The Retractable LED Chandelier

By: Mike Wood

Engineering a centerpiece attraction at the Winspear Opera House

It's only a chandelier, isn't it? Just a few lights. What could be so technologically interesting about that? Well, that's what I was thinking almost two years ago, when I first heard about the proposed chandelier at the Winspear Opera House in Dallas. (See page 46 for the feature story.) However, once I grasped the scale of the proposal, it became clear that this wasn't your ordinary, everyday chandelier, if there is such a thing. It all started with an artist's concept picture from the project's architect, Foster + Partners, and the architectural lighting consultant, Claude R. Engle.

This showed a 40' diameter ethereal construction with seemingly unsupported bars of light hanging in a roughly pyramidical shape from the main auditorium ceiling. Discussion revealed that the intent was to have over 300 illuminated bars, which would reach down 50' in front of the two top balcony tiers in a three-dimensional structure to provide a centerpiece for the room while the audience was being seated before the performance. At show time, these bars would rise until the ends were flush with the ceiling, where they would form a star field before finally extinguishing at curtain up. The bars themselves needed to be illuminated as evenly as possible, should match the warm white of the existing incandescent house lighting, and complement the white gold leaf on the balcony fronts. The chandelier was a key part of the room's artistic design and would be the center of attention—both literally and metaphorically—of the audience before the curtain went up. Okay, that was the concept, but how do you actually build it?

Figure 1: Concept. (Photograph courtesy of Foster + Partners)

The architects had considered a fiber-optic solution but had not been able to find a way to raise and lower it 50' while keeping the suspension invisible to the audience and solely illuminating the final 6' portion of each fiber.

J.R. Clancy was already heavily involved in the Winspear installation. As there was a significant rigging implication to making this chandelier raise and lower safely and quietly over the heads of an audience, the company was also invited to bid for the chandelier addition, which left the project manager, Robert Degenkolb, the task of coordinating an engineering concept that would meet both the artistic and engineering requirements. The chandelier is primarily an artistic installation, with the illumination for the room coming from conventional luminaires, so it needed an engineering design that wouldn't interfere with the aesthetic concept and was essentially invisible without compromising safety and reliability. At that stage, J.R. Clancy brought me in to assist with development of the illuminated rods; it turned into a joint project, with Clancy taking the lead and providing all of the hoists, control, structural support, rigging, and suspension while Mike Wood Consulting and Scott Ingham, of Ingham Designs, provided the illuminated rods, drive electronics, data distribution, programming, and control.

The first task for the team was to develop the rods themselves, as those would be the only portion the audience would see, and, once they were working, everything else in the engineering design would follow from that decision. The team experimented

All photographs by Mike Wood except where indicated with various materials and illumination sources before ending up with an acrylic rod and a custom four-channel RGBW LED illuminator that was optically coupled to the top of the rod. We tried many different types of surface finishes to ensure even illumination but, in the end, simplicity was best, and a polished cast acrylic rod gave the solid bar of light that was needed. Cast acrylic performs much better than an extruded version for light transmission in this kind of application; the cast material is easier to machine and form and doesn't have the entrained air bubbles and imperfections present in the die extruded product. Those imperfections glow like little stars within the rod; they're very pretty, but not what was wanted here. A custom 6'-long cast rod, with the ends polished optically flat, was selected. For illumination, four standard 3W RGBW LED dies were packaged with a custom lens so that the exit angle matched as closely as possible the TIR (total internal reflection) angle of the acrylic; therefore, as little light as possible was wasted in coupling to the top end. The use of TIR in a solid rod is optically identical to the fiber-optic solution that the lighting consultant first envisaged; it's just that it is 318 separate 6'-long rigid fibers rather than flexible bundles. Although the main desire of the lighting consultant and architects was for white light, as previously mentioned, the white had to be controllable to get the right color temperature and warmth to match the color scheme of the room, so an RGBW array gave the flexibility needed.

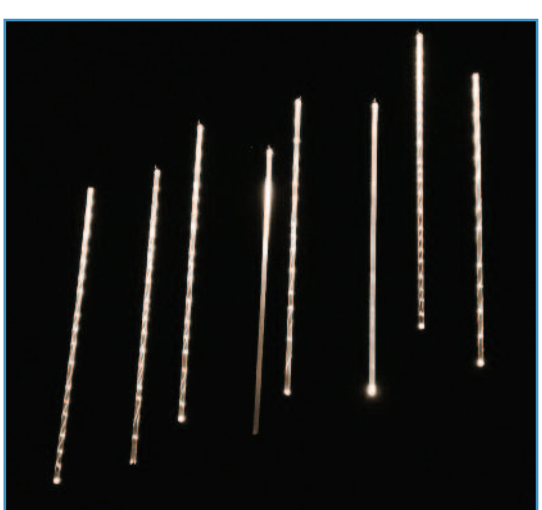

Figure 2: Rod testing.

Figure 2 shows an early trial with various patterns and surface finishes. The plain polished rod (third from the right) performed the best and met the architect's and lighting consultant's requirements.

Once a basic rod shape and style had been agreed upon, the project could proceed to a mock-up of the entire chandelier—or at least half of it! J.R. Clancy took over a local theatre in Syracuse for a day and constructed a full-scale model using black cord and white rope of the same diameter as the acrylic rods. Some effective use of the stage lighting installation completed the job, as shown in Figure 3.

Figure 3: Early trial using white ropes as a proof of concept and scale. (Photograph: Robert Degenkolb)

With this 1:1 model to approve the overall scale and, in particular, the diameter and length of the illuminated rods, the architects and owners signed off on the project, and we had the green light to proceed to a detailed design.

Although we were using 3W LEDs, we wanted to run them at very conservative levels—the installation needs to last at least 10 years with daily usage, and the key to getting a good life from LEDs is good thermal management. Each acrylic rod was capped with a head, which formed the enclosure for the LEDs and their associated drivers, and also provided secure mechanical suspension for the rod. The head was also the heat sink for the LEDs; the thermal design, using heat flow analysis, was specified to allow at least 50% headroom on the expected power usage. The final head design was an interesting collaboration between the mechanical engineers, whose main concern was the safety aspects of hanging a 6' rod over the audience; the electronics engineers, with their requirements for heat flow, EMI shielding and connectivity; and the understanding by all that this was in view of the audience and therefore had to fit the aesthetics of the design. It seemed like the simplest component in the installation—just an aluminum extrusion—but it turned out to be one of the most complicated and critical parts of the design.

Nothing on this project was simple—not even the cabling. Each rod head was suspended from a single custom cable, which contained a shielded twisted pair for data, a pair of wires for 24V DC, and three synthetic fiber suspension members. The whole assembly was enclosed in a matte black sheath to produce a final cable that was just 0.25'' in diameter. This cable had to pass over sheaves and blocks onto a motor drum hoist without breaking, so ultra-flex insulated conductor cables of a type more commonly seen in moving lights were used for the construction. Before committing to the production run, Clancy ran both proof load testing and an accelerated simulated life test, confirming that we could successfully pass data and power through the system over the life of the cable with the specified connected load. The head and rod only weighs about 5lbs; however, we had a concern that there could be problems if the rods ever knocked and entangled with each other, so minimum 8:1 safety factors were used in the development of the suspension system.

Now to the hoists: There are 318 rods in total, and the ideal situation would be if there was one hoist per rod. However, cost put that possibility out of the running very quickly, and a solution using fewer hoists had to be found. In the final installation, the 318 rods are distributed over 44 lifting mechanisms, each of which controls up to eight rods. In the chandelier's operational shape, those 318 rods are at widely different height bands, but each hoist has to be connected to eight rods, which are all at the same position. To make this trickier, the overall conical shape of the chandelier means that rods at the same height are never adjacent and the ceiling itself isn't flat; instead, it is both domed and at an angle. To accommodate these requirements, the hoist cable routing in the grid from each hoist is incredibly complex. A three-dimensional layout had to be prepared (Fig. 4) so that none of the cables interfered with each other as they passed over or under multiple other cables on their route from hoist drum to loft block.

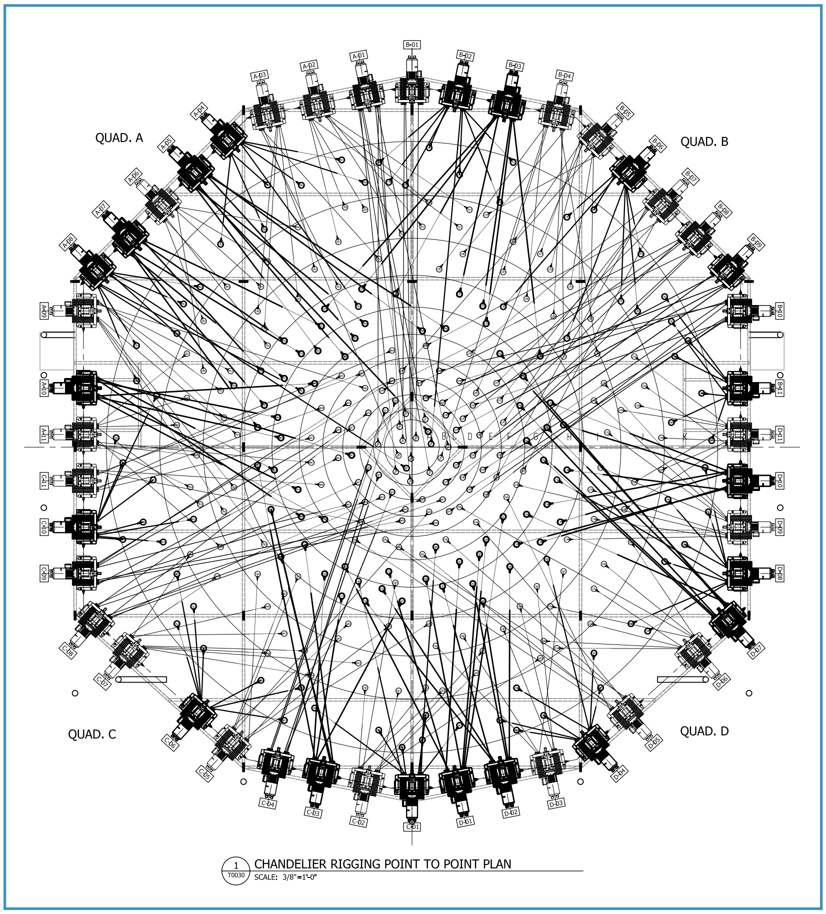

Figure 4: Hoist and cables grid layout. (Drawing courtesy of J.R. Clancy)

Figure 5: A (not so) tangled web.

Figure 5 shows how that translated to reality in the installation. After a lot of work by skilled installers, it ended up being remarkably tidy.

Also visible in Figure 5 are the tops of tubes in the grid that provide guides and protection for the rods when they are parked in the void between the plaster ceiling of the auditorium and the grid. Figure 6 shows those tubes as seen from the surrounding catwalks. The tubes also contain twin stacks of brushes, which serve to both keep the rods clean and to provide a light block.

As mentioned above, each hoist raises and lowers up to eight rods, and every LED in each of those eight rods can be individually controlled from data sent down the cable. We had concerns about hanging 318 long antennas in an opera house and so wanted to minimize that data; we also wanted every rod and its circuitry to be completely identical and interchangeable. The best solution was to have an intelligent data distributor on every hoist, which took in DMX512 data, then formatted it and rebroadcast it down the eight cables, with each rod only receiving its own data. This has the added benefit that the heads are all being fed with home runs, so no addressing or networking is needed. The net result is a vast reduction in the amount of data passing down the cables, which mitigates the risk of electromagnetic noise causing interference with the sound systems. That, coupled with the silent operation of the hoists, meant that we passed the scrutiny of the audio consultants—pretty important in an opera house! To further reduce data flow, each rod has a processor and does all its own cross-fading, interpolating, and smoothing of the incoming eight-bit data to an internal 16-bit and adding pseudo thermal delay so that the output matches an incandescent dimming curve. Key to maintaining the incandescent illusion is avoiding the final "blink" as LEDs turn off, so a great deal of care was taken with the final 10% of dimming. This is particularly important with house lights as, by their nature, they nearly always turn off into a blackout where the slightest imperfection is apparent.

The data distributor is mounted on the rotating portion of the hoist, with power and data fed to it through a data-quality commutator. The software in the data distributor and heads watch for any glitches in the data feed through the commutator and hide it so the output remains smooth. We were helped in this by the application—with normal entertainment lighting, speed of response is critical but, in this case, immediate response can take second place to smooth operation. The cross-fade speed is provided as a programmable operational parameter so, if the Winspear staff wants to change the fade rate through the ETC Mosaic system, they can.

Figure 7 shows some of the installed J.R. Clancy hoists suspended from a Unistrut grid that is attached to the underside of the building structure. At the front of each hoist is a mounting frame diverter assembly that directs each lift line to the ceiling tubes. The diverters incorporate a spring-loaded overload assembly that stops the individual hoist in the event a lift line becomes snagged during operation.

The hoists are controlled by a JR Clancy SceneControl 500 through a wired touch-screen pendant interface. The pendant plug-in stations are located so that the operator has a good view of the moving rods at all times and allows for individual, group, and preset control of the rod positions. Interestingly, the lighting control room is not normally one of those stations, as it has no view of the chandelier! The pendant also provides a wired E-stop connection to the system and allows for password-protected adjustment of the variable speed hoist drives to reconfigure the system.

Figure 6: Guide tubes between grid and plaster ceiling.

Figure 7: Hoists.

Figure 8: Finished chandelier.

Control of the 1,590 channels driving the 318 illuminator heads (each uses five control channels—four colors and a timing channel) is provided through two linked ETC Mosaic show control systems which, in turn, are triggered from the ETC Unison Paradigm and AMX touch panels distributed throughout the building. Programming made full use of Mosaic's ability to map an array of channels to a matrix which dramatically simplified the process. Programming each of those 1,590 channels by hand would have been painful. Instead, we were able to overlay moving patterns and cloud imagery to give a constantly shifting dynamic to the chandelier.

Figure 8 shows the final chandelier. You can't tell from the photo, of course, but the programming is quite subtle; each rod is continuously shifting its color and brightness on either side of the defined warm white by a small amount, and no channel is ever stationary. This movement is not enough to be overt, but it gives the whole thing the kind of life that you get with a candle flame chandelier. We also programmed in red-shift as the chandelier dims so that, again, it matches the color shift in the incandescent house lights on the balcony fronts. These fades are timed to match the one-minute movement of the chandelier as it flies out so that, when the rods reach their top preset with their bottom ends level with the ceiling, the rods have dimmed down to a

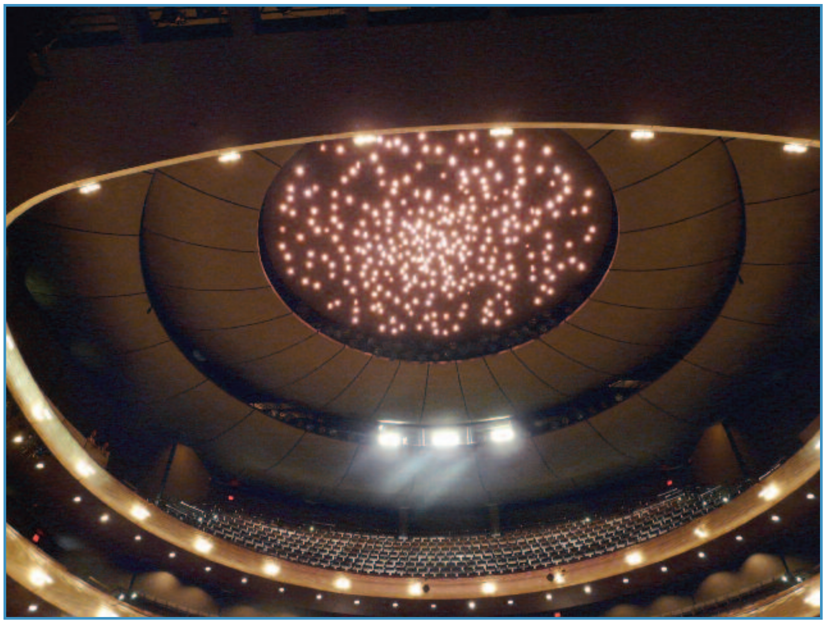

Figure 9 - Star field.

very warm star field glimmer with a superimposed twinkle (Fig. 9).

The Winspear Opera House is now open, and the chandelier runs every night in front of an audience with no idea of the engineering complexities needed to perform such a simple effect. Instead, it's an art installation that, I hope, compares well with the original artist's concept of Figure 1. That's as it should be—we are in the business of theatricality and illusion, after all.

The installation was supervised by Robert J. Degenkolb, of JR Clancy, and Mike Wood and Scott Ingham, of Mike Wood Consulting and Ingham Designs, LLC, respectively, and was performed by Joel Svoboda, Ken Eggers, Charlie Hulme, Byron Payne, and the International Association of Iron Workers Local 263 (Dallas/ Fort Worth).

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