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(54) Title: OPTIMIZATION OF LED LIGHTING SYSTEM OPERATING AT LOW CURRENT LEVELS

(57) Abstract: A high efficiency LED light fixture and power supply designed to maximize system life while doubling electrical efficiency relative to existing LED light systems. The LED efficiency is addressed by operating near the lower end of the LED power rating. At these values the LED chip efficiency is maximum. The longevity is addressed by using a high efficiency cross flow heat sink to significantly lower the LED temperature to within 10 degrees C above ambient conditions. The system uses a 1200 watt power supply to improve the AC to DC efficiency of the system allowing multiple LED troffers to be powered from a single power supply.

Optimization of LED lighting system operating at low current levels

Field of Invention

This invention relates to the synergistic optimization of an LED troffer lighting system. The system is specifically designed as a cost effective solution for the grocery store, department store, green house, and other warehouse application that benefit from improvements in the integration of LED lights into their facility. Vertical integration of product, supply, manufacture, and distribution enhance market penetration for low variability LED product lines.

Background

LED lighting systems are becoming a mature industry with multiple large corporations gaining market penetration in several diverse horizontal application fields. Market applications such as residential, street lighting, outdoor facilities, high end office buildings have been extremely successful.

A very large piece of this market are the stores and warehouse applications that need a "workhorse" product that has its application and decision for retrofit or new use based on the synergistic economic benefit to the customer.

LED and manufacturing processes have both matured to where the LED lights can be built substantially through large scale automated processes and gain economic benefit through a high level of system integration and component standardization.

Summary

Light emitting diodes (LED's) offer an improvement in amount of lumens per watt of power which can be used to light a building or open space. The LED's are direct current devices which are currently approximately half the power requirement for fluorescent lights and a larger benefit for the incandescent lights. This savings allows a commercial or industrial building to save on their electricity costs. LED efficiency over the years has steadily increased to a level of 150 lumens per watt is available for individual elements. The choice of wattage vs LED has been typically integrated into a system which drives the LED in order to obtain a higher level of lumens per LED at the expense of reduced lumens per watt. This allows a reduced number of LED's for a given application. LED's dissipate heat through the circuit board primarily and are subject to overheating affecting life issues.

As a baseline almost all LED systems currently on the market operate with a low voltage LED driver located within the LED hardware system. This includes both the T-8 linear bulbs and troffers. In order to prevent glare or excess brightness from the LED array a lens is used to diffuse the light to make it more uniform.

Scope of Invention

In order to increase the value to the customer a variation study of LED power level, life, and system cost was examined to see if existing technology could be re-optimized to significantly reduce the time to pay off an investment in retrofitting a store which has multiple common lighting fixtures. The driving decision in whether to change from what is typically a high efficiency fluorescent system, which for a 48 inch fixture uses approximately 64 watts for two linear T8 bulbs and produces 4000 lumens, is based on strictly the economics. This is typically described by the time to break even on a retrofit using LED's vs the expected system life or with fluorescent lights the replacement cost which is almost primarily the labor and not necessarily only the tube cost. The fluorescent lights have a projected life of one year to two years for near steady state operation.

Utility subsidies aide in the decision to switch to LED's by providing a rebate based on a one year electricity savings estimate between the existing lighting system and the new LED system. A reduction of 40% electricity use can provide a savings of 33% of the LED fixture cost improving the economics.

There are currently two primary choices in types of Led systems: LED t8 tubes and integrated troffers. LED t8 tubes have come into the market early as a low cost solution to replace fluorescent tubes directly. The T8 led tubes provide a line voltage to 10 VDC driver within the led tube so that the existing ballast system must be removed. Over heat is typically an issue since the led's operate without a heat sink for cooling which results in a reduced led life of approximately 5 years. The economics require approximately a 50% payoff time so 2.5 years is acceptable for the 5 year life. A major issue with installing t8 led lights involve the inability to provide a uniform light source relative to the fluorescent lights which are being replaced. The second choice for led's involve a fully integrated troffer system. The troffer is an open architecture which allows for the integration of both a heat sink, which is critical for cooling the led and extending its life, and a diffusion lens which provides a more uniform light distribution. Reducing the led temperature can result in significant improvements in useful life which has a major impact on the stores economics. The table below shows the dramatic effect of reducing the led junction temperature vs life prediction to 70% of the initial light level.

Junction temperature (C)	Life (hours)	Life (years)
125	20,000	2.3
120	50,000	5.7
112	75,000	8.6
100	100,000	11.4

	85	150,000	17.0
	50	175,000	20.0
Under	50	219,000	25.0

The troffer uses a heat sink to cool the led and has currently doubled the life expectancy of the led system to 10 years. To improve the heat flow path a thermally conductive circuit board is integrated with the led's which are attached to the heat sink with a thermally conductive paste further improving the flow of heat to the heat sink.

Figure 1 shows an 85 C operating led system where the projected life is 150,000 hours. Note the light output reduces as a function of operational life fraction. 70% has been chosen by industry as the led life where the fixture has dimmed by 30% relative to a new led. This is a potential draw back to led systems which are operating at 100% of their design wattage level since they are typically not over driven to compensate for the reduced lumen output as the led ages.

Typical troffer systems are more than twice the cost of the T8 led's which offset the 10 year life benefit and result in similar 50% time to payoff intervals relative to led life. With the added cost of retrofitting the troffer due to having to replace the complete fluorescent fixture the saving becomes less and harder to justify for the store.

Figure 2 shows the led operating characteristics of current vs voltage. The curve is very nonlinear with small voltage changes causing large current output changes. This results in voltage being a very difficult parameter to control the led chip. Typically current level is used for control. The system operates by increasing the voltage into the operating range of 2.8 to 3.4 volts per chip then limiting the current flow so that the chip does not overheat and burn out prematurely.

Figure 3 shows the operating characteristics of an led chip. Two curves are shown on the plot. The first curve, which is the solid line, shows effect of current level vs lumens output. This is approximately linear showing increased light output with increased current. For reference the industry standard is to operate on the right 40% of the curve which is 600 to 1000 ma on this chart. The design choice is tied to trades of manufacturing costs for increased led's which optimized the total system at the higher power output values. The second dashed line in figure 3 shows the led efficiency for varying current levels. The curve shows that at reduced current levels the efficiency is considerably higher than the right side of the curve. A design which can operate at reduced current levels provides two improvements in the led system design.

1) The efficiency is higher in terms of lumens per watt. A baseline design operating at 700 ma has a normalized efficiency of 1. Lumens per watt. Operating at 125 ma gives a normalized efficiency of 1.5 lumens per watt. At a constant light output this is a 33% reduction in input power requirement.
2) The higher efficiency results in a reduction, of approximately 33%, in the total amount of heat rejection for the heat exchanger. For the same size heat exchanger the result is a lower led

temperature which significantly extends the led operating life. This is shown in table 1. As an alternative the heat exchanger can be reduced in size by approximately 33%.

Figure 4 shows a typical high efficiency led chip which is rated at 60 ma. These chips are currently available at a cost of $.01 to $.03/ chip in mass production. Note the data shows nominal lumen level for different chips designed to operate at varying white frequencies which range from a warmer yellow white to a cooler blue white.

Figure 5 shows the 60ma led operating performance of lumens vs current. Note the curve is almost linear and in this case operates from 5ma to 100ma with 60ma being the nominal operating point.

Figure 6 shows the 60ma led with lumen/ watt vs current. Note in this chart that at the lower current levels, which is the left side of the curve the lumens/ watt continuously is increasing. For a given lumen output therefore a reduced current level results in a higher led efficiency. If the price of the troffer is fairly constant then the higher efficiency results in increased savings for the store. Typically however the troffer price increases rapidly as the number of led 's increase.

The unique design space of this patent is to operate at the far left side of the current curve. This region gives the highest lumens per watt and will provide the lowest overall wattage for a given lumen output for the complete fixture. As part of this design space we are setting the led temperature below 40 C at full power operating condition. The design temperature value is sufficiently low that the LED will operate for 25 or more years based on its operating temperature performance. Operating below 50 C allows room for the led's to be slightly boosted in power as the led's age. If a 15 year life is planned then based on figure 1 we would expect a droop value for the lumen level around 82% over the 15 year life with the 70% value being out at 25 years. This has an advantage to the store as any amount of current boost results in increased power usage and thus higher electrical bills in the later years. By minimizing the current droop the fixture operates at its maximum efficiency over almost the entire planned life.

The highest lumens per watt design point will also provide the smallest heat sink area. The best way to understand this is that the lumens are fixed so any reduction in lumens per watt will result in a higher wattage requirement and thus larger heat sink.

The led's are soldered to a high thermal conductivity circuit board which is typically aluminum with a thin dielectric layer and a copper overlay for the circuit. By spacing the led's uniformly over the surface of the circuit board the heat flux into the heat sink will be uniform and thus temperatures will be minimized. This is based on the circuit board having a large contact area with the heat sink to minimize the heat path to the cooling fins. A long heat sink design accomplishes this which is wide and flat. Having the cooling grooves perpendicular to the long direction of the heat sink allows a shorter path for the convective airflow and thus aide in cooling capacity.

For a 4000 lumen design the heat sink in this design is 48 inches in length 0.5 inches thick and 4 inches wide. The circuit board covers 3.6 inches of the 4.0 inches and thus spreads the heat evenly over the lower surface of the heat sink. To ensure an intimate contact from the circuit board to the heat sink a

low temperature solder is added at the interface after a copper electroplate has been applied to both surfaces. Also the aluminum heat sink is given a convex radius of 20 inches across the bottom surface. The circuit boards have a 0.5 inch clamping rail which extends 0.25 inch on the 4 inch heat sink and overlaps the circuit board by 0.075 inch. The clamping rails are pop riveted to the rail at 6 inch intervals. The circuit board is 0.032 inches thick and for ease of production is made 22 inches in length with two boards per fixture. The arc in the circuit board improves the contact between the circuit board and the heat sink. This helps to reduce the temperature drop for the led by improving the conductivity across the interface. The convex shape also spreads the led light angle allowing a more uniform lighting field.

The fabrication of the circuit boards requires a low cost rapid implementation process so that larger numbers of LED's can be integrated in the troffer in order to operate at the lower current levels for the LED. The new circuit board uses a 60 to 80 VDC copper strip on each side of the strings of led's. The strip provides a current flow path with minimal voltage drop. The led spacing is reduced in the side direction to 0.25 inches and the lengthwise direction is spaced at 0.40 inches. The reduced spacing in the side direction is sized based on the width of the heat sink relative to the width of the led's. The rail is 1.6 times the width of the centerline of the led's width. This compensates for the tighter spacing by giving each led the same heat sink area. A 0.4 inch lengthwise spacing gives the same heat sink area as a 0.25 inch sideways spacing. The ratio of 0.4/0.25 is 1.6.

Twenty led's are run in two strings of ten each allowing 3.0 VDC/ led. A resistor is added to each string to level out the voltage between the parallel groups of twenty. Large linear numbers of led's results in an averaging of the led voltage variations thereby minimize the differences between strings. The current control circuit board is placed at the end of the first of the two 22 inch rails. The copper rails are connected where they meet providing power over the entire troffer length. 52 groups of 20 LED's are integrated into the baseline troffer configuration.

The footprint of the led pad is oriented so that there is a visual reference in attaching the led chip direction. The design allows a two-step soldering process. After the first solder pass all of the led's will be in place. An amp meter connects the resistor gap and allows for the current on each string to be checked. Resistors are selected to give a constant current for all the strings along the 60 VDC strip. This allows a process to fix the variation in led voltage at minimum losses. The circuit board is run through an oven a second time to solder the resistors. It may also be possible to adjust the led's if certain strings show excessive variation away from the average. If the led variation is found to be small then a single resistor value can be used for all strings to allow just one solder step. The current tests have shown that a single resistor is adequate due to the small variation between strings.

The total number of led's used in a given troffer design is based on a cost optimization involving both the component costs and the manufacturing costs relative to the savings obtained by operating at lower current levels relative to the zero current and the design point for the led's which is typically 70 to 85% of the maximum steady state current allowed. Design life studies indicate that reaching 25 year led lives are possible with sufficiently low temperature; typically below 40C. For the optimization analysis a constant 15 year life is chosen as a sufficient interval to allow design studies. The heat sink size can be chosen to maintain the 40C temperature over the 15 year life. By optimizing for the 25 year life

projection allows reduced led lumen droop out to the 15 year point and thus helps to minimize the heat sink size requirements. The heat sink is fabricated from a low cost high conductivity material such as aluminum. Fin size and shape on the top of the heat exchanger are designed as a trade of fabrication and material costs. Perpendicular verses parallel grooves favor the shorter air entrainment and conduction path. A perpendicular design allows a 4 inch path verses a parallel design which would have a 44 inch path. The surface area of the fins is increased by creating a milling groove which is deeper in the middle of the heat sink where the thickness is larger. The grooves stop 0.125 inch from centerline to provide a 0.25 inch wide lengthwise structural support in the top of the heat sink which serves as a compression member. A .375 inch flange on the sides of the heat sink provides a bolting flange for the aluminum reflector. A .25 inch groove with a .125 inch fin width provides a baseline for the design optimizations. The slightly larger cutter reduces fabrication time with all the heat sink fin channels.

The bottom side of the heat sink uses a 20 inch radius arc which provides a curved surface to pull the circuit boards onto the heat sink which increases the contact force through the spring loading on the circuit board. This aids in maintaining the contact between the circuit board and the heat sink. A high thermal conductivity paste of low temperature solder is applied between the circuit board and heat sink, on the copper and tin coatings, prior to pulling the circuit board down onto the surface of the heat sink. A set of holes along the outer edge on either side spaced approximately 6 inches apart along the linear direction provides the required clamping using pop rivets. Once assembled it is heated to liquefy the solder and anneal the LED solder joints.

The curved surface also spreads the led beam slightly creating a wider pattern from side to side. A wider beam enhances the lumen uniformity within the store between troffer rows.

The heat sink is attached to a 12 inch wide white aluminum reflector sheet of 0.04 inch thickness and 48 inches in length. The reflector is made of two 5 inch rectangular sheets attached to the .375 inch flange on the fin side of the heat sink with a row of pop rivets every 6 inches. The sheet has its outer side edges bent inward 135 degrees, toward the led's, so that a 0.5 inch flange projects on either side. The flange provides a holder for the Polycarbonate plastic sheet which fits under the lip on both sides. A 12.5 inch wide sheet by 48 inch length of clear or translucent plastic provides an arc when placed under the aluminum reflector lip. The metal flange on the reflector creates a lip which is safer for handling.

End plates on either side of 0.1875 inch thickness provide a rounded template for the plastic sheet. The end caps also serve to hold the electrical connectors which are located on each end. Two positive power cables, one negative cable, and two low voltage control cables are connected between troffers.

Two holes located 1 inch from the ends of the heat sink, on centerline, provide a 0.25 inch hole for attaching standard ceiling fittings.

Modern circuit board led placement using CNC pick and place machines significantly reduces time to assemble. The result is that cost of a led circuit board has dropped to where the fabrication time is approximately 10% of the led cost. Automated soldering machines can be operated without increasing production time for the circuit board.

An excel spread sheet was created which summarized all the production and material costs for a given troffer system. This was used to evaluate total number of led components for a given 4000 lumen design relative to system wattage required. The results showed that operating at the higher led part count level of 500 to 2500 led's for each troffer provided a financial benefit to the end user in terms of cost savings over the life of the troffer system. The design program demonstrated that operating on the left 40% of the curve in figures 3, 5, and 6 was beneficial to the end user. This is a design space that is not typically used by the main stream led troffer designers and represents a unique design space in which to operate. The slightly higher costs for the added led's can be added to the fixture costs while still providing economic benefits in terms of a reduction in troffer wattage requirements.

A further system cost benefit is achieved by removing the requirement to provide a store line voltage to each fixture which results in each troffer having the AC to DC power converters. If the stores have a common matrix of lights across the ceiling then a more efficient power converter is provided by driving multiple troffers off of larger AC to DC power converters. Increasing the converter size by a factor of 30 to 1000 Watt reduces the total number of converters by $1/30^{th}$ which provides multiple benefits including electronic component efficiency improvements and reduced system cost.

This same modular approach can also be applied to the wireless dimming system. Creating zones of 30 to 100 troffers reduces receiver costs and still provides zonal dimming to meet store requirements. This can be operated from a small computer in the store office and can be programed to dim at night or different times of the day. Also a few lumen sensors within the store provide feedback and tuning for the store owner to reduce their electric bill for the lighting use. The current controller is located on each troffer circuit boards. This is an added safety feature which could create problems if the current controller was put into a common power box where it powered multiple troffers. Current overloads in troffers could occur if something disconnected in the series of troffers. By placing a current control chip directly on the circuit boards this is prevented since the LED load is always connected.

For safety the circuit boards can have a non-conducting coating over the circuit so that the outer circuit board can be safely touched.. The plastic lens on the troffer can have screws on the ends to add safety preventing touching of the circuit board.

The plastic cover can be made of a material which shifts the light frequency from cold white to a warmer white. This allows more lumens per watt by using the colder white frequencies.

Detailed Description

The LED (light emitting diode) system consists of two main components an LED troffer(1) and the power box(2). These are shown in figures 7 and 8 respectively. Cables are used to connect to the AC input at the store and to connect from the power box to the troffer. The power box is designed to allow up to 30 troffers to be connected in series with internal wiring inside the troffers. Two DC positive wires and one DC negative wire run inside the troffer and connects to each end using a male electrical thumb clip at the front end and a female electrical connector at the opposite end.

The troffer has a heat sink(3) which provides the central support for the troffer structure. It measures 48 inches long and is 4 inches wide and 0.5 inches in height. It has an attachment flange on each side measuring 0.375 inches in width that is used to hold two reflector plates(4) one on each side. The reflector plates are bent inward so as to support an external plastic lens(5). The heat sink has fins on one side which run perpendicular to the lengthwise direction. 0.25 inch grooves run from the attachment flange to within .125 inches of centerline and are deeper at the centerline. The depth approximately follows the contour of the opposite side which has a convex arc shape that is higher on centerline and is constant radius down the length of the heat sink. The grooves provide increased area for heat dissipation from the LED boards. They stop short of centerline to provide a longitudinal brace for added bending stiffness for the troffer. The curve side provides a surface to attach two LED circuit boards(6)also made of aluminum for increased thermal conductivity for the LED cooling. The LED side has flats on the ends to allow mounting end caps. The end caps(7) are curved on the outer side and provide a convex surface to support the external plastic lens. The reflector panels have an approximately 135 degree bend which matches the curve on the end caps (7) and holds the lens(5). The bend provides a safe edge for handling so there are no sharp edges. Vertical bolts on each end of the heat sink provide attachment to the ceiling.

The cross flow design of the heat sink(3) allows a shorter path relative to a longitudinal heat sink pattern. The heat sink fins are on the top of the troffer during operation and have a gap between the ceiling and the fins. Air from the centerline rises vertically with cooler air coming in from the sides along the fins. The natural convection of the air movement allows for uniform cooling across the heat sink. The groove depth is such that an approximate 0.1 inch gap is maintained between the curved surface where the circuit boards are attached and the bottom of the heat sink grooves.

The LED circuit boards(6) are fabricated from an aluminum backing sheet which has a thin ceramic insulator and thin copper on the top side. The LED circuit pattern is etched into the copper and provides the electrical circuit for the individual LED's. Two copper traces run down the length of the circuit board and provide the positive and negative DC voltage for the LED strings. 1040 LED's are distributed on two circuit boards of approximately 22.5 inches in length and 3.5 inches in thickness. 20 LED's are connected in series between the copper traces with a resistor at one end of each group of 20 LED's. The resistor is sized to minimize the current change which will occur if an LED fails and shorts out. A 215 ohm resistor is currently used for each string of LED's. There are 52 groups of 20 covering the two circuit boards. One board has a small region without LED's to allow for mounting the current control board(8). The LED rows alternate direction on the boards(6) to maintain the polarity of the series connection. The two copper traces are connected between the boards so the DC power runs the entire length of the two boards. Clearance in the copper trace is provided on each outer edge to allow a non-conducting region for the hold down rails. The hold down rails clamp the two circuit boards against the convex curved surface of the heat sink(3).

The heat sink(3) and circuit boards(6) have a copper electroplated coating on their mating surfaces to allow a solder joint between them. The copper is electroplating using a zinc interface which is displaced during the copper plating operation. A tin layer is added over the copper to improve the soldering characteristics. During assembly the solder paste which has the solder and flux premixed is applied to

the heat sink and the pre soldered LED boards are attached using the hold down rails(9). The assembly is heated as a unit to 130 C to allow the solder to liquefy and join the two surfaces together. This step also softens or liquefies the LED solder connection and allows them to re-solidify stress free in the curved position.

The sizing of the heat sink for the LED's is such that the LED's operate as approximately 5 degrees C above ambient conditions. This gives the LED's over a 20 year life with steady operation. There are two primary benefits from this design approach.

1) The droop in lumens per watt is minimized over the troffer life. Any droop that does occur allows the user to increase power slightly to easily maintain lumen level. This allows the cost savings due to electricity usage to stay almost constant.
2) The troffer can operate at elevated temperatures, up to 40 C, without significant degradation in LED life. This allows the use in greenhouses and other facilities where the ceiling temperature is warmer.

The circuit boards(6) have a 3mm toughened curved glass lens(10) held by attachment fittings, angled inward at 45 degrees, running lengthwise along the top of the hold down rails(9). A 4 inch x 45 inch piece of safety glass can be inserted into the hold down rail from one end prior to the end cap being added. The glass provides a U.L. 94-5VA safety level and protects the user form the DC voltage on the LED circuit boards.

The end fittings(7) hold the electrical snap lock connectors(11) allowing both easy assembly and no need for added wire in the store for the string of troffers.

The current control circuit boards(8) contain the LT3956 control chip and the differential voltage control for the chip. Output from the control chip varies the DC voltage on the two copper traces to maintain the desired current level from zero to 125% power level. The current controller is designed to provide 5000 lumens at maximum power rating. An aluminum shield(12) is placed over the current control board to minimize the RF emanating from the circuit board(6). It is box shaped and grounds with hold down bolts to the heat sink(3).

To disconnect a troffer within a series of troffers the external plastic lens(5) is removed allowing access to the electrical thumb clamp(11) on both the troffer that is being removed and the troffer located at the female end of the troffer. The allen bolts are removed that hold the male electrical clip(11) on the two troffers where the thumb clamp is located. By squeezing the thumb clamp the electrical fitting can be disconnected from the adjacent troffer. The nuts on the two ceiling fittings, at location(13) can be removed allowing the troffer to be removed. To add a new troffer reverse the process.

The current control board(8) is located with each troffer to add a layer of safety for the system. It is directly wired to each set of LED boards(6) within the troffer. A centrally located current control within the power box(2) could be used; however if some of the troffers become disconnected the current controller could overdrive the upstream troffers which could cause them to fail so it is not used in this design.

The power box(2) is the second major piece of hardware which is used to power the series of troffer units. The box(2) also provides the differential control voltage, on the wireless circuit board(23), used to control the lumen level on the string of troffers(1). The power box(2) consists of an eight inch by eight inch by six inch high metal box(14) with a hinged lid(15). The complete box is made of thin painted steel. The box(2) provides the safety enclosure for the transformer(18) and AC to DC circuits(16). The box(2) mounts above the ceiling directly to a 277 VAC input line; through connector(26). A 4 amp circuit breaker(17) is placed just downstream of the input to the box which trips at slightly above 1000 watts. A high efficiency toroidal transformer(18) is located in the lower region of the metal box and is anchored to the bottom. Four choke coils(19) are mounted in the inside corners of the box and provide the passive power factor control for the transformer(18). The metal box(14) has two sets of cooling holes with metal screen placed over the holes for fire safety located on two sides of the box. Rubber spacers(20) are placed both between the box(14) and the transformer(18)and between the transformer(18)and a hold down plate(21) for the transformer(18).

Two rails(22) are added above the transformer(18) and are used to hold the AC to DC electronic bridges(16). Rails made from PEEK plastic provide a non-conducting support. Metal screws hold the rails securely in the box. A six inch by six inch circuit board(16) contains an AC to DC electronic bridge. The circuit uses 20 transistor mosfets and one control chip. Diodes are added to the input and output for safety and surge protection from the choke coils(19) which are used for the passive power factor correction. The primary board(16) also contains a 4 second delay surge circuit which prevents line surges when the toroidal transformer is plugged in. A second AC to DC bridge, without the surge circuit, is located directly above the larger board(16) and provides a second parallel DC power output. Each bridge powers up to 15 troffers with a total of 30 per power box(2). Two separate positive DC lines and one common negative DC line goes out to the troffers along with the two low voltage differential control wires. All of these are inside a single power cord hooked to connector(25).

Two choke coils(19) are used for each electronic bridge and minimize line distortion from the capacitors located on the bridge. The toroidal transformer(18) has one primary set of wires and two secondary sets of wire so that the two electronic bridges are supplied with independent AC power. This prevents the passive power factor chokes(19) from interfering with each other so as to maintain a high system efficiency.

The AC to DC bridges(16) contain two 7 amp DC fuses one for each electronic bridge adding further protection. The choke coils(19) are attached between the DC fuses and the DC power output to the troffers.

A wireless receiver mote(23) is located in a plastic cover(24) on top of the metal box lid(15) to allow it to communicate with the transmitter. The primary electronic bridge(16) provides the power to the wireless circuit(23). The circuit board(23) for the receiver also contains the differential input voltage circuit which is used to control the 30 troffers. A differential control design is used to minimize line interference which could affect the dimming circuit. The transmitter for the wireless system is connected to a central laptop or smart phone and can be used to control all the receiver motes(23) through a single dimming table throughout the day. The wireless system is sufficiently flexible to allow

feedback systems to be added to the store. Feedback systems can be added to further optimize the power usage based on lighting condition requirements throughout the day.

Non obvious integrations

- Use of 2nd heat-up cycle on curved circuit board allows integration of brittle solders such as bismuth-tin
- Use of lens above circuit board is a low cost approach to protecting DC voltage regions and can have a magnesium fluoride anti reflection coating on the id of the glass.
- For blue LED's: A specific coating on the od of the glass that passes blue light and reflects white could be used. Use of a yttrium aluminum garnet doped cerium phosphor on outside of lens integrates with this coating and is located directly above it.
- For cold white LED's: use phosphor only on the outside of glass lens. Magnesium fluoride still applied on id.
- Use of more than three transistor mosfets on electronic bridge for improved efficiency
- Integration of toroidal transformer with electronic bridge and passive power factor control chokes to provide a low cost high efficiency low RF design
- Use of 65 vdc as the troffer supply to minimize line losses in series troffers
- Use of buck design in LT3956 chip to provide 98% current control on led board
- Use of differential control as acceptable low cost approach for dimming
- Use of non-pwm design in current controller to minimize RF
- Use of copper studs with steel hold down bolts and nuts on electronic bridge to minimize voltage drop at connectors
- Overall synergy of complete system which allows major economic benefit to customer: efficiency, system life, larger power supply, automated manufacturing, direct sales and installation
- Multi level efficiency benefit for electricity use reductions where air conditioning or cooling of bulding is required
- Use of electrical snap connectors on ends of troffer and power box to allow ease of installation and added safety during earthquake
- Use of high end wireless system that allows ease of "smart building" feedback systems at low integration cost

Variations

The light fixture can be longer or shorter as needed. It can also be narrower or wider. The heat sink can have substantially lengthwise cooling fins. The circuit board surface can be flat. The light fixture can operate without a diffuser lens. The fixture can have just one power and control wiring input. The fixture can operate without the reflector plates. A lens cover which is attached directly to the heat sink can be used to narrow the fixture. A clamping arrangement can be integrated into the fixture to attach multiple fixtures together. The wiring fittings can be located on the back or side of the fixture. A wiring fitting located at the end of the fixture can have the ability to be disconnected from the end of the fixture to allow inserting fixtures between other fixtures.

Conclusion

Operating at the low end of the LED chip range with a closely integrated heat sink and the use of independent power supplies provides a market opportunity for the product that gives the customer a distinct cost advantage relative to existing products.

Claims

1) An LED lighting fixture consisting of heat sink, LED circuit boards which operate the LED chips in the lower 40% range of the chip operating curve. The heat sink is sized to maintain the LED junction below 20 C above ambient conditions
    a. A fixture having a translucent lens in front of the led matrix to create a more uniform light
    b. A heat sink made primarily of a high conductivity material such as aluminum, copper, magnesium, and zinc or a combination of these in alloy form.
    c. A heat sink with substantially cross channels located on the back side of the heat sink
    d. A heat sink with a lengthwise integral rail for structural support integrated into the fins so that the fins are on either side
    e. A heat sink with a curved surface on the opposite side as the cooling fins which provides a region to attach the led circuit board
    f. Two hold down rails which pull the circuit board down to the heat sink located on either side of the heat sink
    g. A thermally conducting paste or solder between the LED circuit board and the curved surface
    h. A thin reflective sheet of metal attached to the heat sink on either side which reflects light downward
    i. A reflective sheet, attached on either side of the heat sink, having an outer lip of approximately 0.5 inches in width which is folded approximately 150 degrees toward the led and which is used to hold the lens
    j. An LED circuit board with an LED pattern composed of multiple LED's in a series using a DC voltage supply of approximately 64 VDC
    k. An LED circuit board with a small non conducting region on the circuit board edge for clamping
    l. An LED circuit board having parallel strings of LED's all connected to two DC voltage rails integrated into the circuit board and with the series patterns between the DC rails
    m. A coating over the circuit board to prevent accidental electric shocks from handling.
    n. A glass lens, either curved or flat, directly over the LED circuit boards for shock and flammability protection.
    o. A glass lens with an anti-reflection coating on the inside surface such as magnesium fluoride
    p. A coating on the convex side of the glass that passes blue light but reflects white light
    q. A glass lens with a phosphor on the outer glass surface made of Yttrium aluminum garnet with cerium doping or directly above the blue filter if it is used
    r. A current control circuit located within the led light fixture which controls the current level for all the LED's in the fixture

s. A dimming control on the current controller which also has the capability to operate in PWM or variable voltage mode for dimming
t. Latchable wire connectors attached on either end of the light fixture which have wires running under the hold down plates for the circuit board for power and dimming control

2) A separate power box which converts the AC line voltage to approximately 74 VDC
   a. The power box which is used to power multiple led fixtures
   b. The power box connects to multiple lighting fixtures either in series or parallel
   c. A power box that integrates an electronic bridge with passive feedback chokes
   d. A box which uses a high efficiency toroidal transformer to step the AC voltage from line voltage down to 66 VAC
   e. Two electronic bridges operating in parallel with a common ground and a dual secondary on the toroidal transformer
   f. An electronic bridge that operates with more than 12 transistor mosfets on each bridge
   g. A surge circuit integrated with the toroidal transformer providing a short, approximately 4 second, delay to prevent startup power surges

3) A wireless transmitter receiver system which is used to control the lighting fixtures
   a. A central computer system which is used to provide either manual or programmable lighting schedule throughout the day
   b. A computer system which senses the lighting in the store and adjusts light level based on a programmed feedback system
   c. A receiver circuit either separate on the outside of the power box or located within a power box which connects to the current controller in the lighting fixtures
   d. The use of a differential control system as a low cost approach to zonal dimming
   e. The use of the wireless dimming receiver in a power box that drives multiple troffers to provide "zonal dimming" as a low cost approach
   f. The dimming system that integrates with the LED chips operating at their low power end so as to allow both dimming and brightening as needed by the user and reduced droop over the life of the LED light fixture

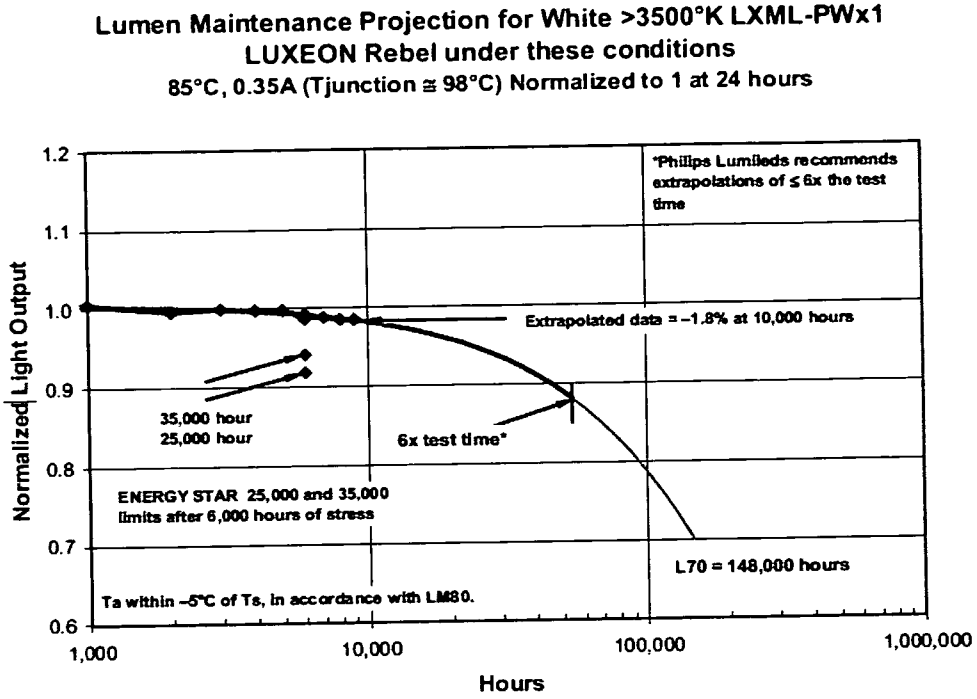


Figure 1

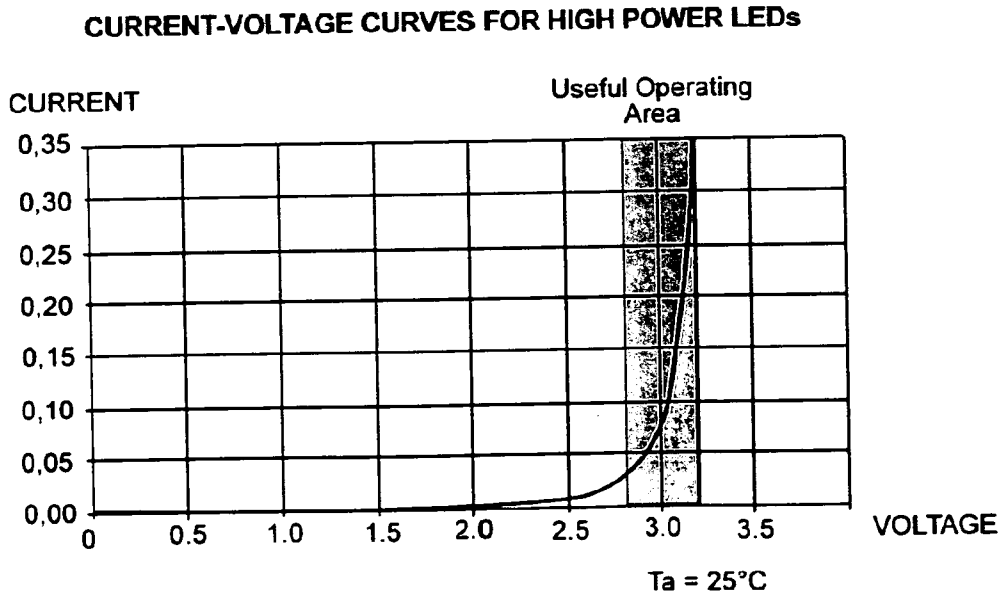


Figure 2

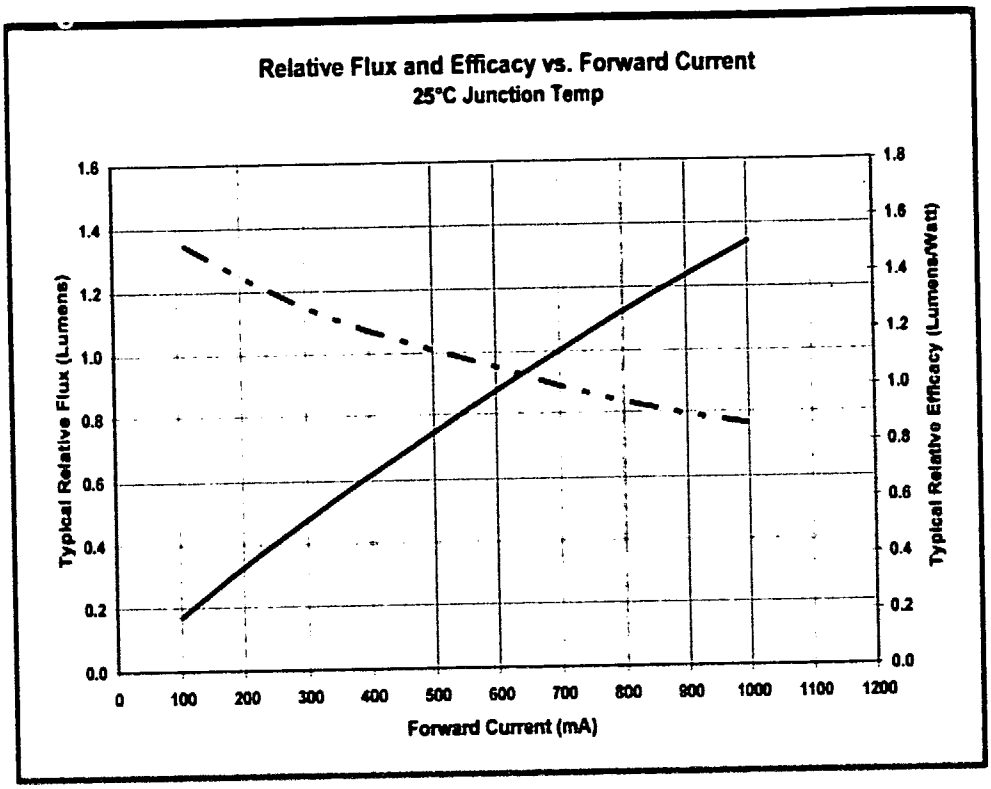
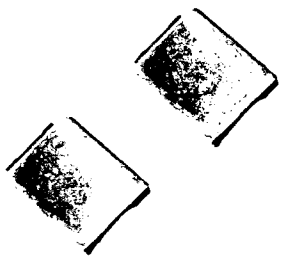


Figure 3

2835 SMD LED Diodes High CRI 80 60mA

Specification *meijiuled.en.alibaba.com*



Item Name	SMD2835
Lumens(LM)	20-24LM
	22-24LM
	24-26LM
	26-28LM
	28-30LM
CCT(K)	Warm White: 2800-3200K
	Natural White: 4000-4500K
	Cool White: 6000-6500K
	Cold White: 7000-8000K
Voltage(V)	3.0-3.4V
Current(mA)	60mA
CRI(Ra)	>70Ra
	>80Ra
Chip Brand	Epistar

Figure 4

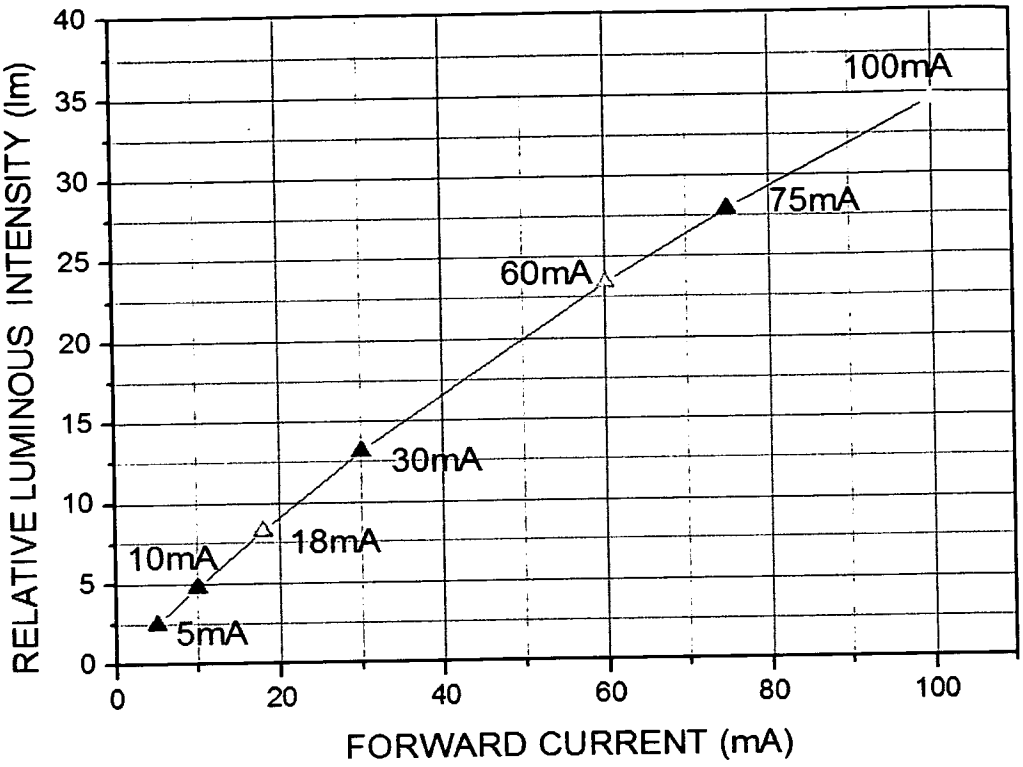


Figure 5

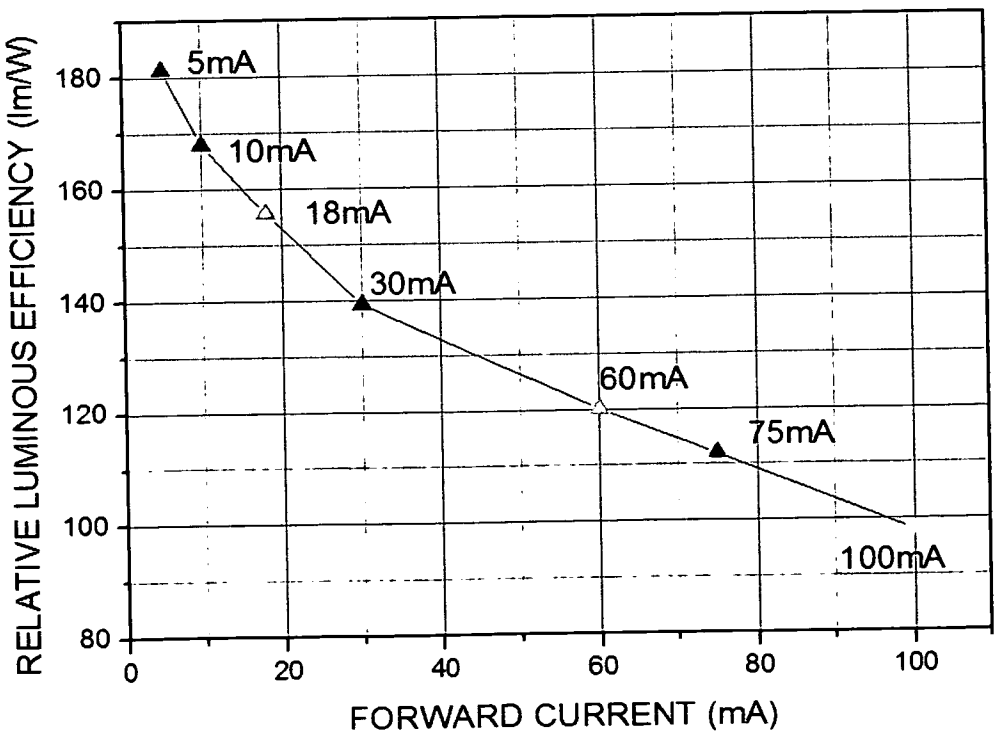


Figure 6

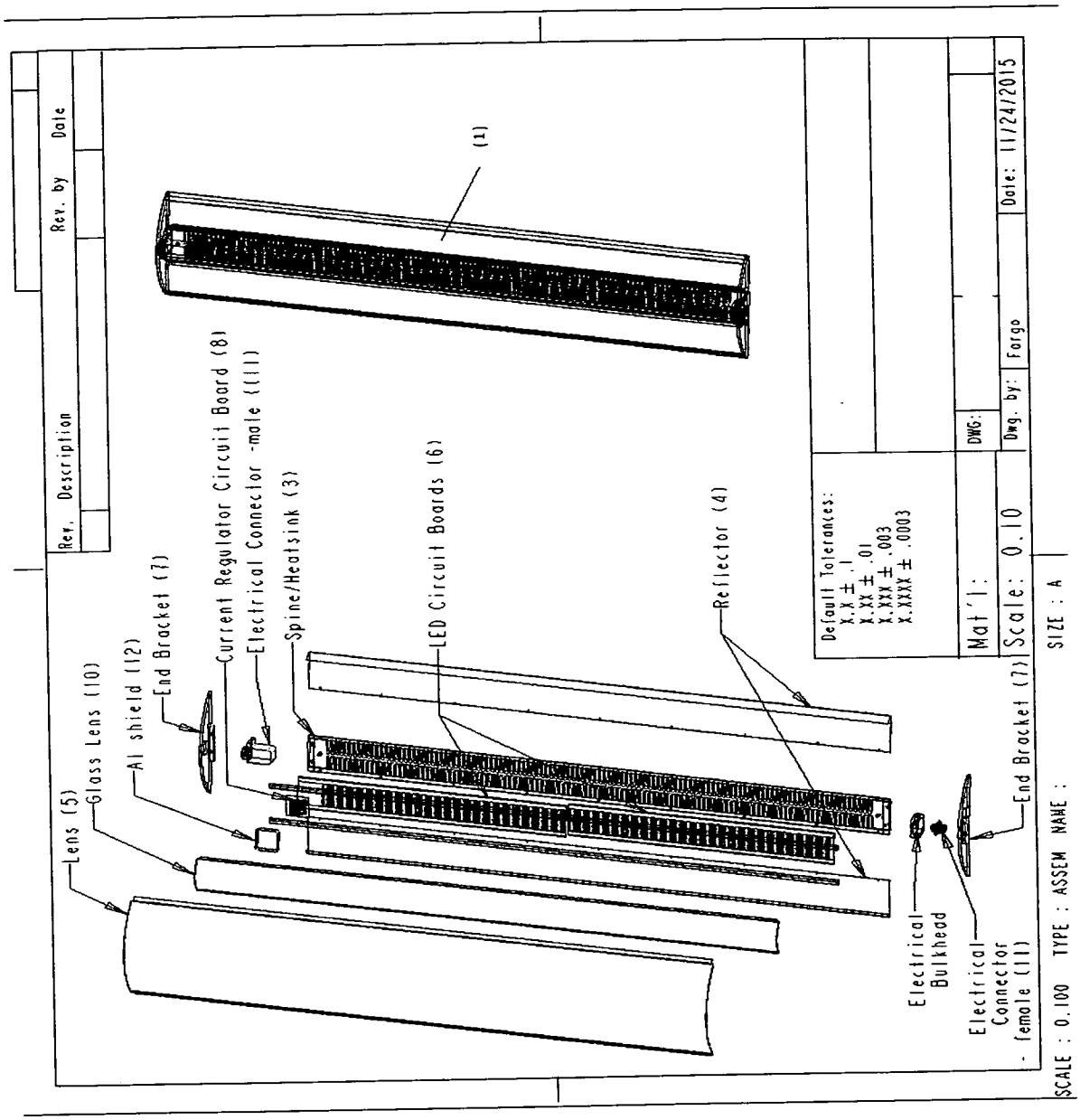

(1)
Current Regulator Circuit Board (8)
Electrical Connector -male (111)
Spine/Heatsink (3)
LED Circuit Boards (6)
Reflector (4)
End Bracket (7)
Al shield (12)
Glass Lens (10)
Lens (5)
Electrical Bulkhead
Electrical Connector - female (11)
End Bracket (7)
Rev. Description
Rev. by
Date
Default Tolerances:
X.X ± .1
X.XX ± .01
X.XXX ± .003
X.XXXX ± .0003
Mat'l:
DWG:
Scale: 0.10
Dwg. by: Fargo
Date: 11/24/2015
SIZE : A
SCALE : 0.100 TYPE : ASSEM NAME :

Figure 7

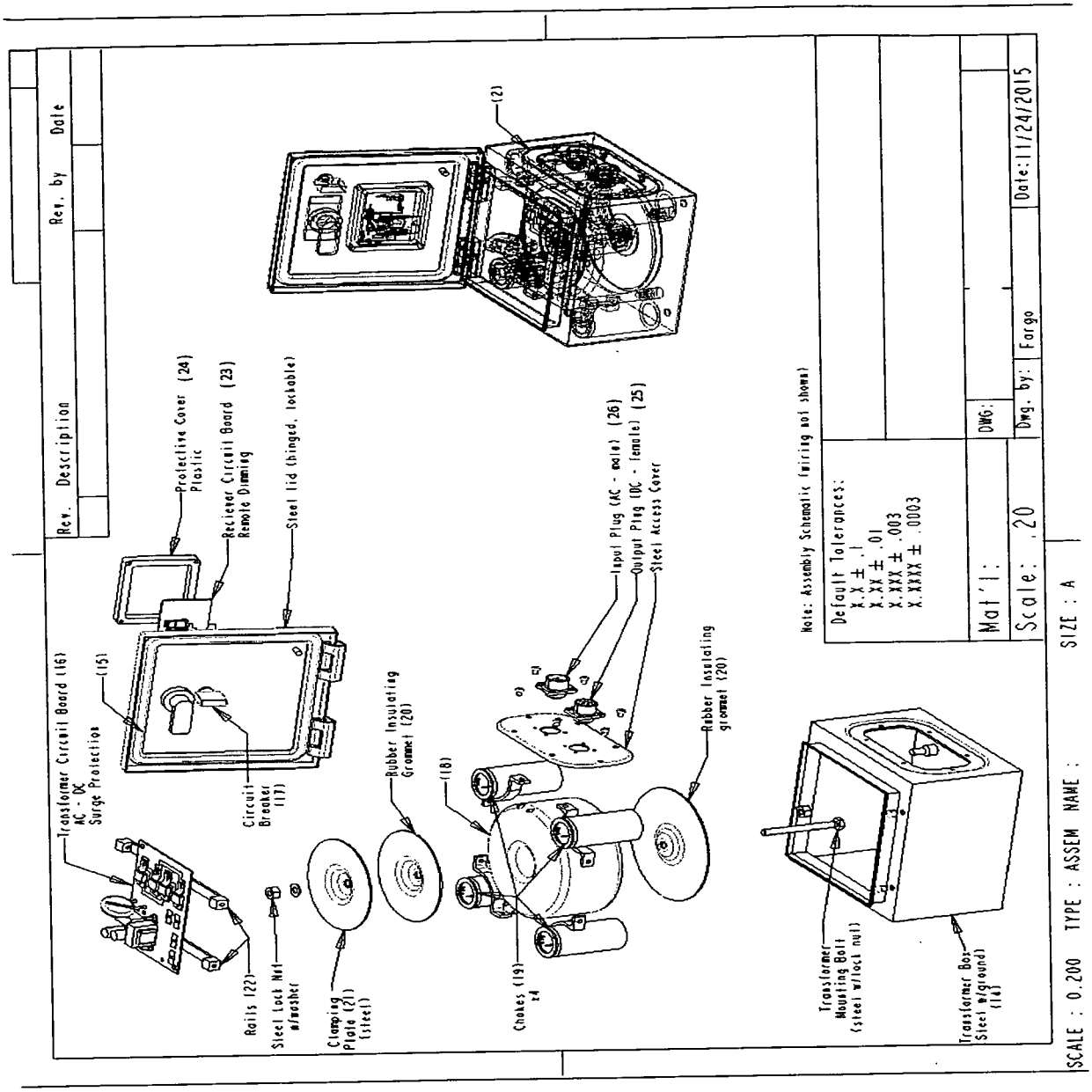

Rev. Description
Rev. by Date
(2)
Protective Cover (24)
Plastic
Reciever Circuit Board (23)
Remote Dimming
Steel lid (hinged, lockable)
Transformer Circuit Board (16)
AC - DC
Surge Protection
(15)
Circuit
Breaker
(17)
Rubber Insulating
Grommet (20)
Input Plug (AC - male) (26)
Output Plug (DC - female) (25)
Steel Access Cover
Rubber Insulating
grommet (20)
(18)
Rails (22)
Steel Lock Nut
w/washer
Clamping
Plate (21)
(steel)
Chokes (19)
x4
Transformer
Mounting Bolt
(steel w/lock nut)
Transformer Box
Steel w/ground)
(16)
Note: Assembly Schematic (wiring not shown)
Default Tolerances:
X.X ± .1
X.XX ± .01
X.XXX ± .003
X.XXXX ± .0003
Mat'l:
DWG:
Scale: .20
Dwg. by: Fargo
Date:11/24/2015
SCALE : 0.200 TYPE : ASSEM NAME :
SIZE : A

Figure 8