
Clear Connect™ RF Technology

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Forward thinking

In 1991, Lutron® identified the need for a completely retrofit light control system (LCS). The retrofit requirement drove the communications to be RF-based. Lutron knew that light control in a home or business was operationally essential, therefore ultimate reliability was vital. These systems can never stop working; in fact, they can't even tolerate latency issues. The required performance standard for a light control system is much higher than for many other systems. The company began analyzing the needs in the global marketplace, investigating possible communication topologies, observing and predicting changes and trends in RF technology and usage, and working through the various frequency bands and their regulatory requirements.

A groundbreaking retrofit light control system required new communications technology. The mission was defined: design an ultra-reliable RF communications system that works to specification every time—in every installation—today and well into the future.

The result? RadioRA® became the first easy-to-install, versatile and reliable RF home light control system (LCS). In addition to RadioRA, many diverse product lines were developed using this patented technology: HomeWorks®, RadioTouch®, AuroRa®, and Sivoia QED® electronic shading systems. In 2008, after more than a decade of experience and refinement with the system, and with over a million RF devices installed globally, Lutron introduced Clear Connect™ RF Technology — its latest advancement in reliable RF communication. Clear Connect has since been deployed in Lutron's next generation RF systems including Maestro Wireless®, Radio Powr Savr™ sensors, GRAFIK Eye® QS Wireless, Sivoia® QS Wireless, and RadioRA®2.

This paper will describe the Lutron requirements, investigations and decisions regarding best methods for RF communications in an LCS. Other available frequencies, system topologies, industry standards for RF products, and practical field issues will be discussed.

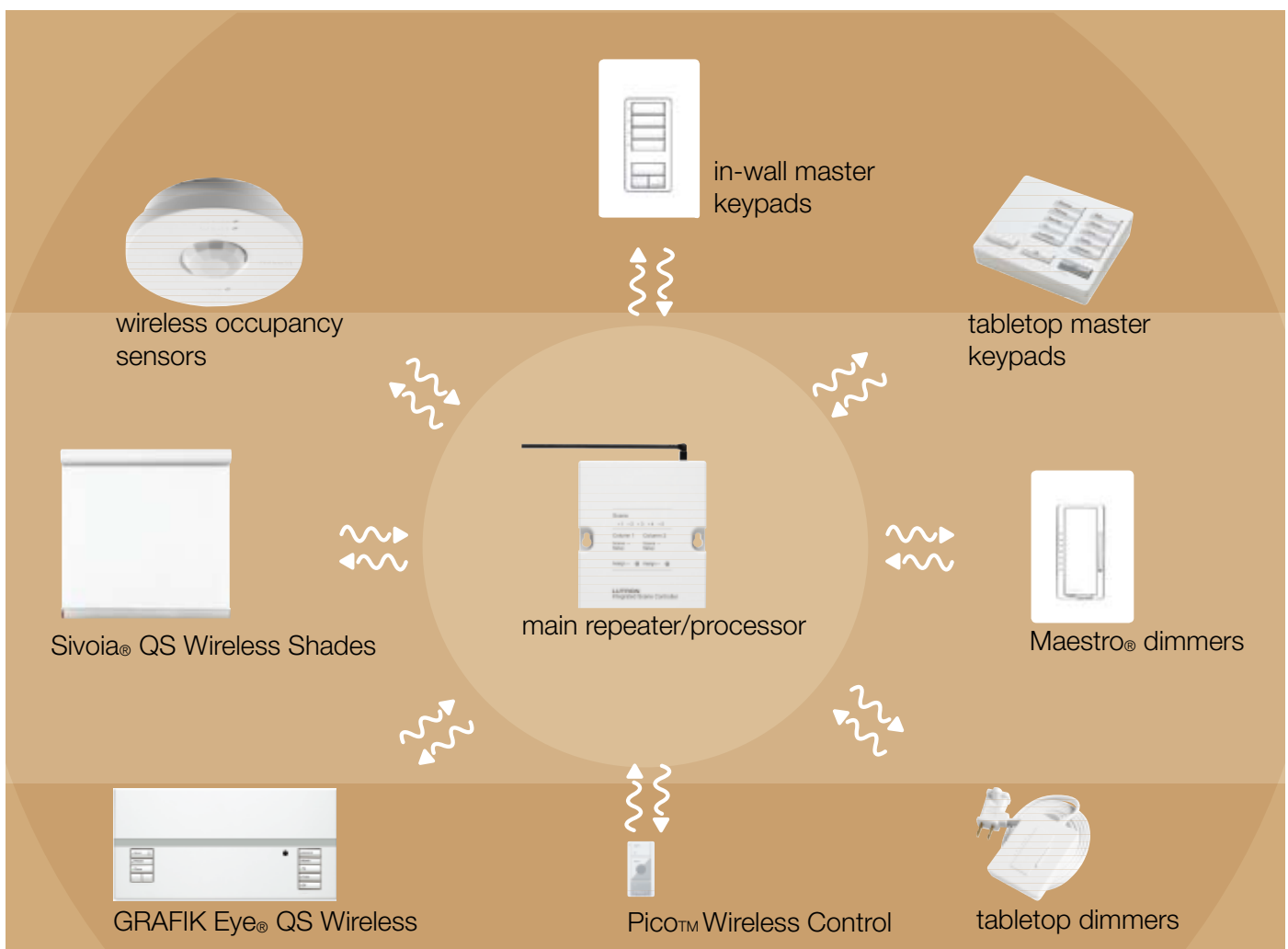
The company's exhaustive research and unwillingness to compromise on performance led to its leadership in the RF lighting control market. The following pages have been written to present the Lutron perspective on the science of RF light control. Lutron hopes that you will find this information useful in determining the parameters for RF systems that meet the unique needs of your clients.

The requirements

When investigating RF communications, ultimate reliability was key due to the operationally essential nature of a LCS. Beyond ultimate reliability, the system had to be completely “retrofitable” and easy to install. No special tools or workmanship would be required. It had to replace existing switches and dimmers

using the existing wiring — calling for dimmers that operate without a neutral wire, which takes significantly more engineering effort and skill. The complete solution would control all load types, have wall-mounted and tabletop keypads and dimmers, controls for the car, and integration devices. Components would have elegant aesthetics and be easy to use and understand — something Lutron has always required of its

products. Many new entrants to the RF light control market miss several of these key elements. A system that provides the ability to control “most” of the lights from “most” locations loses “most” of its value. Having the ability to control table lamps, or provide control from your car, is the difference between ordinary and extraordinary control.



With Clear Connect™, Lutron's RF systems are extremely reliable and completely “retrofitable” solutions.

The investigation

Lutron investigated many different frequency bands, such as 400MHz, 900MHz, and 2.4GHz. The company also considered numerous regulatory requirements from a global perspective. RF emission surveys were conducted in the field to assess the best bands for operation. Measurements were taken in major cities and around major RF transmission sites (antenna farms), all in an effort to understand real-world issues and activity. Existing RF products (like cordless phones) were also put to the test.

What did Lutron learn?

- Every tested system was subject to interference and could be compromised—regardless of sophisticated modulation, hopping or coding schemes.
- While higher RF power would extend range under “quiet” conditions, it did not ensure **reliability**. Since all devices in a given operating band can radiate at the same power level, the risk of in-band interference greatly outweighs the benefit of additional power.
- Bands allowing “continuous” transmissions (like those from cordless phones and wireless routers) would always be problematic (too many devices with too much “on” time). Those bands must be avoided.
- Lower frequencies experience less attenuation through—and reflection from—construction materials than higher frequencies (analogous to low frequency audio signals).

Testing and analysis concluded that operating in “quiet” bands—allowing only very brief, low-power transmissions—optimized overall system performance. The ideal band was defined by FCC regulations Part 15.231.



FCC 15.231: A brief description

- Devices are relatively low power (fractions of a watt). This reduces the possibility of interference between adjacent systems and eases the power supply requirements of a product.
- Devices may not transmit continuously. Generally speaking, all activity is driven by user action (like pressing a button), which further reduces the likelihood of interference.
- Devices may not poll or generate periodic transmissions. There is a 5-second maximum event time after pressing a button.
- Devices in this band include garage door openers, security sensors, and car key fobs.

Benefits of 15.231

- Band is essentially silent.
- Plenty of frequency room available, ~170 MHz; overcrowding is not foreseeable.
- The band has a long and stable history with respect to regulatory changes.
- No proposed rule changes.
- Bands with similar definitions were available globally by other governments' telecommunications authorities.



Typical devices found in FCC Part 15.231.



Imagine how many 900 MHz or 2.4 GHz devices could exist in a building like this.

The decision

Lutron decided that operation under the 15.231 regulations would provide the best overall system performance. This decision was key in the development of the initial RadioRA® system, as well as all domestic Lutron RF systems, including those with Clear Connect™. After reviewing the devices currently operating in this band (public domain information on the FCC website), the company then chose frequencies that did not line up with other popular devices— such as garage door openers.

The result was an ultra-reliable system that has been all but free of in-band interference. This band has proven to be great for high-density installations like multi-dwelling units, urban areas, and dense single-family developments. The proliferation of wireless devices in the global market has had minimal impact on this band.

In 2002, Lutron began work on RF HomeWorks®—their second major RF product line. Its system size and feature set mandated changes to the communications system. Ultimately, the data protocol was modified. However, after careful re-evaluation, Lutron agreed that they were operating with the correct frequency band and rules (15.231).



How many of these popular devices do you own?

Why not 900MHz or 2.4GHz?

These bands allow for continuous-on, high-power transmitters such as telephones, Wi-Fi routers and Bluetooth® devices. This puts customers at high risk for interference, which result in performance issues.

Complex radio techniques such as Direct Sequence Spread Spectrum, Frequency Hopping Spread Spectrum and Orthogonal Frequency Division Multiplexing, are used in these bands.

These techniques are required for several reasons. First, due to the fierce competition for bandwidth, they are required just for basic operation of several

co-located devices. Next, personal voice and data require the highest level of security provided by these techniques. Finally, many of the intended applications require very high data rates (e.g., Wi-Fi router).

The extra hardware, processing power, and software required to operate in these bands adds no value to light control applications. These applications prefer not to compete with co-located devices. Security concerns are more than adequately addressed with several basic, low overhead techniques. The data payloads required for normal operations are relatively small; the key is to have them travel through the system quickly. There will be more

about that later.

Both the industry and public equate higher frequency and higher power levels to higher product performance levels. While all of this makes for great marketing— admittedly important to selling products—the “benefits” are mostly just trade-offs. Lutron’s design decisions have always been based on superior, total system performance — not on great advertising.

Clearly many 900 MHz and 2.4 GHz projects will install flawlessly and operate successfully for years. The knowledgeable integrator (hopefully you, or others you are working with) will identify potential risks — and mitigate them.

Let's assume that you make the right decision and install a DECT 6.0 (1.9 GHz) phone system along with a 2.4 GHz-based lighting control system. What happens when the occupant or a neighbor buys a new 2.4 GHz baby monitor? What if he installs a 2.4 GHz wireless camera for security? What happens after the building, development, or community is built out? How many service calls can your business provide before your reputation and profits suffer?



Interference may not be a problem in your cozy little duplex...

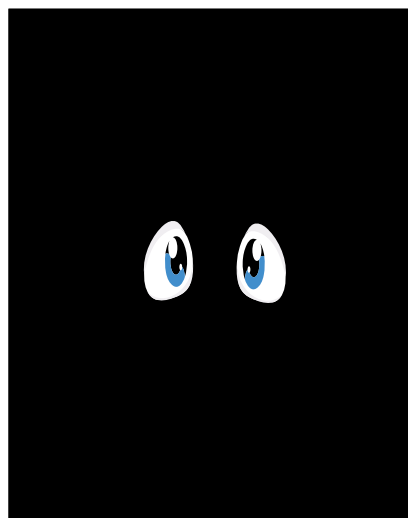


What happens when that duplex becomes a community?

Electronic devices are going wireless at a breakneck pace. All of us have experienced dropped cell phone calls or a lost Bluetooth® connection. It's something we've learned to expect and to live with. When an AV system goes down, it's inconvenient. But lighting control is operationally essential in a home or commercial building — so when a light control system goes down, it's unacceptable. It is likely that you will have to dispatch a truck to that location immediately, including evenings, weekends, and holidays.



Losing a cell phone call is really frustrating.

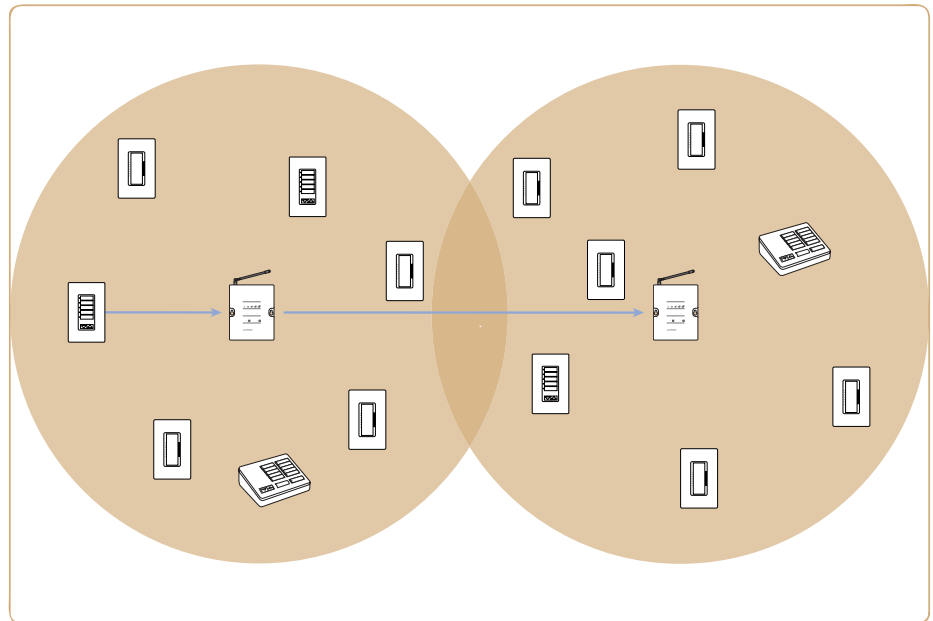


When a light control system fails, it's unacceptable.

Message delivery: Fixed or mesh network?

In applications where the network of devices covers a large area and point-to-point direct communications among devices is not possible, messages must somehow be relayed through the system. There are two primary methods for delivering messages around an extended whole home automation network. One calls for dedicated sending, receiving, and computing stations in predetermined locations— providing RF coverage to all system devices. These stations are commonly known today as Wireless Access Points, or WAPs. Lutron began calling these devices “repeaters” over a decade ago. Through years of development, their functionality now extends well beyond the usual definition of the word. This message delivery scheme is called a “fixed network,” meaning the coverage area and message route are constant. It is fairly simple to create this coverage for homes 10,000 square feet or larger. Messages are moved up and down the fixed network quickly and in a predetermined manner. Lutron RF systems use this delivery mechanism.

Another common method for message delivery is called a “mesh network.” In this topology, messages can be relayed from a source device through most other device(s) to reach their destination. The devices



Fixed network

Lutron’s Clear Connect™ RF Technology utilizes a fixed network to quickly transmit group commands—to the entire LCS.

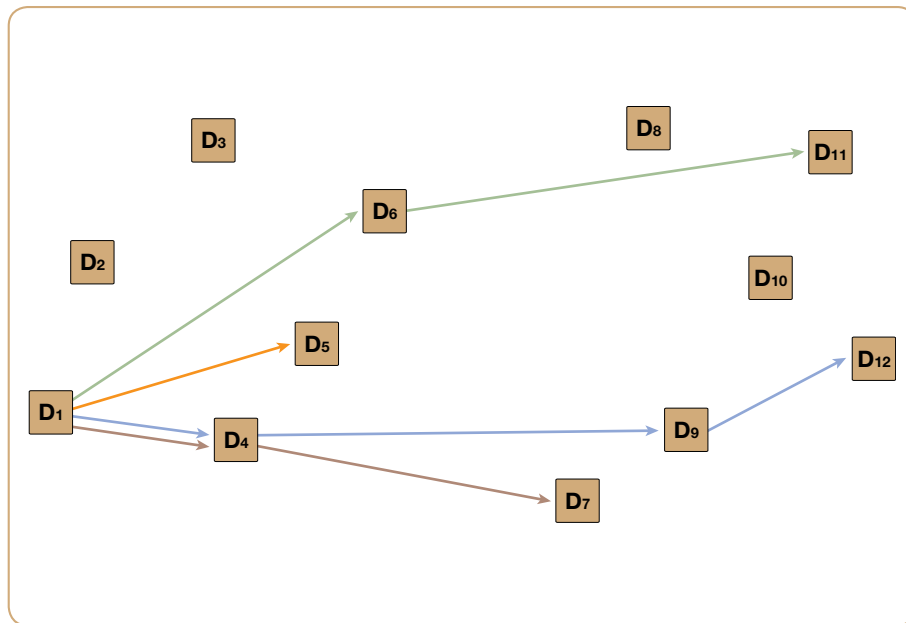
in the network form a matrix of possible message delivery routes. When a source device needs to send a message to a destination device, it uses a routing table to figure out how to get the message delivered—by way of hops through other system devices. If there are enough repeating devices in the network, no dedicated signal relay stations are required. If a preferred route is unavailable, another route could presumably be identified (although in practice this network “healing”, if possible, takes a noticeably long time especially if you are in the dark waiting for the lights to come on).

These descriptions are brief, conceptual overviews. While pages of detail could be provided, it is widely accepted that both methods will work for home automation systems. Each has its advantages

and disadvantages. The advantages of Lutron’s fixed network are revealed when we think specifically about light control applications— as opposed to general home automation applications.

The predetermined route in the fixed network always provides predictable, fast reaction time to a button press, regardless of that button’s location within the system. The network is not shared with, or doing work for, any task other than lighting control.

Lutron has designed its repeaters to be ultra-reliable. They are separated from the line voltage by a robust low voltage transformer that suppresses any damaging line phenomenon. Their solid state design generates very little heat. And because repeaters are installed in hidden locations—and are not interacted



Mesh Network

A mesh network can use any participating devices for message relay. This diagram shows delivery of four directed commands.

with during normal operation—they are less susceptible to electrostatic discharge failure through touching and are less likely to be moved, replaced (as is a TV that may get upgraded regularly), or unplugged. These are important factors when considering the long-term stability of the communication network.

Depending on the locations of the source and destination devices in a mesh network, system reaction time may vary from imperceptibly fast—to unacceptably slow. When a device that was part of the normal route is moved, replaced, unplugged, switched off or fails, a new route must be identified. This will take time. Hopefully, there is another route.

Mesh network troubleshooting can also be challenging, since the number of possible message routes

is large and dynamic and may be traversing unrelated products. Also, there is no mandatory requirement that every device participate in the relay of messages from other system devices. While it may be good citizenship to participate, not all devices take on the additional duties because it requires additional processing resources, additional memory, may not be possible given battery power operation, etc.

You might not notice if it takes a few extra seconds to turn on the coffee maker from a bedroom control, or for the lawn sensor to report a “dry” condition. However, if you are standing at the door at night holding a bag of groceries and the lights take a few seconds to come on—you will notice that. These realities have a serious impact on perceived system quality. Erratic performance issues can lead to service calls,

even though the overall system is operating fine.

Group Commands vs. Directed Commands

Unrelated to how the messages move around the system is the issue of the content of the message and how the system design reacts to that content. Lutron systems, including those with Clear Connect™, use “Group” or “Preset” commands. In this scheme, a button press sends out a generic command like “Preset 01.” The devices have distributed intelligence (e.g. devices have non-volatile memory and a database, and know how to react to this command). When a button is pressed, the system transmits “Preset 01” down the fixed network one time. All devices “hear” and respond simultaneously. These systems can be expanded with no degradation in performance. Most system designs do not have this mechanism and are unable to provide it. The reason is that it requires ownership, coordination, and hardware (memory) of all the devices in the network. In systems comprised of devices from a disparate group of manufacturers, commands must be issued to each device sequentially. These commands are called “directed commands.” To turn on 10 different devices requires 10 unique commands. This can create the “popcorn effect.” One light turns on; there is a pause, the next turns on, and so on. To see it in the application is a real letdown. Customers may be happy with the initial installation, add more devices, and become dissatisfied at a later date.

Practical field issues

It is not the goal of this paper to denigrate the RF standards, but it is important to discuss the issues that prevent them from being the best choice for your light control subsystem specifically. Industry standards are valuable tools in general; they add value to society and to our industry as a whole. However, they are generally designed to solve as large a problem as possible and therefore result in less than optimum performance for a given specific application. Built on over a decade of experience, Lutron's Clear Connect™ RF communication technology was designed specifically for the needs of a light control system. essential to a home or building.

Low-cost, plug-in power-line-carrier devices are fine for the hobbyist turning on Christmas lights. Likewise, RF standards will probably provide the do-it-yourself amateur good performance for his various home automation projects. However, Lutron asserts that the RF standards can fall short on their promises and that they do not provide professional grade products for light control systems. Here are four reasons why:

Point 1 – Control system is still required

The promise of RF standards is that all devices can talk to one another seamlessly – just start buying devices and they all interoperate. Let's think about

that in practical terms—within the context of complete home automation. Is someone going to make a thermostat that has a user interface to control your audio amplifier? Is my audio amplifier going to have buttons to arm my security system? How will I program these buttons, since this could get somewhat complex? Is the thermostat manufacturer going to develop a PC utility for programming the system? Clearly having all devices able to talk to one another is much different than coordinating them to all talk to one another. The point is that we will always have the need for a “parent” or “control” system or device to program and control all these devices. That requirement doesn't go away with an RF standard.

Point 2 – Quality and experience

The existence of the RF standards greatly lowers the barriers of entry into the RF market. RF chip manufacturers would lead you to believe that all you have to do is plunk down their chip, and presto, it works! Device manufacturers who would not have the engineering resources, expertise, and commitment to develop RF technology on their own can now jump right in. Let's assume that the standards are absolutely flawless—perfect hardware, software stack, and protocol. Each manufacturer still has to execute that perfect standard correctly. Mistakes and oversights can be made in the implementation (such as not meeting timing requirements to turn around a message). It is particularly difficult to design an RF dimmer. Placing sensitive radio receivers in an inherently electrically

challenging environment is a difficult task. Understanding all the possible states, conditions and tolerances is not an easy feat. Newcomers—and their customers—will likely endure the pain of this learning curve.

Point 3 - Accountability

Imagine an RF network comprised of equipment from three different manufacturers utilizing an RF standard. During the set up process, you're experiencing some difficulty getting the handheld remote to hop through the security sensor to talk to the dimmer. Who do you call? Which company will stand behind the system if it fails to operate as specified, even though they are only one element of it? Who will be sending field service out to help you? Which manufacturer even has a field service department?

Point 4 - Compatibility

When revisions to the standards, device profiles, and application layer firmware occur, how do you ensure compatibility? Will you be stuck with all the old features even when you add new devices—because you have to operate under the old rules? As an example, the way 802.11g operates with 802.11b is by slowing all the “g” devices down to “b” speeds. Therefore, one “b” device holds back your entire network.

Published specs: Don't just read them. Read into them.

A number of RF equipment manufacturers appear to be eternal optimists. Many of them write specs stating “works up to 100 feet.” Does that mean it will work at 50 feet? How does one design a system using this ambiguous specification?

Still others specify ranges based on results in flat, unobstructed outdoor environments. This specification is appropriate for devices operated outside, like a remote controlled toy or a car visor transmitter, but it is not appropriate for a device operating within a home or commercial building. Devices boasting an operating range of 300 feet in those ideal conditions may not work 30 feet inside a building. Dense construction materials attenuate RF signals quickly. A number of RF reflective materials such as metal, cause multi-path fading and shadowing. Grounded metal wallboxes, metal wallplates, large sections of metal duct work, refrigerators and more can be the cause of problems.

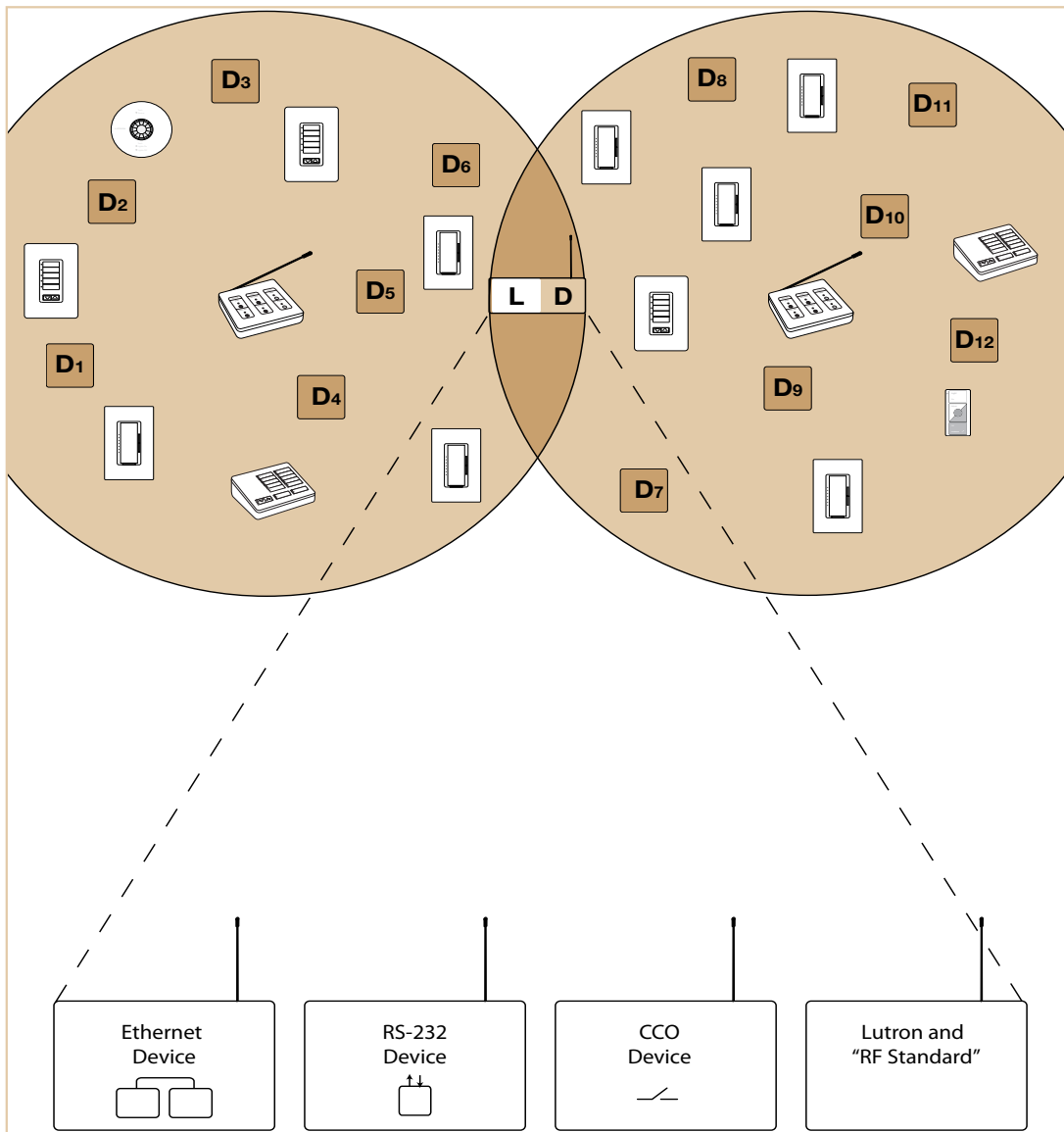
Lutron publishes definitive specs based on the real-world conditions that the product was designed to be operated in. Very often Lutron products will exceed the company's worst-case spec, but the spec is one that you can design to in the planning phase and then depend on at installation time (and for years thereafter). When Lutron states their indoor ranges of 60 feet from repeater to repeater—which translates to a sphere of 2,500 square feet of coverage per repeater; or 30 feet from a repeater to another device they are accounting for the worst-case conditions so that you don't have to. To provide installers the maximum utilization of their equipment, for certain indoor products (like an occupancy sensor) the company additionally provides some unobstructed or line-of-sight range values. These values are not the misleading “outdoor” specs because they are still accounting for real indoor conditions, like multi-path fading, but they are logical specs for the line-of-sight type applications they cover. For outdoor products (like a car visor transmitter) Lutron provides outdoor specs.

Don't be misled by various “specmanship” techniques used by other manufacturers. While the range spec is the most visible and touted, other specs such as power output or data rate are similarly used as misleading selling points. These specs taken in isolation of the total system design are meaningless. Customers don't need 10dBm more power—they need the command to get through. Specs with bigger numbers aren't better – specs that are accurate, real-world, reliable, and meaningful are better.

The best specification point of all is a system that works – it's a one-name spec – Lutron's Clear Connect™ RF Technology.

Lutron integration

Lutron systems can operate independently of equipment from other manufacturers. The systems are designed to allow you to isolate and troubleshoot them on a stand-alone basis. Lutron makes integration with third-party equipment simple, seamless, and cost-effective. If there becomes a real market need, the company could make an interface that directly ties Lutron RF systems using Clear Connect™ to other systems using RF standards. There is minimal inefficiency in mixing a Lutron LCS and any other subsystem together. The result is an ultra-reliable LCS. Lutron has the service organization, decades of experience, and unflinching commitment to stand behind their systems and products—RF or otherwise.



Lutron systems using Clear Connect™ RF Technology can co-exist seamlessly with other subsystems. Integration between Lutron light control systems and any other subsystem is simple and reliable.

Always evaluating and anticipating

Lutron has always evaluated new technologies and anticipated customer needs. It is a practice the company lives by today, and one they will always embrace. Let the following details on the evolution of Lutron's patented RF Technology stand as testimony:

1997

RadioRA® 418MHz – one channel (AM)

World's first RF professional-grade two-way LCS.

Today it's the "gold standard" to which all LCSs are compared.

1999

RadioRA "B" Frequency 434MHz – one channel (AM)

In nearly a decade—and with over 1 million devices sold—only one isolated area in North America has interfered with Lutron's one channel RadioRA system—New York City. The "B" frequency was developed to address this situation. More proof of the Lutron commitment to their customers and the light control business. This empirical evidence speaks volumes about the appropriateness of operating in FCC 15.231.

2003

HomeWorks® – 434MHz – 60 channels (FM)

When Lutron decided to design RF products for the HomeWorks product line, the system size and feature set required a multi-channel transceiver (allows multiple subsystems to communicate simultaneously). This was a complete redesign of the radio transceiver, and the company reevaluated all the decision points that were discussed in this paper. Ultimately, they came to the same conclusions: FCC 15.231 was still the best band of operation, and their fixed network topology yielded superior results.

2008

With more than a decade of experience in RF Technology and having installed over a million RF devices, Lutron develops **Clear Connect™ RF Technology** as its latest advancement in reliable RF communications. All subsequent Lutron RF systems utilize Clear Connect™.

Stanza is introduced as the new standard for lighting control in hotel guest rooms.

The **Radio Powr Savr™** wireless sensor and **Maestro Wireless** families are introduced as the simplest way to retrofit energy savings and convenience into a space.

2009

The introduction of wireless capability to **GRAFIK Eye® QS** and **Sivoia® QS** brings the flexibility, ease of installation, and convenience of wireless control to two of Lutron's flagship product families.

RadioRA® 2 is introduced as the long-awaited next generation RadioRA system with expanded capabilities, a broadened product offering, and simpler system set up.

Which RF technology offers the most for your customers? The answer is Clear Connect™

The leader in light control

- 50-year company history
- Global organization
- 24/7 technical support
- Focus on light and energy control
- Industry leader expanding the market with trade and consumer campaigns
- Industry leader who is providing programs to develop your business

RF Experience

- Pioneered RF LCS category
- Over 1 million devices sold
- More than a decade of production, sales, and installation
- Many diverse product lines

RF Technology

- Seven RF-specific patents
- Fixed network message delivery topology
- Fast group or preset commands (not directed commands)

- Unique house codes, device addresses, serial numbers
- Easy and reliable integration (Ethernet, RS232, IR, CCI, CCOs and telephone interfaces)

Depth

- Load types: Incandescent, ELV, MLV, FL, LED
- World's most advanced shading solutions
- 2-wire, neutral-wire
- Dimming and switching
- Wall-mounted and tabletop dimmers and keypads
- Aesthetic styling, colors, and finishes

Quality

- Recognized industry leader
- ISO 9001:2000 certified
- 100% end-of-line testing

In closing...

This document detailed Lutron's RF design philosophy and methodology which has led to the development of the company's Clear Connect™ RF Technology. What is unwritten, but obvious, is Lutron's steadfast commitment to designing and manufacturing the world's premier RF light control systems. It is with hope that the information presented will be of value to you when making your critical business decisions. There are a number of things to consider when deciding what manufacturer will supply your business with products – choose the one who will supply your business with success.



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