A Learning Remote-Controlled Speaker Selector

DESIGN CONTEST WINNER

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Scott and Clark set out to find remote-speaker selection without replacing their current stereo system or spending too much money. The ultimate solution: an add-on component with an innovative intrared learning algorithm and a highly integrated microcontroller.

The Remote Controlled Speaker Selector (RCSS) addresses the challenge of creating a convenient, multiroom listening environment for the home. Most stereo systems have manual A/B speaker selection which provides music to one of two rooms or both rooms simultaneously (A+B). If that's not enough, an external speaker selector can be added easily.

But what if you're outside in the pool and the urge to swim laps to "Born in the USA" suddenly grabs you? In this scenario, you must go inside, negotiate a polished kitchen floor with wet feet, and switch the stereo to play over the pool speakers-not exactly the dream of home automation.

Some high-end systems address the problem of multiroom listening by using proprietary modulation schemes. These schemes multiplex audio and two-way data over user-installed coax to each room. The problem with this solution is that a perfectly good stereo system has to be replaced.

Alternatively, a few add-on devices can be used with existing stereo systems in one way or another-some use X- 10, infrared, or combinations thereof. However, these systems are fairly expensive, often compromise amplifier safety by switching only one side of the output, or lack user feedback, which is essential in remote switching.

DEVICE DESCRIPTION

The RCSS is an add-on home-stereo component designed for loudspeaker selection from virtually any infrared (IR) remote controller. An innovative learning algorithm and high-integration microcontroller make the RCSS "smart" as well as inexpensive with its low parts count.

The RCSS can be used with off-the-shelf IR repeater systems for separate room-speaker selection. This lets a listener select speakers from whatever room they are in without having to physically make a selection at the amplifier or receiver location. Since most existing stereo systems can already be remotely controlled with an off-the-shelf IR repeater, the RCSS adds the speaker-select function that most stereo systems lack. With the RCSS, the user obtains multiroom listening convenience while retaining their existing audio equipment. A diagram of the RCSS is provided in Figure 1.

SYSTEM OVERVIEW

Specific highlights of the RCSS include:

- Learning algorithm-The RCSS offers maximum flexibility. It can be controlled by virtually any IR remote controller, regardless of manufacturer. Low-cost generic IR remotes can be used for selection control.
- Four speaker pairs-Four independent speaker pairs can be selected with the RCSS.
- Manual operation-A front-panel push button provides manual selection of individual speaker pairs as well as dual-pair combinations for two-room listening.
- Indicator lights-Four green LEDs give visual status of speaker selection(s). A red LED marks learn status (on = learn mode). The red LED flutters on initial powerup to show that the RCSS needs programming.
- Confirmation tone-A dual-frequency confirmation tone is sent to the selected speaker pair before the music source is switched in. The

confirmation tone provides an audible indication that the correct speaker pair has been selected.

- Program retention-RCSS remembers the commands it has learned when power is interrupted or the unit is unplugged. A replaceable 10-year lithium coin cell provides power backup.
- Low cost-The cost for the electronic portion of the prototype was under $50.

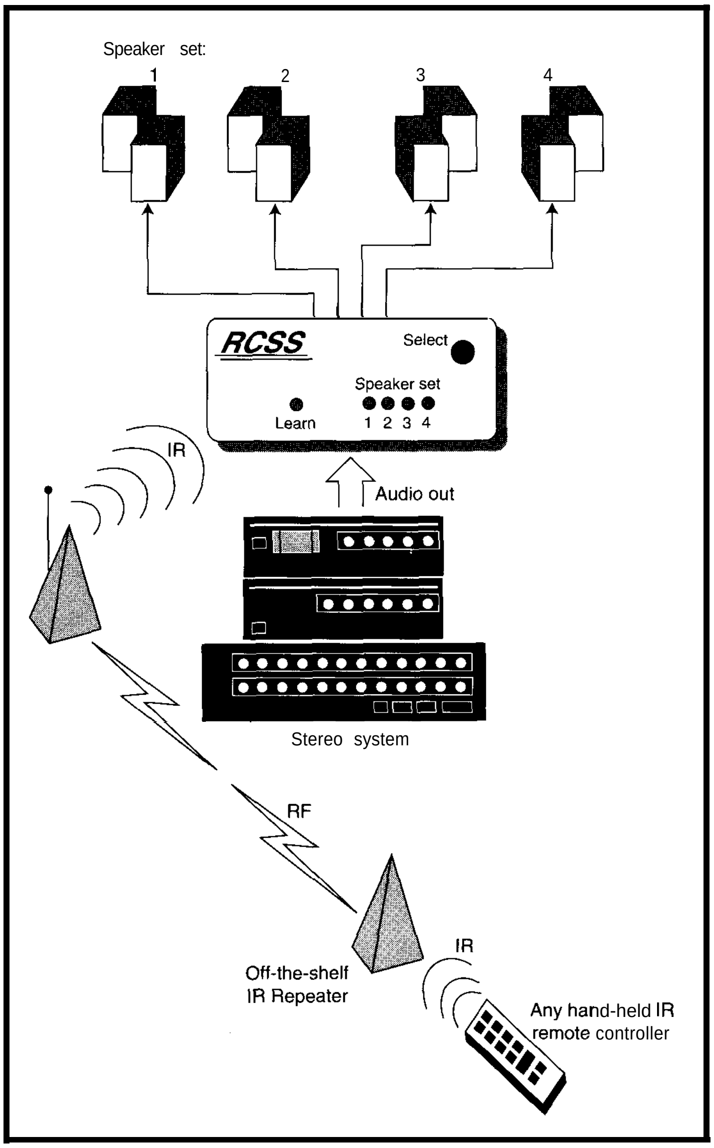

Figure 1: *This conceptual diagram shows how the RCSS can be used in a home environment. Low-cost IR repeater transmitters are located with each speaker pair.*

DEVELOPMENT OBJECTIVES

A major design goal in the development of the RCSS was to make it compatible with most hand-held IR remote controllers—no one needs another remote to add to their collection. And, most controllers have extra, never-used buttons. Thus, developing a device capable of learning and recognizing existing IR controller codes was central. Although a simple sampling method could work, the memory requirements for even a single IR code are relatively large, even with the application of rudimentary compression techniques (INK 29).

IR CONTROLLER CODES

When you push a button on a remote controller, the remote emits a series of infrared bursts. The bursts, which amount to switching a pulse carrier on or off, carry the code corresponding to the button.

Pulse-carrier frequencies range from 25 kHz to 60 kHz, with the most common around 38 kHz. The carrier bursts usually last from 0.5 to 2 ms in duration and correspond to a bit in the function code. An entire code sequence may have 12 to 32 bits (or bursts), so the code frame time would be on the order of tens of milliseconds.

Most remotes also have a common sequence marking the start of all the codes they transmit. It essentially acts as a wake up preamble. The modulated information sent by the remote is demodulated by the receiving device into an asynchronous stream of binary highs and lows which generally contains a preamble sequence, manufacturer and device information, and the specific function command.

Manufacturers can and do use different schemes for embedding information in the infrared flashes-there are no industry standards for encoding. Most use some form of pulse-width modulation which conveys bit information according to carrier-burst duration. The bits can be represented by the actual bursts or by the time between them.

Manufacturers also have unique schemes for repeat functions. Say you want to crank up the TV volume. You hold down the Volume+ button. One manufacturer's remote transmits the entire Volume+ command repeatedly, while another sends the Volume+ command once followed by a shorter repeat sequence for as long as you hold down the button. Figure 2 shows the start of a few typical received IR codes.

Though there are undoubtedly countless control codes, with a learning device, it does not matter. For the RCSS, the only thing that matters is that it recognizes a learned button when it is pushed again. To do this, the RCSS has to pick apart and store the necessary elements of a button's code sequence. In general, the code sequences follow these criteria:

- Code sequences always follow the format: preamble, space, code information
- The preamble is at least three times longer than a space
- Space defines the duration for a binary 0 (arbitrarily assigned)
- Space is always the inverse polarity of binary 1s and 0s.

That is, when bits (1 s and 0s) are represented during the times the LED is modulated on, the space between bits occurs when the LED is off. Conversely, if the bits are represented during the times that the LED is off, then the space between bits occurs when the LED is on.

These generalizations hold true for the vast majority of infrared codes. In the simplest terms, the RCSS algorithm measures the duration from one transition to the next, producing a count. The count represents both the time that the LED is modulated with a burst and the time between bursts.

The count is stored, another event is timed, and the new count is subtracted from the previous count. From this result, the program determines whether the bit of code information is a 1 or a 0, and the process repeats for succeeding bits.

The algorithm has been developed based upon the following protocol generalizations:

- The first and second counts, essentially the preamble, don't matter and can be discarded
- The absolute difference between a low and high count following the preamble is significantly greater than 0 for a binary 1 and near zero for a binary 0.

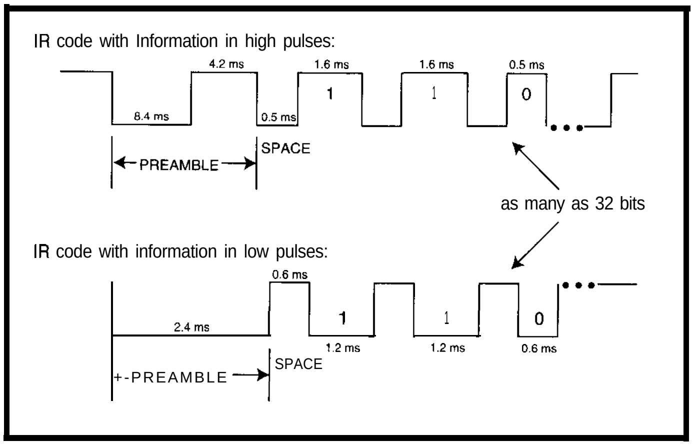

Figure 2: *The typical IR code sequence contains pulse-width modulated data in either the low or high portion of the pulse train. Binary bit information is encoded in the pulse-width variations. Fixed-width pulses correspond to spaces between bit information.*

Using these assumptions, the RCSS algorithm produces a compact binary representation of the incoming remote code, regardless of the carrier frequency, the bit rate, or the format for 1s and 0s.

In the program, each absolute difference is checked against a tolerance value for translation into either a 1 or a 0. The bit is then packed into a four-byte holding location. Each IR remote button learned is represented in 32 bits (whether it needs that much room or not) to keep the algorithm simple. Occasionally, more than 32 bits are required, but the majority of controllers operate at 32 bits or fewer.

FIRMWARE

The general development approach of the RCSS was to do as much as possible in firmware including switch debouncing, IR signal recognition, confirmation-tone output, and front-panel indication. This approach not only minimizes cost by reducing parts count and circuit-board real estate, but also facilitates the development of an intuitive user interface. The interface is important because most of the time the user would not be within sight of the RCSS. Additionally, the intuitive interface bolsters user confidence in the training process and front-panel operation.

FIRMWARE OPERATION

Figure 3 is an overall flow diagram of the RCSS software. The program starts at the beginning of ROM (location $0200) with a series of qualified initializations. The ports are defined, then port A is read. If the lower four bits of port A are cleared-a normally illegal state-thenthe TEMP2 register is loaded with $FF as a first-time powerup flag for use later in the program. Other qualified initializations include clearing the IR code storage locations (CODE), common registers, and count variables. This portion of the program is recycled by different routines to conserve program memory.

After qualified initializations, the computer operating properly (COP) register is reset. This paves the way for a series of bit-level interrogations. First, port A, bit 4 is checked for manual switch closure. If the switch is closed, control is transferred to the MANSW routine.

Next, the Learn switch, bit 1 of port B, is checked for closure. If it has been pushed, both the first LED (speaker set 1) and the Learn LED are lit. The program then monitors for IR input. If the Learn switch has not been pushed, TEMP2 is checked for $FF and the Learn LED is toggled if it is $FF.

Finally, bit 0 of port B is checked for IR input. If none is present, the program returns to reset the COP register. It continues this loop until IR is detected at bit 0 of port B.

When port B, bit 0 finally goes low-signaling IR input-program control is transferred to the READ routine. The IR data is serially sampled at a 0.1 -ms rate and stored in indexed code RAM locations. After input, control is transferred to the STORE routine.

STORE first checks for learn mode. If the learn register, TEMP2, is set to 1, 2, 3, or 4, code bytes are transferred to the appropriate storage locations. If not in the learn mode, program control is transferred to the RECOG routine.

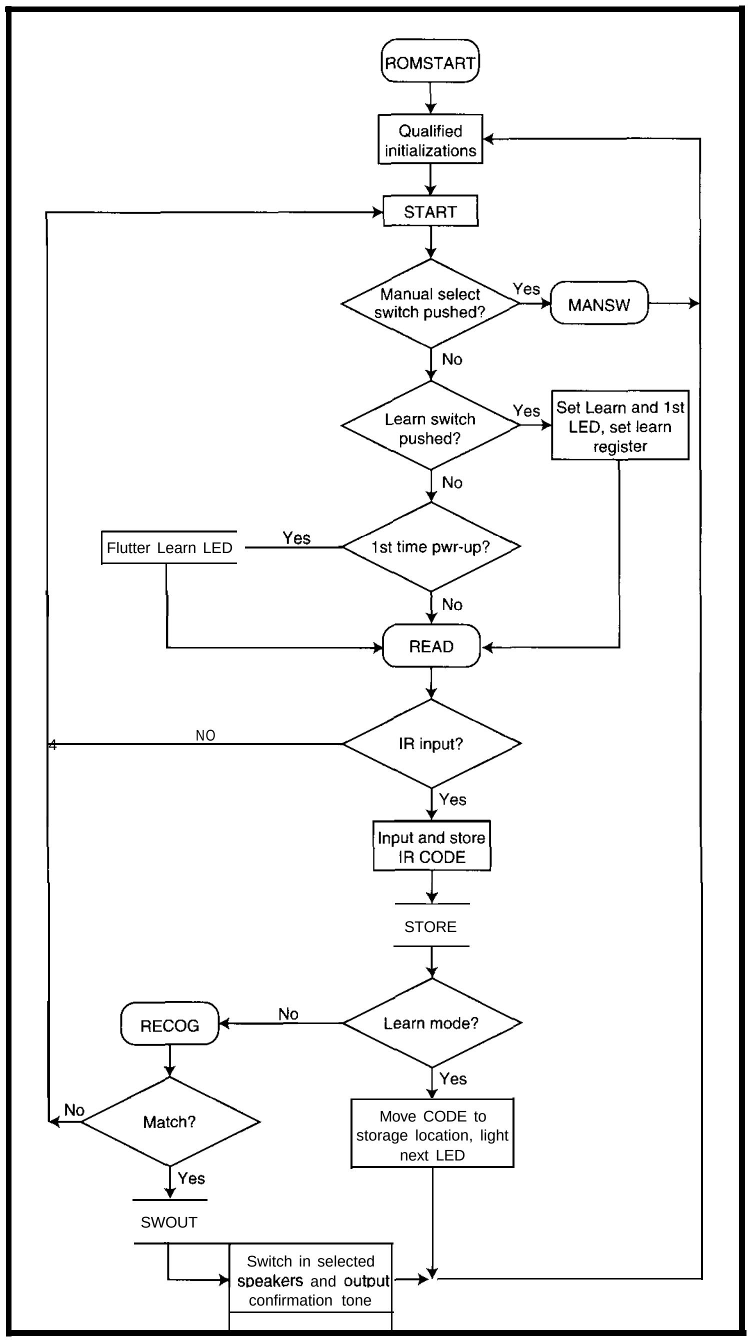

Figure 8: *A modular approach was used in the development of RCSS firmware when possible. This overall flow diagram shows that some routines are recycled to make best use of the 68HC705's tiny 0.5 KB of ROM and 32 bytes of RAM.*

RECOG sequentially compares stored bytes with the code read in. If there is no match, the program returns to the beginning where sequential checks are performed again. If there is a match, control is transferred to the SWOUT routine.

SWOUT performs speaker and source relay switching and debouncing, and output confirmation-tone generation. After the switching is complete, the program returns to START

The program fully utilizes the 68HC705 microcontroller to provide IR code learning and recognition as well as an intuitive user interface. All RAM and most of the ROM is used. Real-time interrupts are not used because of RAM limitations and they simply are not needed. The microcontroller operates in the microsecond world, whereas IR codes are in the millisecond domain.

HARDWARE

The hardware components and layout are designed for a high degree of integration, low parts count, and short wiring runs. All components are available from several sources.

The RCSS is designed so that all wiring connections are made at the rear panel, with the front panel of the aluminum enclosure reserved for operating controls and indicators. Construction is by hard wiring, but the circuit board may be removed from the case by unfastening the front and rear panels. This design provides for high reliability while using commonly available components. Figure 4 shows the schematic layout.

POWER SUPPLY

Power enters the RCSS at rear-panel power connector J1, a 3.5-mm phone jack. A 1N4004 diode protects the circuitry from reverse voltage should a power source of opposite polarity be plugged into the rear panel. A 1-µF ceramic capacitor filters the power input, and a MOV provides surge protection for voltage spikes over 33 V to the voltage regulator (U5). U5 is a 5-V linear regulator in a TO220 package. The 5-V output of the regulator is bypassed by both a 0. l-µF and a 0.01 -µF capacitor.

Battery backup and switchover is accomplished by U4, a Maxim MAX704 supervisory circuit designed for use with microprocessors. During normal operation, U4 simply passes the 5-V supply to the Ul microcontroller V_{DD} pin. However, if the 5-V supply drops below 4.4 V, U4 holds the microcontroller reset pin low and switches the V_{DD} supply to a 3-V lithium battery.

This scheme provides backup power for the microcontroller RAM. Thus, the microcontroller RAM is nonvolatile and its contents are retained in the event of a power outage. Even frequent, short-duration power interruptions do not significantly reduce the battery's life below its expected shelf life.

All other power connections are made to the 5-V regulator output.

MICROCONTROLLER

U I is a Motorola MC68HC705Kl microcontroller. Ul receives data from the infrared module at port PBO. The Select and Learn switches are read at ports PA4 and PB l, respectively. A 4.000-MHz crystal clocks the microcontroller. Port PA6 is configured as an output to control the input audio-source relay driver. Output ports PA0 through PA3 control the four speaker audio-output relay drivers. Output port PA5 generates a confirmation tone, which is sent to one of four speaker outputs. Output port PA7 drives an LED driver for learn-mode indication. The IRQ line is pulled up (disabled).

Under software control, the microcontroller reads and learns infrared codes, or reads IR codes and selects speaker-pair outputs. Ul also disconnects the audio-source input, generates a confirmation tone, and reconnects the audio-source input when a new output is selected.

RELAYS AND LEDS

Relays Kl-K6 are all Aromat JW-series relays, which can switch up to 5 A. Kl and K2 are input relays that have two form-C contacts each, thereby enabling the hot and ground signals from both channels of a stereo amplifier to be disconnected during confirmation-tone generation. During tone generation, Kl and K2 select local ground and tone from Ul port PA5 to be sent to the output relays.

K3 through K6 all have two form-A contacts, which switch only the hot (+) signal from each channel input, either on or off. All relay drivers are PNP transistors contained within U2 and U3 transistor packages. The PNP relay drivers are protected from inductive kickback by 1N914 diodes across the relay coils. The output relay driver U2 also drives four green, front-panel LEDs for indicating front-panel output selection. One of the U3 transistors drives the red LED for front-panel indication of the learn mode.

SWITCHES, HARDWARE, AND IR MODULE

The front-panel, momentary push-button switch Select is read by Ul to sequentially select the speaker output from the front panel. The rear-panel Learn switch is read by Ul to put the unit in learn mode.

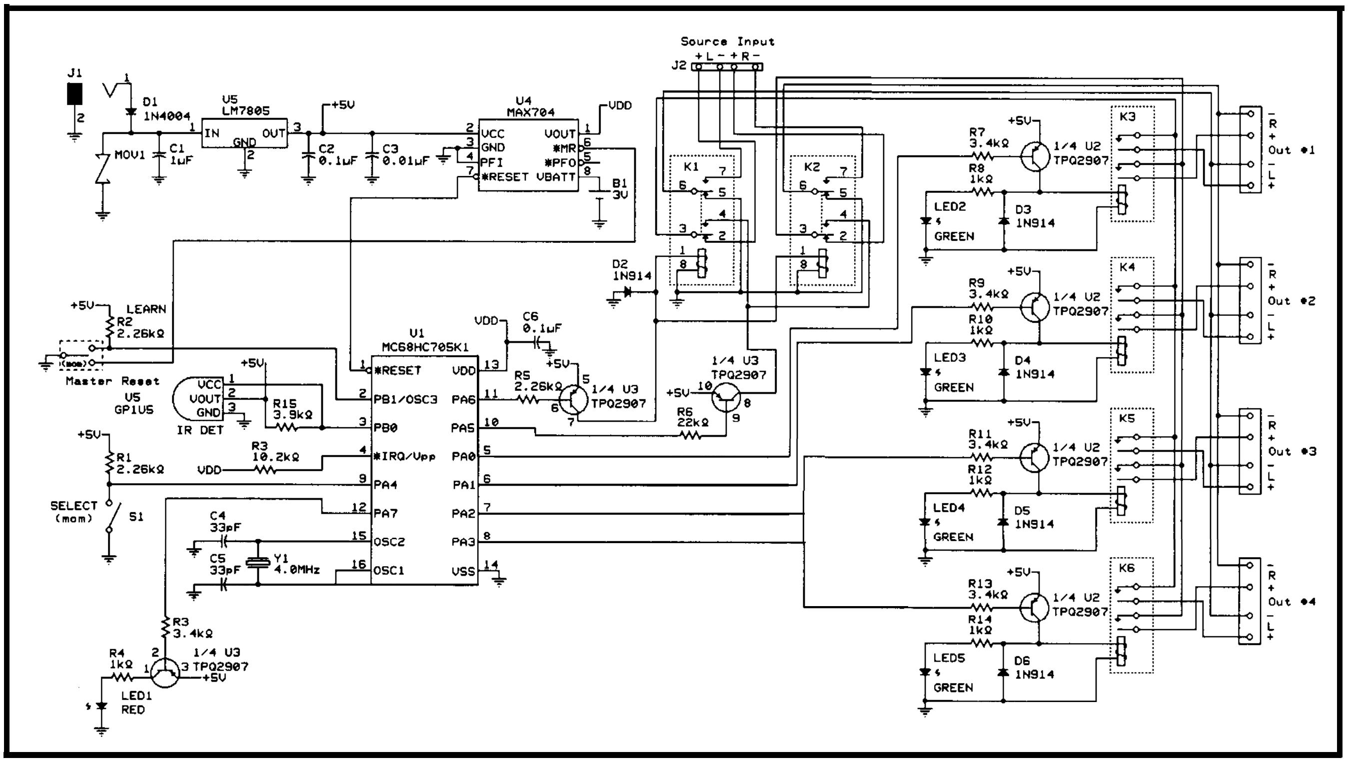

Figure 4: *Hardware for the RCSS was kept to an absolute minimum by performing most tasks in firmware.*

An infrared receiver/demodulator (Sharp GP1U5) on the front panel filters and demodulates the incoming infrared code to be read by U1.

The rear panel has spring-terminal connectors for four speaker pairs (16 terminals). All connections from the rear panel to the perfboard are made with stranded 20-AWG wire. A rear-panel, 4-position, polarized interlocking connector provides connection to the source amplifier. Power is supplied through a 3.5-mm phone jack on the rear panel. The case is black, anodized, extruded aluminum with an integrated card guide for the board.

OPERATION

The RCSS is operated with an IR remote control. To use the RCSS, it must be installed and programmed for the particular system it is to be used with. Up to four speaker sets may be connected. Speaker wiring should be installed before the RCSS is set up. The following sections address installation, setup, and operation.

INSTALLATION

Before making any connections to the RCSS, the lithium backup battery should be installed. Although the backup battery is not required for operation, it enables RAM data retention when normal power is disrupted. This means that the RCSS does not have to be reprogrammed after a power interruption.

Refer to Figure 5 for the connection layout on the rear panel. The easiest way to get the RCSS up and running is to first make connections to the speaker sets and source amplifier on the rear panel, then position the RCSS where it can receive infrared signals. Speaker sets are wired to the rear panel using 16 spring-release terminals. Red is positive and black is negative for the four sets of terminals with the right channel located along the top row. The source amplifier is connected through the interlocking connector (Molex) with pigtails.

Power is supplied through a wall transformer. Plug the 3.5-mm phone plug from the wall transformer into the power jack on the RCSS rear panel, and plug the transformer into a 110-VAC outlet. There is no power switch so the RCSS normally remains on. When power is connected for the first time, the front-panel Learn indicator (red) blinks. The RCSS is now installed and ready for setup programming.

SETUP PROGRAMMING

Figure 5 shows the front panel during the setup programming discussion. The RCSS blinks the front-panel red LED when it has not been programmed. The first step in setup is to decide which remote control operates the RCSS.

Virtually any common IR remote control works. The idea is to pick four buttons on a remote (or remotes) to select among the four speaker set outputs. In many cases, there are some buttons on an existing remote control that are unused or operate a component not used in the your system.

An example of this might be a receiver remote that includes buttons for controlling a same-brand CD player when the CD player owned is a different brand. In this case, the CD buttons can be used to operate the RCSS from the receiver remote. You could also purchase an inexpensive replacement remote for TV or VCR or use four buttons on a remote from a remote-controlled component or TV not being used. Again, most remotes work. Just pick four buttons on any remote.

To program the RCSS, push the rear-panel Learn switch down. This puts the RCSS into learn mode (indicated by the steady illumination of the red LED on the front panel).

Stand several feet away from the unit, point the remote control at the unit, and push and release the four buttons on the remote corresponding to each speaker set in sequence 1, 2, 3, and 4.

Each time a button is pressed, the green LED corresponding to the next speaker set to be programmed illuminates. When all four buttons have been pressed, all front-panel indicators go out. When the red Learn indicator turns out, the unit is in recognize mode. When all green indicators turn off, no speaker sets are selected. By pressing any of the four buttons just programmed, the RCSS selects the corresponding speaker set output. The RCSS will not respond to other IR remotes or buttons.

Note that programming the RCSS must be done under optically quiet conditions. This means that any IR repeaters should be covered or otherwise disabled and no other IR remotes are in use. Also, during programming, if the remote buttons are held down too long, then several speaker sets will be programmed to the same remote button. If this happens, simply reprogram the RCSS by depressing the rear-panel Learn switch and pressing the appropriate remote-control buttons again.

USING THE RCSS

When the RCSS has been programmed, it is ready for use. The RCSS works with commonly available IR remote repeater sets. These sets usually have a transmitter and receiver. They convert the remote control's IR signals to an RF signal, transmit them to a receiver, which then converts the signal back to IR to control the component.

Some repeaters are hard wired. But, regardless of the technology used, the result is the same. A repeater can be placed in any room where secondary speakers are located, enabling remote-control selection of that set of speakers from that room.

When a particular set of speakers is selected by remote control, a confirmation tone is sent to the speaker set. This confirms that the correct selection was made since the user typically cannot view the front-panel indicators on the RCSS. Each time the selection is made by remote, a confirmation tone is sent.

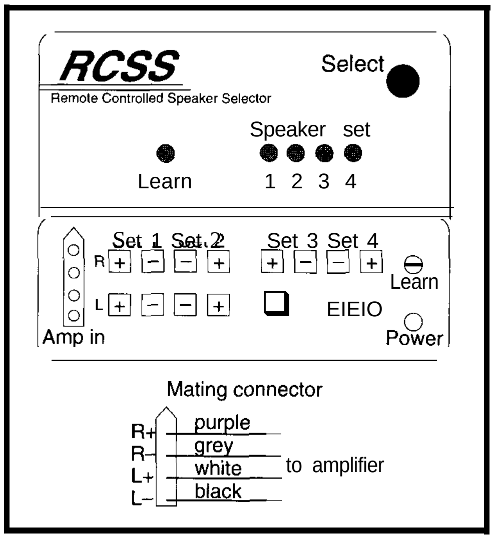

Figure 5: The front panel has LEDs for speaker selection and learn status and a switch for manual selection of speaker pair(s). Rear-panel push terminals are for speaker connection and a molex connector is for the source amplifier. The switch is a momentary, center-off switch. Down invokes the learn mode and up resets the microcontroller.

The Select button on the front panel enables a local speaker-set selection. Each time Select is pressed, another speaker set is selected as indicated by the front-panel indicators. The Select button also enables the user to select any two speaker sets at once. The Select button follows this sequence: 1, 2, 3, 4; 1 and 2; 2 and 3; 3 and 4; 1 and 3; 2 and 4; 1 and 4. The pattern then repeats. There is no confirmation tone when Select is used to select speaker sets.

The infrared detector in the RCSS is quite sensitive and is typically able to read infrared codes from 30' or more. This means remotes or IR repeaters can be conveniently and aesthetically located. The only requirement is that there must be a clear line of sight from the repeater receiver to the RCSS IR detector on the front panel.

CONCLUSION

The RCSS switches four speaker pairs from one stereo source by recognizing unique IR codes from common IR remote controls. Combining the RCSS with an IR repeater enables remote-controlled speaker selection from any location within the repeaters range.

Relay-switching capacity during audio peaks is 5 A, which corresponds to 200 W into 8 Ω. The peak current capacity of closed contacts is much higher, so virtually any power level can be accommodated with no interference to sound quality (low-resistance contacts).

The unit has optional front-panel manual controls and indicators and an internal tone-signal generation to provide user feedback of successful remote switching. A very efficient code-recognition algorithm means a small and inexpensive microcontroller can be used. No exotic parts are necessary for construction, so cost is reasonable.

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SOFTWARE

Software for this article is available from the Circuit Cellar BBS and on Software On Disk for this issue. Please see the end of "ConnecTime" in this issue for downloading and ordering information.

SOURCE

A preprogrammed 68HC705 may be ordered for $25 postpaid from:

RCSS Project
10104 St. Helens Dr.
Yukon, OK 73099

I R S

422 Very Useful
423 Moderately Useful
424 Not Useful