Lighting*Answers*

Controlling Lighting with Building Automation Systems

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NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM

Introduction

The potential for substantial energy savings has made the use of automated lighting controls such as timers, occupancy sensors, and photosensors commonplace in modern buildings. Similarly, building automation systems that control heating, ventilation, and air-conditioning (HVAC) have become common in new construction and are now included as part of many retrofit projects; more than half the large commercial buildings (averaging 200,000 sq ft) surveyed by the Wisconsin Center for Demand-Side Research (WCDSR 1995) included a building automation system.

Building automation systems can also be used to control lighting; however, high initial and maintenance costs, the apparent complexity of these systems, and concerns about the *interoperability** of lighting systems and other building systems have limited such applications. The National Lighting Product Information Program (NLPIP) prepared this issue of *Lighting Answers* to explain the options, benefits, and potential pitfalls of controlling lighting with building automation systems and to direct lighting specifiers and facility managers to resources for further information.

Building automation system-controlled lighting systems may offer incremental energy savings over properly applied timers, occupancy sensors, and photosensors; in addition to these savings, which are not usually large, building automation systems offer other benefits:

- Detailed reports on occupancy and energy use
- Enhanced operation scheduling
- The ability to share occupancy information with other building systems
- Diagnosis of lighting system problems
- A wide array of manual control options for building occupants and building managers
- The ability to monitor and control lighting throughout a building or even throughout a multi-building facility
- The ability to minimize peak demand, thereby reducing energy costs where utility rate structures are based on peak demand and real-time pricing

Conventional lighting control systems often control equipment in a single room or over a limited area, because they are *centralized control systems*, which means that all the controlled circuits must be wired to a single control panel. The computers used by these systems are typically dedicated microprocessors that perform only lighting control functions.

By comparison, modern building automation systems are *distributed control systems*, which means that their computing hardware and software are distributed as a network that comprises microprocessor-based control modules and standard personal computers (PCs). The control modules use *direct digital control* technology to communicate with each other and act together as an "intelligent" whole. Direct digital control systems are extendible virtually without limit, so that all the lighting in a facility can be controlled by a single, unified system—the same system that also can control and monitor the building's HVAC, security, and smoke detection systems, manufacturing processes, elevators, and more.

What is a building automation system?

A building automation system is a computer network that integrates the controls of a building's various electrical and mechanical systems. There are two main techniques for implementing a building automation system: integrating a number of existing control systems and creating a new distributed control network to control all of a building's systems. Often strategies for automating

*Terms in *italics* are defined in the glossary on p. 7.

building controls combine both techniques. For example, an existing HVAC control system can be connected to a new distributed control network that controls lighting, security systems, and fire alarms.

Building automation systems require computers, and thus are only as useful as their programming. The sophistication of software for these systems varies widely. The simplest system may merely schedule operation of the equipment. A more sophisticated system running custom software developed using *fuzzy logic* may have the ability to learn occupancy patterns, so that it can anticipate when to turn on devices that require warm-up time, such as metal-halide lighting systems, manufacturing equipment, or copy machines, and so that it can adjust the HVAC system according to the schedules of occupants.

What is direct digital control?

Direct digital control is the technology used in a distributed control system. Each circuit to be controlled or monitored is connected to a direct digital control module or a multi-circuit direct digital control panel which represent *nodes* on a distributed control network. Unlike centralized control systems, which require that all nodes be wired to a central hub, each new direct digital control node can be wired to the nearest node on the network. For network setup, monitoring, data logging, and direct control, PCs with a direct digital control interface card can be connected anywhere on the network as an administration node.

Direct digital control modules are miniature computers. Each one informs the network about the status of the device to which it is connected, and each one can be programmed to respond to direct commands from other modules or to a change in status of any other device on the network. Direct digital control modules are available for any type of lighting load or sensor; many lighting control components, including occupancy sensors and photosensors, are available with this technology built-in. Direct digital control modules and components for other building systems are also widely available.

The hardware for a direct digital control system can be installed more easily and faster than that of a centralized control system. Expanding or modifying the system is also quick and easy.

How does a building automation system control lighting?

A building automation system can control lighting using schedules, manual controls, occupancy sensors, and photosensors, either singly or in combination.

Schedules. Much of the energy savings produced by a building automation system comes from scheduling the operation of electrical loads. For instance, the lighting in a building can be programmed so only occupied spaces are lighted during the evening or at night. Different schedules can be programmed for individual circuits or groups of circuits (called *zones*). Each zone also can have a unique schedule for weekdays, weekends, or special events. Some systems automatically adjust a lighting zone's schedule to account for seasonal variations in the availability of daylight. A building automation system using fuzzy logic could dynamically adjust schedules based on typical occupancy patterns.

Manual controls. The availability of manual controls often is a key factor in occupant acceptance of a new lighting system. Manual controls may also increase productivity by providing a means by which occupants can optimize their work environment to their changing needs. A study by Rensselaer Polytechnic Institute's Center for Architectural Research showed that productivity in an insurance office increased 3%, and complaints about the environment dropped to zero when occupants were given convenient manual

Figure 1
Programmable control pad for DDC manual control

Customers of the electric utility Central and Southwest Corporation in Laredo, Texas, use this bilingual control pad to program the operation of their air conditioners, water heaters, and other appliances. Customers can set their appliances to automatically respond when the utility varies the cost of electricity during the day in response to demand.

control over the temperature and lighting in their workstations and lighting systems. (Kroner et al. 1992). Manual dimming controls can also save energy in daylit offices, or where occupants perform tasks requiring low lighting levels for part of the day.

Direct digital control modules can be connected to existing manual light switches and dimmers. The system can be programmed to let manual controls override signals from sensors or to consider the status of manual controls and sensors and the time of day in an algorithm when determining what lighting control commands to send.

A wide variety of specialized manual controls are also available for direct digital control networks, including control pads with multiple programmable buttons, multifunction liquid-crystal display panels (such as the one in Figure 1), and hand-held remote controls. Interfaces are available that make manual control possible through touch-tone telephones. PCs with access to the control network can perform advanced functions, such as adjusting the lighting when a particular application is launched and, if equipped with voice recognition capability, voice-activated control. Manual controls can be located anywhere on the building automation system network, so that, for example, manual controls for lighting in an open office can be located at every entrance to the office and at any workstation.

Occupancy sensors. An important benefit of controlling lighting with a building automation system is that the lighting system can share information with other building systems. For example, after business hours, if an occupancy sensor node tells the network that a certain private office is occupied, the building automation system can turn on the hallway lights on that floor, adjust the temperature in that office, alert the security staff that the room is occupied, and even send an empty elevator to that floor to pick up the occupants.

A building automation system can also be programmed to respond to a signal from an occupancy sensor by dimming lights rather than switching them off or by dimming them at first and then switching them off only if the space remains unoccupied for an extended period of time, to minimize the likelihood that occupants will be left in total darkness.

Actual lighting energy savings from occupancy sensors vary widely from none to almost 80%, but manufacturers frequently cite an average savings of 30% for private offices (*Sensors Save A Lot, Field Tests Show*, 1995). Allowing occupancy sensors to also control the HVAC system may substantially increase the total savings.

Photosensors. There are two types of photosensors: those used for switching and those used for dimming. A photosensor used for switching sends a *binary signal* to the direct digital control network when the amount of light it detects reaches a certain (adjustable) threshold. The building automation system can then turn off lights or set them to a lower level. A photosensor used for dimming sends a *continuously variable signal* indicating how much light it is detecting. With this information, a building automation system can gradually dim lamps as daylight increases or gradually increase power to the lamps as they age to maintain constant illuminance (light level).

Table 1
Comparing characteristics of control network media

Network Medium	Bandwidth (kilobytes/second)	Typical Range (meters)
Twisted pair	0.3–2,000	1–1,000
Coaxial	300–10,000	10–10,000
Fiber optic	1–100,000	10–10,000
Power line carrier	0.06–10,000	10–5,000
Radio transmitters	1.2–10,000	50–30,000
Infrared transmitters	0.05–20	0.5–30
Telephone-modem	1.2–56	unlimited
TCP/IP (Internet/intranet)[a]	1.2–10,000	unlimited

[a] One TCP/IP router gives selective network access to any workstation with Internet access.
Adapted in part from *IEEE Spectrum* (Razi 1994).

What wiring and wireless networking options are available?

Low-voltage, twisted-pair wiring is the most common direct digital control networking medium, but, depending on *bandwidth* needs, proximity, and other factors, many other media can be specified, including coaxial cable, fiber optic cable, narrow-band or spread-spectrum *power line carrier (PLC)* signaling, radio frequency (RF) transmitters, and infrared (IR) transmitters. *Routers* are also available to extend a direct digital control network over standard or dedicated phone lines via modem or over a transfer control protocol/Internet protocol (TCP/IP) network such as a corporate intranet or even the global Internet. Characteristics of these media are compared in Table 1.

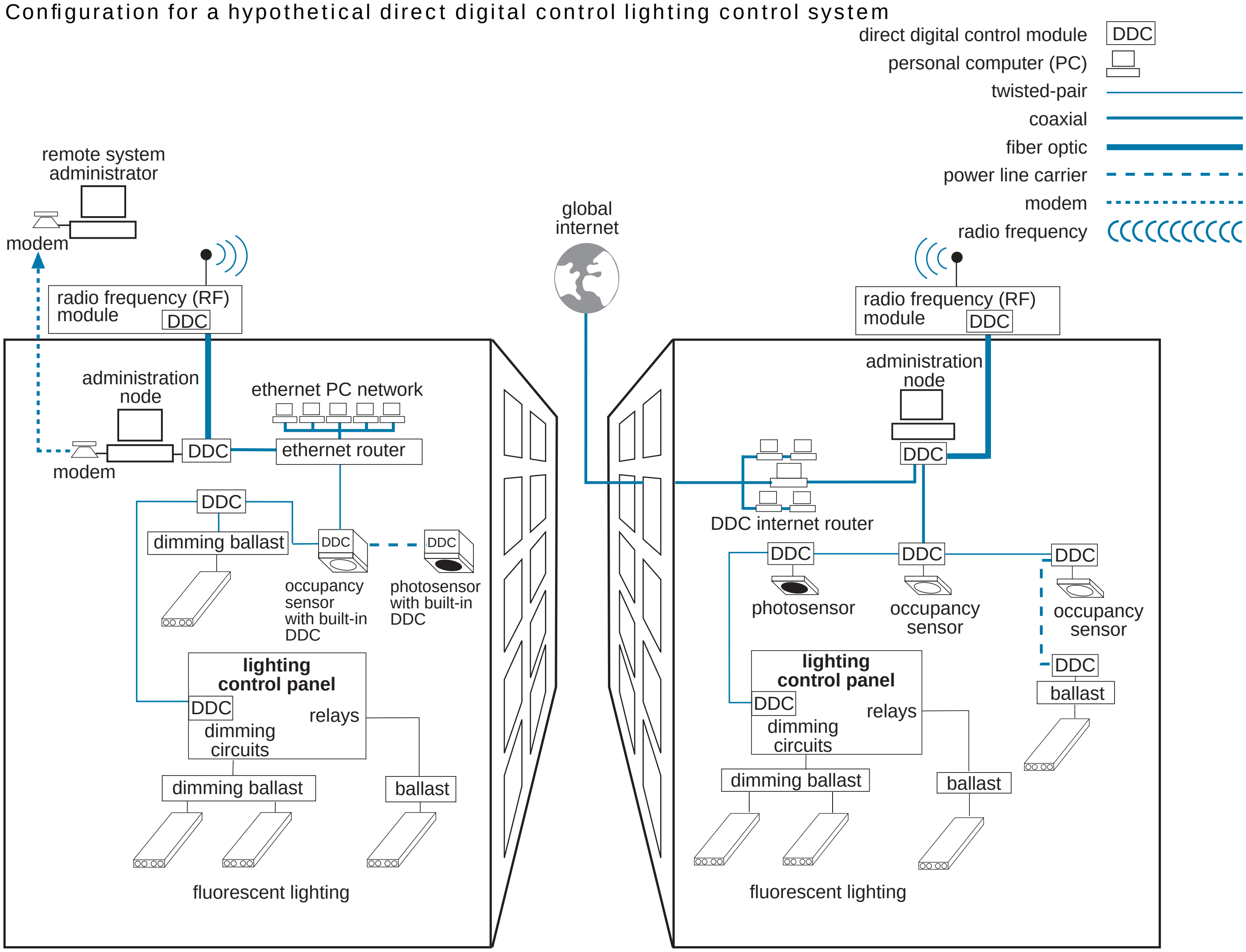
These media can be mixed within a network so that the most convenient and effective option can be used for each node on the network. Media with greater bandwidths provide higher data transmission rates, which are necessary for real-time monitoring or control. Where instantaneous feedback is not needed, such as for controlling an HID lighting system, the slower media are appropriate. The typical operating ranges shown for the networking media in Table 1 can be extended by using signal repeaters. Figure 2 illustrates how networking media can be mixed throughout a multi-building direct digital control lighting control system.

How much do direct digital control systems cost?

A direct digital control system consisting of 29 HVAC and lighting nodes costs approximately $4700 for the necessary hardware, software, and installation. A comparable centralized control system would cost about $8500. A direct digital control system with a few hundred nodes may cost about $25,000. The components range in price from as low as $50 for a binary direct digital control module, to $4000 for an Internet/intranet router. Setup costs range from $50 to $150 per node (Morris 1996).

Direct digital control systems may also be rented or leased. Some building automation system installers will require little or no up-

Figure 2
Configuration for a hypothetical direct digital control lighting control system



Scheme for a theoretical direct digital control (DDC) network that controls lighting in two separate buildings. Various networking media are used, including coaxial cable, twisted-pair wiring, power line carrier signaling, telephone lines (via modem), and the Internet. Also used are radio frequency transmitters (shown connecting the two buildings into a single network), which have a range of 50–30,000 meters.

front payment, in exchange for a share (such as 10–20%) of the monthly savings in energy costs that the system provides, over a period of several years. Also, some electric utilities may assist in paying for a direct digital control system in exchange for limited ability to monitor the system and control electric loads as peak demand varies.

What are BACnet, LonWorks, and CEBus?

BACnet, LonWorks, and CEBus are among the most popular communication protocols used by direct digital control networks. A communication protocol can be described as the language that direct digital control modules use to communicate with each other. Ethernet and Token Ring are examples of communication protocols for data networks; these and other data network protocols are not ideally suited for the high, sustained volume of data that control networks generate. LonWorks, BACnet, and CEBus were designed specifically for the data transmission needs of a control network. All three are open standards, meaning that any manufacturer of direct digital control components can use them, and if they follow the standard closely, their products should be compatible with any others using the same protocol. By contrast, many building automation system manufacturers use proprietary communications protocols such as Metasys and MicroTech. These can only be used in components from licensed manufacturers, which helps assure compatibility of components but limits product selection.

BACnet (Building Automation and Control Network) was designed specifically for HVAC control networks by the American Society for Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). The BACnet protocol is described in ANSI/ASHRAE 135-1995. ASHRAE's intent was to create a protocol that would allow the interoperability of various manufacturers' existing distributed control systems for HVAC. An appealing feature of BACnet is its ability to share the wiring of an existing Ethernet or Arcnet local area network (LAN) as the backbone of its data infrastructure. BACnet signals can even be transmitted over a LonWorks network; however, LonWorks devices cannot interpret BACnet signals, they can only pass the signals along until they reach a BACnet device. BACnet has broad support from the HVAC industry; BACnet-compatible HVAC devices from 13 manufacturers were shown at an ASHRAE exposition in February 1996. The European Committee for Standardisation (CEN) has also adopted BACnet as a pre-standard. However, lighting control components using BACnet are not yet widely available.

LonWorks was designed by Echelon Corporation for use with virtually all types of control systems. Over 2000 companies worldwide use LonWorks for applications ranging from manufacturing process control to theme park ride control. Off-the-shelf LonWorks components are available for controlling lighting, security, fire safety, access control, and HVAC. Although LonWorks and BACnet components are not compatible in the same network, a LonWorks control network can operate as a subset of a BACnet network.

CEBus (short for Consumer Electronics Bus) was developed by the Electronic Industries Association and is used primarily in residential applications by consumer electronics products, such as stereos, VCRs, and televisions. CEBus offers fewer advanced communication features, such as data encryption, than BACnet or LonWorks offer, and it also has a lower maximum bandwidth. Although CEBus is suitable for residences, its lack of security features makes it unsuitable for many commercial applications.

Many manufacturers of lighting control systems are working on *gateways* that will allow limited interoperability between their proprietary systems and the open protocol direct digital control networks. How well lighting control systems will integrate with the direct digital control network will vary greatly, so not all the advantages of a direct

Compatibility of electronic ballasts with PLC components

Most older PLC products are not compatible with electronic ballasts for fluorescent lighting, but some new PLC components are. Consumers are most familiar with X-10 protocol PLC components. Available since the 1970s and sold relatively inexpensively ($10–$40 per control module) through retail outlets, these components are also the basis of a new control system for residences that IBM is packaging with its Aptiva PCs. The X-10 protocol uses a relatively wide frequency band to carry analog signals. Many electronic devices, including electronic ballasts and baby monitors, can produce signal-obscuring interference within that frequency range. In addition to this limitation, the manufacturer of X-10 systems recommends that X-10 systems not be used to control lighting loads other than incandescent, making them inappropriate for most nonresidential applications.

LonWorks control modules are available using any of three new PLC protocols, one of which, PLT-21, operates within a narrow frequency band (125 to 140 kHz). PLT-21 is compliant with FCC regulations in the United States and with European standards set by the European Committee for Electrotechnical Standardization. Digital signals, error detection, and signal confirmation are used to further enhance reliability, so that these PLC components should be immune to the interference problems that plague X-10 systems. Indeed, there are many LonWorks PLC control modules available specifically for controlling electronic ballasts.

digital control network will be available through gateways in every application. However, if a lighting control system is already installed, or if one has unique, necessary features, using a gateway to provide at least some interoperability with other building systems may be advantageous.

In the future, BACnet-to-LonWorks gateways may allow these systems to function together seamlessly, or one of these two may become the *de facto* industry standard while the other languishes. At least for the foreseeable future, however, both of these standards have enough market support to coexist. Even so, having only two standards would be an improvement over the more than 27 different protocols in use today.

Contact information is given below for the organizations that created the direct digital control protocols discussed in this report. These organizations should be contacted directly to identify manufacturers of compatible products and to find qualified installers.

What other factors should be considered when choosing a direct digital control protocol?

Rarely is a building automation system installed solely to control lighting. More often, installations are initiated to control HVAC or machine processes, because these systems offer the largest potential savings. Lighting control usually is considered later or after the fact, if at all. The choice of which direct digital control protocol to use for lighting control depends on the type of facility and on what control systems are already installed.

For new construction or installations where no control systems yet exist, LonWorks offers many advantages for commercial and industrial applications:

- Wide selection of lighting control components
- System administration software designed specifically for lighting
- Control modules that can operate on low voltage supplied over the twisted-pair wiring used for data transmission
- Narrow-band PLC option resistant to interference problems associated with older, spread-spectrum PLC technology
- Wireless data transmission (radio frequency or infrared) options
- TCP/IP routers available to extend network globally, or to allow system control from any workstation using web browsers
- Easy integration of diverse building systems
- An organization, the LonMark Interoperability Association, that certifies product interoperability

However, BACnet should also be considered if a distributed control system is already in use for HVAC control, especially if an extensive Ethernet or Arcnet data network is already installed in the building. In such cases, BACnet may leverage the most benefit from the existing investment.

For residential or other small-scale applications, X-10 systems are also popular, but are not recommended for controlling any type of lighting load other than incandescent. CEBus systems should also be considered for residences as a growing number of manufacturers are making compatible products.

For more information

For more information about the communication protocols discussed in this report, including names of companies that may offer compatible lighting control products, please contact the organizations listed below.

BACnet:
ASHRAE
1791 Tullie Circle, N.E.
Atlanta, GA 30329
Phone: (404) 636-8400
Fax: (404) 321-5478
E-mail: ASHRAE@ASHRAE.org
WWW: http://www.ashrae.org

LonWorks:
Echelon Corporation
4015 Miranda Avenue
Palo Alto, CA 94304
Phone: (800) 258-4566
Fax: (415) 856-6153
E-mail: lonworks@echelon.com
WWW: http://www.lonworks.echelon.com

CEBus:
CEBus Industry Council
4405 Massachusetts Avenue
Indianapolis, IN 46218
Phone: (317) 545-6243
Fax: (317) 545-6237
E-mail: cebus-staff@cebus.org
WWW: http://www.cebus.org

X-10:
X-10 (USA), Inc.
91 Ruckman Road
Closter, NJ 07624-0420
Phone: (201) 784-9700
Fax: (201) 784-9676
E-mail: x10usa@aol.com
WWW: http://www.hometeam.com/x10/

Glossary

bandwidth The capacity of a digital networking medium to transmit data, typically expressed in kilobits or megabits per second.

binary signal A signal that communicates data that can have only two possible values, such as on or off, open or closed, and above or below.

centralized control system A control system with a single computer and a central control panel to which all controlled loads must be wired directly.

continuously variable signal A signal that communicates data that can have a theoretically unlimited number of possible values between two end points. Examples include voltage, temperature, and illuminance.

direct digital control (DDC) The technology used by the components of a distributed control system. DDC modules exchange digitally encoded signals with each other, indicating the status of devices connected to the network and executing commands when appropriate. Each module contains a programmable microprocessor, hardware for at least one type of network connection, and some means of detecting or changing a device's status.

distributed control system A control system in which the computing hardware and software are contained in a network of control modules or multi-circuit control panels physically distributed throughout the facility.

fuzzy logic A decision system in which Boolean operators (such as true, false, on, and off) are replaced by continuous operators (such as very cold, moderately cold, slightly hot, and very hot), yielding improved decision-making in control systems.

gateway A networking component that links together two or more data networks that use different communication protocols, making them interoperable.

interoperability The ability to communicate such information as temperature, illuminance levels, status of security devices, and occupancy among building systems and their controls.

node A point on a control network consisting of a DDC control module and the device(s) that it monitors or controls.

power line carrier (PLC) A method of data transmission in which high-frequency analog or digital signals are transmitted over line voltage power distribution wires.

router A component that links together two or more segments of a data network, selectively allowing information to pass between them.

zones A group of nodes on a control network that are associated so that they can all be controlled with a single command.

Resources

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Guide to Specifying High-Frequency Electronic Ballasts, 1996

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Exit Signs, 1995
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Principal Investigator: Robert Wolsey
Program Director: Robert Davis
Technical Editor: Kevin Heslin
Production Manager: James Gross

Other Lighting Research Center members who contributed include Joseph Ceterski, Kathryn Conway, Erika Gillmeister, Claudia Hunter, Russell Leslie, Dorene Maniccia, Naomi Miller, Mark Rea, and Susan Sechrist.

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For publications ordering information, contact:
Lighting Research Center
Rensselaer Polytechnic Institute
Troy, NY 12180-3590
Telephone: (518) 276-8716
Fax: (518) 276-2999
Internet e-mail: lrc@rpi.edu
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