenon arc weathering instrument configurations are typically used: flatbed and rotating rack. In flatbed instruments, one (or more) filtered xenon lamps with parabolic reflector is/are positioned parallel to and above a horizontal exposure area. In multiple lamp configurations, lamp placement and reflector design is optimized to provide a high degree of irradiance uniformity over the exposure area. However, the radiant flux density will be higher toward the center of the lamp, leading to a fall-off of irradiance nearer the ends. With multiple lamp designs, (Figure 3) the overlap in light distribution will inherently result in some spatial non-uniformity in irradiance as shown in Figure 4 [3].

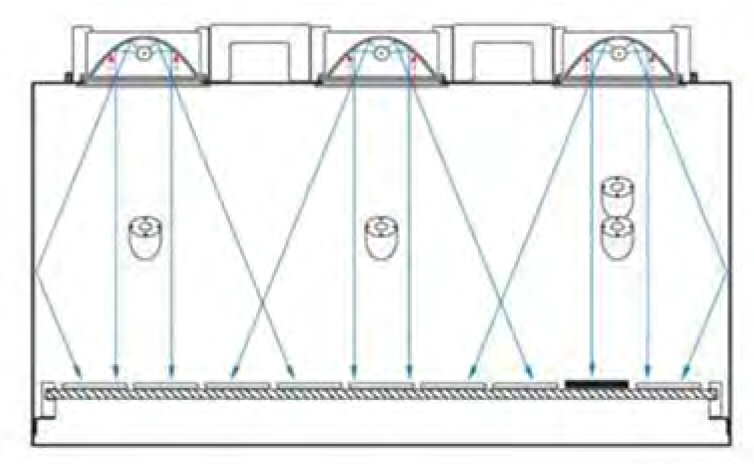
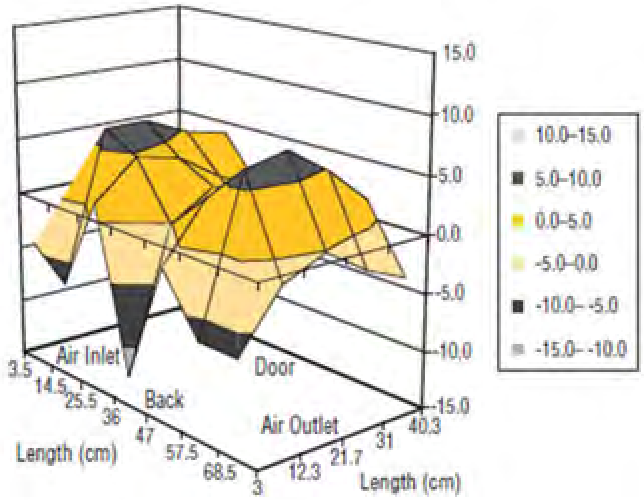


Figure 3 - Lamp placement and optical paths in typical multiple-lamp flatbed system.



Static flatbed with 3 lamps
E = 0.68 W/(m^{2}nm) at 340 nm
Maximum deviation: ±10%

Figure 4 - Irradiance uniformity map for typical multiple lamp flatbed system; note the irradiance is highest in the overlap regions between lamps.

Most higher performing weathering instruments have used a vertically oriented xenon lamp(s) centrally positioned within a rotating specimen rack of 1 or more tiers oriented along iso-planes (demarking points of equal irradiance in the chamber) for positioning the test specimens (Figure 5).

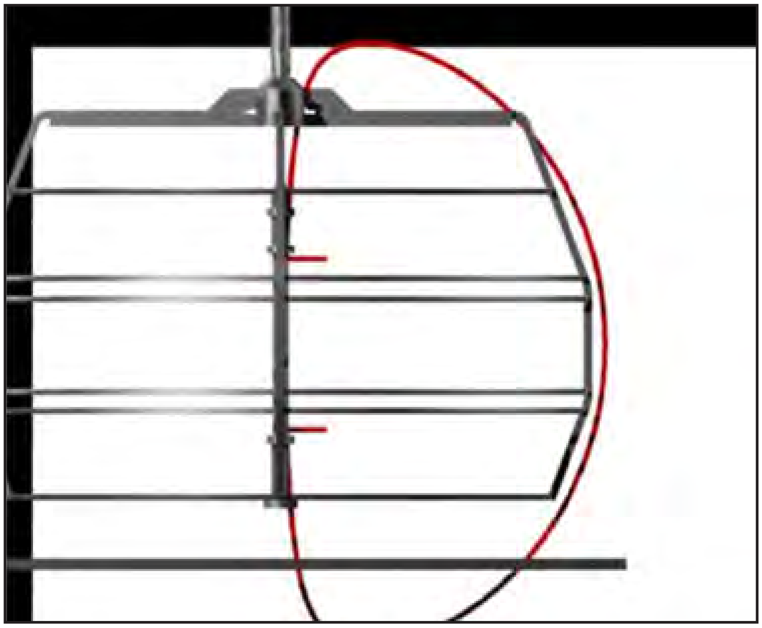


Figure 5 - Iso-irradiance pane indicated in red in a 3-tier rack Weather-Ometer.®

Figure 6 shows the temperature uniformity attained with an Atlas Weather-Ometer® with inclined 3-tier rack oriented along the iso-irradiance line. Temperature uniformity is partially related to irradiance uniformity.

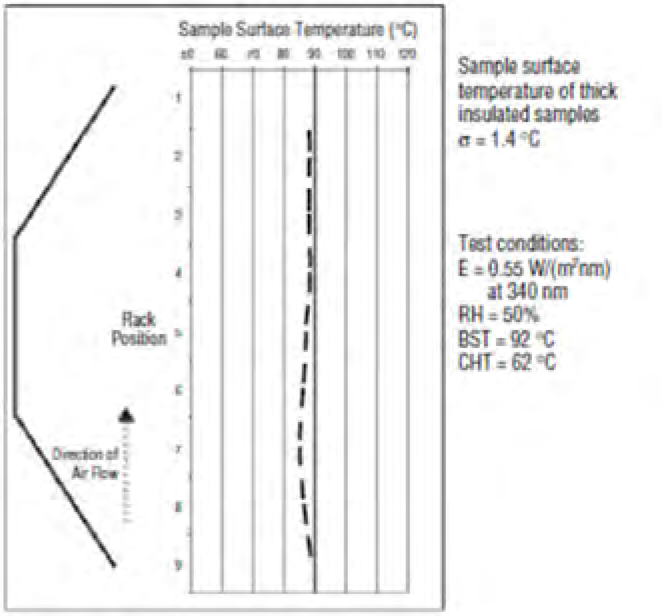


Figure 6 - Temperature uniformity on 3-tier inclined Weather-Ometer® rack along iso-irradiance plane.

Larger sample capacity instruments typically use a single high power water cooled xenon lamp, while smaller more compact designs may use one or more air cooled xenon lamps. The rotating rack substantially reduces spatial irradiance non-uniformity as well as variability in test specimen microclimate, particularly regarding air temperature, specimen surface temperature, airflow and air humidity. While they may be insignificant in very short duration exposures, any minor differences in exposure conditions may influence test specimen response as the exposure time increases. Since ageing of xenon lamps and some filters decreases the optical output, an irradiance monitoring system is used to automatically adjust lamp(s) power to maintain the specified irradiance. Depending on design, the irradiance sensor may be in a fixed static position or mounted on the rotating rack, similar to a test specimen.

5.1 On-rack Measurements

Power to, and analog or digital data signals from, on rack sensors such as black panel temperature and irradiance have been routinely transferred between rotating racks and the instrument electronics via electrical contact “collector rings” (also known as “slip rings”). Some irradiance monitors, however, have used stationary light guides, to

On-rack sensors can increase measurement accuracy and precision

transferring the light energy to a sensor positioned outside of the severe environment of the test chamber (Figure 7).

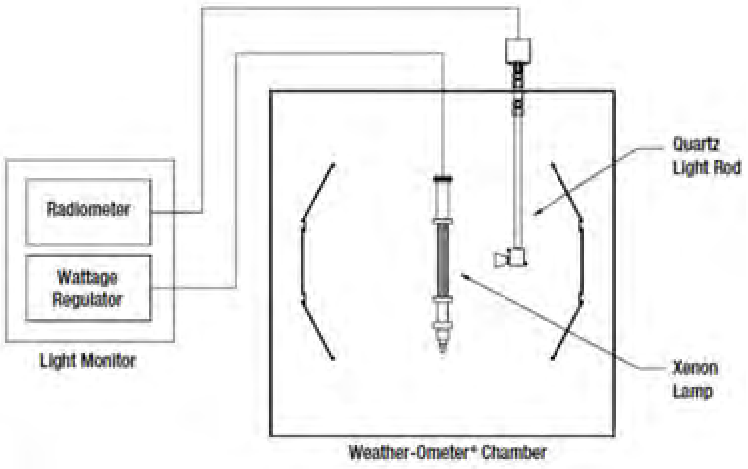


Figure 7 - Controlled irradiance 3-tier rotating rack system (static fixed position irradiance monitor) configuration

Alternatively, stand-alone on-rack sensor/data loggers (such as Atlas' XENOCAL® series temperature and irradiance and LS-200 Full Spectrum Monitoring spectroradiometer) have been available for intermittent use. However, these require manual post-run data downloading and processing and they are not designed nor intended for continuous real time monitoring and control.

5.2 Digital/Wireless Measurement Technology

Real time permanent on-rack XENOSENSIV® irradiance and temperature sensors have, however, been routinely and quite successfully used since 1992 to transfer power and data signals from a rotating rack through electrical collector rings. Recently, Atlas has developed several new sensors with non-contact wireless radio digital data transfer capability (XENOSENSIV® RC series). This permits precise measurement of the test specimen microenvironment while only requiring an annual battery replacement.

5.3 Cosine Response and Sensor Durability

Secondarily, the irradiance sensors must possess the necessary cosine response (Figure 8) to accurately measure the direct and scattered radiation in the test chamber, similar to outdoor exposures. The scattered radiation can be as much as 30% of the total impinging on a test specimen. When taking a solar irradiance measurement, a requirement is that the detector response to direct beam radiation varies with the cosine of the angle of incidence. This is so there will be a full response when the solar radiation hits the sensor perpendicularly (i.e., normal to the surface, sun at zenith, 0 degrees angle of incidence). Further, there should be zero response when the sun is at the horizon (i.e., 90 degrees angle of incidence, 90 degrees zenith angle), and 0.5 response at 60 degrees angle of incidence. It therefore follows that an on-rack sensor should have a directional (cosine) response that is close to the ideal cosine characteristic when measuring solar radiation.

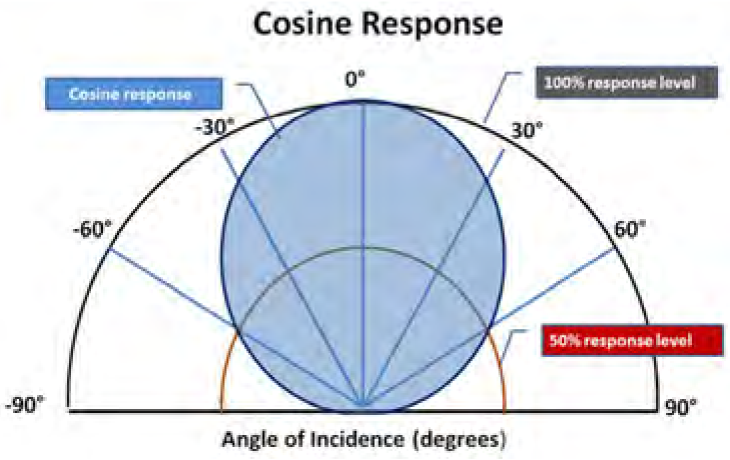


Figure 8 - Cosine response for solar radiation

Detectors typically use a transparent optical dome and a light diffuser element to provide the necessary cosine response. Many irradiance cosine sensors employ Teflon® diffuser lenses, but these degrade and change transmittance under UV exposure in the chamber; this makes them unsuitable for continuous long term use. Atlas' Xenosensiv® technology uses specially designed patented [4] stable fused silica diffuser elements to overcome this degradation problem.

Proper cosine response is important to match solar radiation measurements

5.4 Digital Signal Processing (DSP)

The irradiance monitoring system must possess sufficient time resolution to properly detect important short term transients, such as momentary light attenuations from stationary objects such as the water spray system, but not so sensitive as to produce a noisy signal. This is accomplished through a multi-step signal data acquisition and integration process. A generalized illustration of digital signal processing techniques is portrayed in Figure 9 where the black dots represent a transient such as light reflection from a stationary object, the blue dots represent a first-pass smoothing process, and the red dots the time-averaged values.

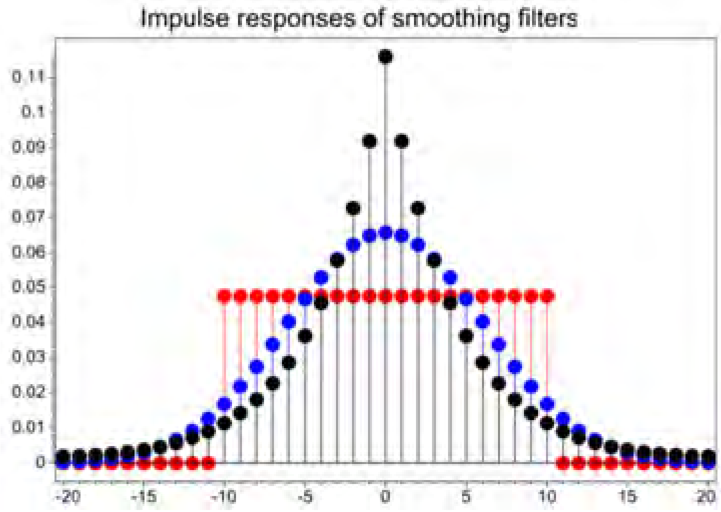


Figure 9 - Generalized digital signal processing methodology

As a real example, in the first step, irradiance is integrated (analog) over 0.4 s periods at intervals of 0.1 s (Figure 10a).

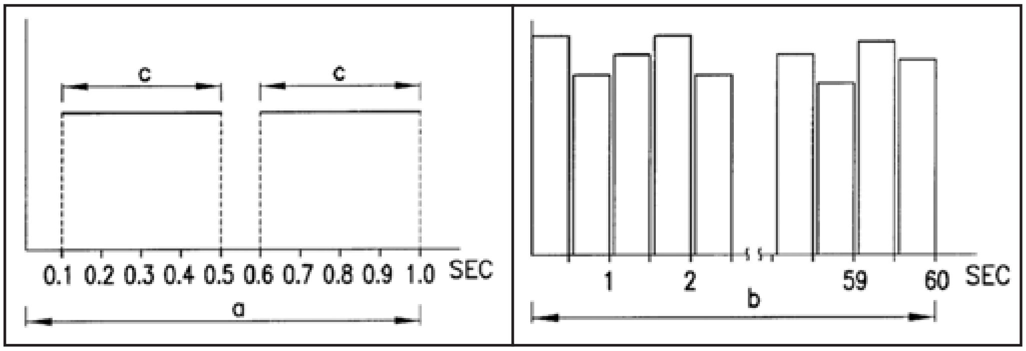


Figure 10a Irradiance integration intervals **Figure 10b**

These values are then converted to a train of digital values (Figure 10b).

Strings of this data train are summed and averaged over 1 minute (or other) increments (Figure 10c).

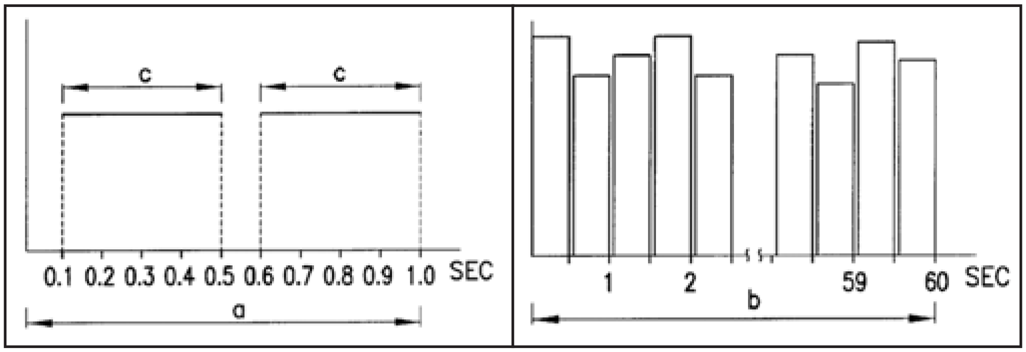


Figure 10c Integrated values averaging and summing **Figure 10d**

Digital signal processing provides high sensor sensitivity with signal noise immunity

This produces a string of integrated irradiance values (Figure 10d) during the test exposure which are summed to determine the radiant energy exposure. With the optimized settings, this method provides sufficient time resolution to detect significant irradiance transients while simultaneously filtering to avoid "data overload."

6. Summary Conclusion

We now have the fundamental understanding and tools to improve xenon lamp life in weathering instruments:

- Lamp degradation and usable service life is inversely related to lamp power (i.e., irradiance level); XenoLogic™ control determines the optimum operating mode to extend usable lamp service life in multiple lamp systems.
- Real time measurement and control of irradiance irrespective of instrument geometry, is possible with stable and durable optical sensors possessing the proper cosine response.
- Precision on-rack measurement of parameters is enhanced with digital signal processing and radio controlled wireless data transfer.

All of these factors have led to the innovative XenoLogic™ [4] concept, now available in the Xenotest® 440 xenon lightfastness/weathering instrument.

Clearly, many advances in xenon weathering instrument technology have provided incremental improvements in reliability, operating logistics and cost, and the accuracy and precision of the test conditions and, by extension, improvements in the resulting test data. However, the synergy provided by leveraging these individual improvements in hardware and software into a new operating concept has resulted in an advanced instrument for today's needs and a blueprint for continued advances in future lightfastness/weathering instrument designs.

XenoLogic and enabling technologies improve weathering testing while reducing costs

6. References

1. International Commission on Illumination, Publication No. CIE 85-1989 Technical Report Solar Spectral Irradiance, Table 4, ISBN 3 900 734 22 4.

2. Patents pending.

3. A.Riedl, What Makes a Xenon Weathering Instrument High-end?, Atlas SunSpots Newsletter, Volume 33, Issue 70, Fall 2003.

4. F. Kellner, et al, Ultraviolet sensor, Patents US 5497004 A, EP0653613A1, EP065361B1.

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